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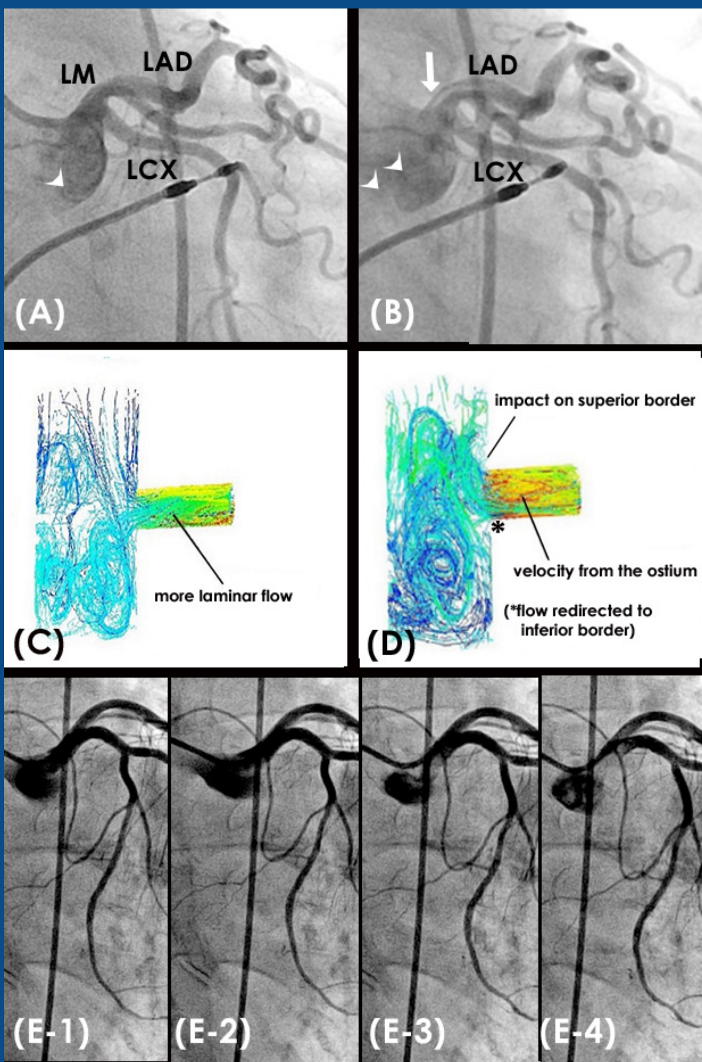
Pushing forward with novel approaches in the new frontier of Anatomy



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PUSHING FORWARD WITH NOVEL APPROACHES IN THE NEW FRONTIER OF ANATOMY

Madrid, April 2021

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PREFACE / INTRODUCTION

The term anatomy derives from the Greek "anatomē" meaning dissection and focuses on the study of the structural organization of organisms and their parts. Anatomy is the study of the human body's structure. Macroscopic anatomy is referred to as human gross anatomy, but anatomical sciences also encompass histology and cytology, embryology, neuroanatomy, medical imaging and comparative anatomy. In the past hundred years, significant advances have been made in anatomical research. However, modern anatomical research has become increasingly molecular, and fewer young anatomists have the training or desire to teach a demanding and time-consuming course that might interfere with obtaining extramural funding and tenure. New modalities of imaging (i.e., CT, MRI, ultrasound, and computerized software and 3D printing, etc.) are changing how anatomy is taught, how it is discovered and how it changes with underlying pathology. Progress in anatomy today appears to center on understanding development, evolution, kinesiology and biomechanics, physiology, pathological interpretation, and regenerative medicine.

The challenges facing anatomy (and anatomists) in this new era are broad, diverse and enormous, where curricular time devoted to anatomy and dissection is declining, new computer-based technologies are being introduced; opportunities for research and funding are becoming more difficult, and there is a shortage of trained anatomists capable of teaching clinical anatomy (and its disciplines) and cadaver-based wet labs. Some opine, that we do not need anatomy research when there is nothing new to discover. Others suggest that the human cadaver is obsolete or no longer needed secondary to technology and software applications. Administrators and accreditation bodies seem to increasingly cut back on basic science disciplines, favoring the earlier introduction of medical students to clinics with "on-the-job" training. Yet, basic science and clinical faculty, attending physicians and residency directors cite decreased foundational knowledge and the need for "refresher" courses in students and graduates. Still further, there are the costs associated with maintaining anatomical donor programs, and concerns that these programs may not be reasonable in underdeveloped countries secondary to economics and sustainability, institutional facilities and cultural beliefs. Even further, because of the outbreak of the novel coronavirus (COVID-19) that began in Wuhan, China, in late December 2019, and spread exponentially around the world resulting in a pandemic, students and faculty lost access (or had limited access) to dissection rooms, to cadavers, to research facilities, and also to a range of other optimal learning modalities including prosections, models, pathology specimens, skeletons, and others. In a way, the COVID-19 pandemic has accelerated the development of, and changes to, new methodologies for anatomy education.

All of the above begs the questions: Are anatomists interested in saving their own profession? Are anatomical societies (and anatomists) doing enough to preserve and promote anatomical sciences and research? What will be the impact of these factors on anatomy and medicine? Will anatomy continue?

No one (anatomist or clinician) or group (i.e., anatomy society) has a clear vision of the outcome of all of these factors relative to the future of anatomy (and anatomical science disciplines). Even more so, the impact on graduating physicians, anatomists, and patient care is less clear.

Therefore, it was the goal of this special, supplemental issue of the *European Journal of Anatomy*, to seek out leading experts in anatomy, clinicians and students across the world in an attempt to answer these questions and to determine the direction (or perhaps re-invention) of anatomy in this new frontier. Scholarly manuscripts were sought out to show how modern anatomy research can go beyond case studies and anatomical variations extending to translational concepts and implementation. A diverse range of educational perspectives were obtained including reviews, designer approaches, expert treatises on pre- and post-graduate teaching, as well as the application of new modalities, pedagogies and technologies in anatomy education and in the COVID environment. Lastly, experts examined the feasibility and future of continuing education, mortuary science and anatomical donor programs.

It is my privilege to serve as the Guest Editor-in-Chief, and it is my hope that you will enjoy the unique, insightful and innovative perspectives in this special issue. On behalf of the editorial board and staff of the *European Journal of Anatomy*, and the experts and authors herein, I invite your discussion and comments.

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PUSHING FORWARD WITH NOVEL APPROACHES IN THE NEW FRONTIER OF ANATOMY

SECTION 1. ANATOMY RESEARCH AND TRANSLATIONAL APPLICATIONS IN THE NEW FRONTIER.

Description. This four-part manuscript symposium presents a *novel and groundbreaking* approach to examine lesions of the coronary arteries suggesting mechanisms based on hydraulics and physics relative to the underlying anatomical structure and anatomical variations in the coronary arterial system. The authors' research presentation is an excellent example that *highlights the challenges* faced by today's investigators (i.e., anatomists, cardiologists, interventional cardiologists, etc.), and discusses possible answers to these challenges; demonstrating the important and continual role of anatomy research and its applications. Further, this symposium is global in that it includes *descriptive anatomy*, *translational anatomy*, *predictive anatomy* and *interventional anatomy* with new discoveries – all critical to anatomy educators and researchers, as well as clinicians. The authors not only incorporate real patient, anatomical/case-based discussion, but also allow readers to have access to an Image Research Depository that provides access to all images and angiograms (i.e., data) used in the development of this model, and readers are invited to explore, and to comment and discuss. The approach of this international team is innovative and provocative, and brings fresh air and new ideas into the arena of learning and research in anatomy.

SECTION 2. ANATOMY EDUCATON IN THE NEW ERA OF ANATOMY AND DURING AND AFTER THE COVID-19 PANDEMIC.

5. ANATOMICAL DISSECTION AND MEDICAL EDUCATION: A SYSTEMATIC REVIEW OF LITERATURE
   Bruno Grignon, Fabrice Duparc

   Description. Here, two world-renowned experts in anatomy and medicine collaborate and present a review article focused on anatomical dissection (AD) with the aim of assessing the current place of AD in both undergraduate students' curriculum and more generally in medical education, and to evaluate both the students' perception and the effectiveness of AD compared to other teaching techniques. Despite the decrease in time devoted to anatomy education, a striking finding was the concept of the "silent mentor" or "first teacher" suggesting the strong impact of AD as the first step of medical practice and ethics. Thus, AD continues to stand out as an *unparalleled pedagogical tool* in medical education in the light of published literature.

6. DESIGNER DISSECTIONS: TAILOR-MADE FOR YOUR CAREER IN ANATOMY AND MEDICINE
   Vania Arboleda, Sarah Cushion, Seth Shoap, Cheryl Purvis

   Description. This manuscript is unique in several aspects. First, as a concept paper, it introduces a *pioneering movement* called "Designer Dissections," a personalized, medical education experience in a specific anatomical region and in an area of specialty-interest. Second, this concept is innovative, and re-invents teaching of anatomy using *interdisciplinary* teams composed of both allopathic and osteopathic medical students and faculty/clinician mentors. Third, it is an approach that is applicable to horizontal and vertical integration in medical education curricula, as well as to electives, continuing medical education programs and workshops. Fourth, the products of "Designer Dissections" are a diverse array of materials that can be used for anatomical sciences education and scholarly publication. Lastly, it is proposed by a scholarly *student team* (and a faculty mentor); thus, highlighting students' desire, understanding and value of human cadaveric dissection as the *Gold Standard* in human anatomy education.

7. PRACTICAL PRE-GRADUATE TEACHING IN HUMAN ANATOMY: A REVIEW
   José Sañudo, Ernest F. Talarico, Jr., Fabrice Duparc, Friedrich Paulsen, Teresa Vázquez, Francisco Valderrama, Blanca Mompeó, Rosa Mirapéix, Rodrigo Elizondo-Omaña, Theresa Larkin, Marko Konschake, Stephen McHanwell, Eva Maranillo

   Description. This manuscript is a treatise that represents the collective experiences and recommendations of an international team of experts in clinical anatomy education and research. Together, these experts review where pre-graduate teaching in human anatomy has taken faculty and students, and the authors look toward the future and focus on the critical elements of successful practical sessions and outcomes in anatomical sciences education. Still further, this team agrees and demonstrates that anatomical donors remain the *Gold Standard* for anatomy teaching, especially topographical anatomy.

8. POSTGRADUATE ANATOMY TEACHING: A REVIEW

   José Sañudo, Teresa Vázquez, Ernest F. Talarico Jr., Fabrice Duparc, Friedrich Paulsen, Veronica Macchi, George Feigl, Rodrigo Elizondo-Omaña, Raffaele De Caro, P. Aragonés, Stephen McHanwell, Marko Konschake

Description. The same team of international experts in clinical anatomy education and research that examined pre-graduate teaching in human anatomy, returns here and gives an expert treatise on postgraduate anatomy teaching. Using an elegant approach, this team of authors gives and extensive review of postgraduate anatomy teaching and provides a focused, reproducible flow for organizing successful continuing medical education (CME) and other professional development courses. They opine that courses should have a large practical component (in content and organization) but also should provide the latest scientifically based theoretical knowledge, respecting the learning of anatomy as well as aiming at performing different techniques. Anatomy departments should support these courses by establishing hands-on practical training courses and components.

9. THE HIVE: a multidisciplinary approach to medical education
Milton Alberto Muñoz-Leija, Braedon R. Paul, Ge Shi, Ishan Dixit, Alejandro Quiroga-Garza, Rodrigo E. Elizondo-Omaña, Claudia Krebs

Description. This team of international experts and authors presents a manuscript focused on the HIVE - The Hackspace for Innovation and Visualization in Education at the University of British Columbia Faculty of Medicine. The HIVE is composed of multidisciplinary teams of students and educators that have solved pedagogical challenges, and work on implementing new technologies and educational tools for anatomical sciences education. The HIVE encourages student participation and may serve as a model for purposeful implementation of new technologies. Its unique, *multidisciplinary approach* and use of cutting-edge technology makes the HIVE *innovative and valuable* in the new era of anatomy. The HIVE allows free access, and encourages global faculty, clinicians, students and staff to get involved.

10. MAINTAINING CADAVERIC DISSECTION IN THE COVID ERA: NEW PERSPECTIVES IN ANATOMY TEACHING AND MEDICAL EDUCATION
Cecilia Brassett, Nicholas Chilvers, Richard G.C. Lloyd, Peter Fletcher, Isla H.H. Fay, Michelle Spear, Helen L. Taylor

Description. Cadaveric dissection provides a unique learning experience in anatomy teaching that maps well to the required outcomes for medical graduates as prescribed by the General Medical Council (GMC) in the UK. This paper describes in detail why *cadaveric dissection remains key* in anatomical education and demonstrates this by mapping its additional benefits to each of the three sets of GMC Outcomes for Graduates (professional values and behaviors, professional skills and professional knowledge). Further, in the face of the COVID-19 pandemic, the authors describe their team's experience and how this led to the development of strategies to retain the practical element at the core of anatomy teaching.

11. Teaching embryology through information technologies during SARS-COV 2 pandemic at the Medicine School of the University of Costa Rica: Experience and Results
Jessica González-Fernández, Brenda Alfaro-González, Adriana Murillo-Chaves

Description. Due to the onset of the pandemic caused by the SARS-COV 2 virus, a series of restrictions were implemented by the Costa Rican Government including all the primary, secondary and university educational programs. Therefore, it was necessary to adapt the courses to a 100% virtual mode. Here, the authors describe their experiences and outcomes of transforming lesson methodologies, evaluations and laboratories for *teaching embryology in virtual space*. Their *unique combination* of problem-based-learning, laboratories, focus groups and online databases and questionnaires, culminates in a model that can be reproduced at other institutions and in a time when embryology is becoming more of a self-directed discipline secondary to the decreasing time devoted to anatomical sciences in the classroom and laboratory.

12. COVID-19 AND DISTANCE LEARNING: DO STUDENTS STUDYING GROSS ANATOMY FIND FAVOUR WITH THE CHANGE IN PEDAGOGIC APPROACH?
Maria A. Sotgiu, Pasquale Bandiera, Vittorio Mazzarello, Laura Saderi, Alessio Pirino, Andrea Montella, Bernard J. Moxham

Description. In response to the COVID-19 pandemic, many universities have suspended face-to-face academic activities, replacing the more traditional methods of teaching and learning with technological approaches. Thus, a team of educational experts from the University of Sassari in Italy assessed the attitudes of medical and non-medical students studying gross anatomy and/or undertaking examinations through online platforms. These authors describe how their online course was structured, the technology platforms used, and how the course was evaluated. Their work provides a novel model that could be used at other universities. The authors also document findings that indicate that, while students retain a preference for more traditional, face-to-face, teaching and learning approaches, the use of online classes and examinations in gross anatomy were perceived as being beneficial during the emergence of the COVID-19 pandemic.

13. AN ALTERNATE FOCUS OF POCUS IN MEDICAL EDUCATION: HOW ANATOMY KNOWLEDGE IS ESSENTIAL FOR ULTRASOUND SKILLS, RATHER THAN HOW ULTRASOUND CAN IMPROVE ANATOMY LEARNING
Theresa A. Larkin

Description. Point-of-care ultrasound (POCUS) is effective not only in triage of critically ill and infectious patients in emergency departments, but also in rural and remote medicine. Incorporating ultrasound into medical curricula provides an opportunity for multimodal, active, experiential learning in a clinical context, increasing students' engagement and motivation. Increasingly, POCUS is being utilized in this new frontier of anatomy education. In numerous institutions, ultrasound is promoted to enhance anatomy learning. In a *unique and interesting perspective*, this author suggests that the focus of POCUS in medical education should be reversed, *to instead highlight the importance of anatomical education as a pre-requisite for ultrasound skills*.

14. ANATOMY EDUCATION DURING COVID-19: REVIEW OF TEACHING METHODS AND THEMATIC MAP
Aurimas Kudzinskas, Miranda Giddins

Description. These authors from the UK utilized an extensive literature review to gain insight in current themes and trends surrounding anatomy education and to evaluate which teaching methods are most effective during the COVID-19 pandemic. A thematic map was constructed and explored by evaluating full texts of peer-reviewed, scholarly articles. Furthermore, articles reporting on the effectiveness of teaching methods were analyzed according to the strength of analysis, country, teaching methods, and issues identified. This work highlights the value of different approaches to online anatomy education, and the authors stress that only effective mixed online learning methods in combination with traditional teaching methods be utilized.

SECTION 3. ANATOMICAL DONOR PROGRAMS AND MORTUARY SCIENCES - FEASIBILITY AND FUTURE.

15. BUILDING BRIDGES WITH ANATOMY: CAN CONTINUING EDUCATION IN MORTUARY SCIENCES TRANSFORM THE PROFESSION?
Claudia Mosley, Wanda Lee, Roxana Gilani, Gina Terry, Rachel Reeves, Joy Y. Balta

Description. Human cadavers have long been used to teach anatomy to different cohorts of students. The training within mortuary schools is primarily technical based and geared towards the funeral services profession. Meanwhile, embalmers operating within anatomy departments require a different skillset that is currently learned on the job. Thus, this team from The Ohio State University and the Cincinnati College of Mortuary Sciences suggest that because of the increasing use of human cadavers to train physicians and develop new medical equipment, there is a need to *transform mortuary sciences* into a rigorous research-based discipline. These researchers explore this concept with the initial step of gauging the interest of embalmers in continuing education (CE) courses that would prepare them for a career as an embalmer in an academic research institution, thus building bridges between mortuary sciences and anatomy research (and education).

16. WILL BODY DONATION PROGRAMS EVER BE FEASIBLE IN AFRICA? (Letter to the Editor)
Oluwanisola Onigbinde

Description. In recent times, there have been advances in technological innovations in medical education and anatomical teaching, and virtual platforms for cadaveric dissections. These platforms are either complementing, competing, and or gradually replacing cadaveric dissection. Nonetheless, cadaveric dissection *remains the ultimate standard* for teaching human anatomy. Yet, in developing (i.e., Third World) countries, little is known of how anatomy is taught and about anatomical donation programs. Further, the impact of cultural beliefs and socio-economic factors, and how these may influence feasibility of cadaveric dissection, are not completely understood. In this *Letter to the Editor*, the author examines these issues in relation to whether anatomical donation programs may be feasible in Africa. This brief presentation offers a perspective not seen in the modern world of anatomy education, and will hopefully stimulate feedback and suggestions for start-up and maintenance of anatomical donor programs in Africa, and perhaps as a model for programs in other developing countries.

SECTION 1

ANATOMY RESEARCH AND TRANSLATIONAL APPLICATIONS IN THE NEW FRONTIER.

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Challenges of the 21st Century: Part 1 - Diagnostic, prognostic and interventional anatomy

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SUMMARY

Gross anatomy is a fundamental component of the medical school curriculum, anatomy research and cardiology. There remain new and continued applications of anatomical research that are critical to maintain (and improve) the levels of medical care in humans and animals. To demonstrate the role of continued application of anatomical research in the new frontier of anatomical sciences, the authors present a novel and groundbreaking approach to examine lesions of the coronary arteries. The subject cohort patients who underwent a coronary angiogram were screened and the angiograms were selected if there were one or two de novo mild-to-moderate lesions in any of the coronary arteries. Patients with prior coronary bypass graft surgery, percutaneous coronary interventions or ST segment elevation myocardial infarction, were excluded. Coronary angiograms were examined frame-by-frame. Challenging concepts and questions were proposed, discussed and answered. The format that the authors use is a four-part series of anatomical/case-based discussions that present the clinical context, the anatomical findings and the possible mechanism based on hydraulics and physics of the cavitation phenomenon. This approach is innovative and provocative and brings fresh air and new ideas into the arena of learning and research in anatomy.

Key words: Angiogram – Cardiology – Cavitation Phenomenon – Coronary Arteries – Coronary Lesions – Descriptive Anatomy – Interventional Anatomy – Predictive Anatomy – Translational Anatomy

ABBREVIATIONS

Coronary Artery Bypass Graft Surgery (CABG)
Left Anterior Descending Artery (LAD)
Left Circumflex Artery (LCX)
Left Coronary Artery (LCA)
Left Main Coronary Artery (LM)
Percutaneous Coronary Interventions (PCI)
Right Coronary Artery (RCA)

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INTRODUCTION

Gross anatomy is a fundamental component of the medical school curriculum. During this course, students gain a distinct visual understanding of the organ systems and their relationships to one another. Traditionally, this visual understanding has been obtained through a surgical perspective provided by gross dissection or prosection (Winkelmann, 2007; Talarico, Jr., 2010; Ghosh, 2017). More recently, with the advent of modern medical imaging, anatomy education has increasingly been supplemented by a radiological perspective integrated with clinical correlations, case studies and angiography (Talarico, Jr., and Painter, 2020; Choi et al., 2008; Erkonen et al., 1992; McNiesh et al., 1983). Still further, translational research in anatomy and radiology combine to impact patient diagnosis, management and care (Petrou et al., 2009). *Thus, there remain new and continued applications of anatomical research that are critical to maintain (and improve) the levels of medical care in humans and animals.*

As anatomists (i.e., researchers and educators) or interventional cardiologists (i.e., coronary artery anatomists/treaters), lesions of the coronary arteries are examined by reviewing coronary angiograms. When observing coronary lesions, it is both important and interesting to ask three critical questions:

1. WHY do lesions of the coronary arteries occur?
2. HOW do lesions of the coronary arteries happen (i.e., What is the underlying *anatomic mechanism* of lesion formation in the coronary arteries?)
3. WHAT happens next after the development of lesions in coronary arteries, and is this based on *anatomical structure* and/or physiology?

To demonstrate the role of continued application of anatomical research in the new frontier of anatomical sciences, the authors present a *novel and groundbreaking* approach to examine lesions of the coronary arteries with answers to these three important questions (Nguyen et al., 2018a-d). Because of the complex nature and implication of this research, the presentation is broken down into a series for four articles. In this first article of the four-part series, the authors highlighted the list of challenges faced by today's investigators (i.e., anatomists, cardiologists, interventional cardiologists, etc.). The answers to these challenges will be discussed in detail in the subsequent three articles. The second article describes the raw observations of the relevant lesions and coronary flow (i.e., *descriptive anatomy*). The third article discusses the predictive or prognostication value of these observations (*i.e., translational anatomy*). An anatomical observation stays irrelevant unless the observation has diagnostic or prognostic significance (*i.e., predictive anatomy*). The last article focuses on the impact of this anatomical research on medicine or mechanical interventions (i.e., angioplasty and stenting) in order to restore the natural anatomical structure (*i.e., interventional anatomy*).

The format that the authors use in this four-part series is anatomical/case-based discussion. In every situation, the authors/investigators present the clinical context, the anatomical findings and the possible mechanism based on hydraulics and physics; mainly of the *cavitation phenomenon* (Nguyen et al., 2018a-d; Rigatelli et al., 2019; Zuin et al., 2018). This approach is innovative and provocative and brings fresh air and new ideas into the arena of learning and research in anatomy. These are challenges to today's anatomists, internists, cardiovascular surgeons, cardiologists, interventional cardiologists, radiologists and interventional radiologists. Still further, in this real-life assessment, young anatomy researchers can take up these challenges and build on the concepts and principles proposed in this novel approach to the anatomy of coronary arteries and coronary lesions.

METHODS

Subject Cohort. Prior to the start of this study and subject recruitment, approval was obtained from the Internal Review Board of each participating hospital in the University Research Consortium. Patient consent was obtained.

All of the patients who underwent a coronary angiogram were screened and the angiogram was selected if there were one or two de novo mild-to-moderate lesions in any of the coronary arteries. Fifty normal coronary angiograms of patients without left ventricular dysfunction nor valvular abnormalities served as control subjects. Patients with prior coronary bypass graft surgery (CABG), percutaneous coronary interventions (PCI) or ST segment elevation myocardial infarction, were excluded.

Image Research Depository. The complete database of images used in the development of this novel model and in this research investigation has been established at DIGITAL ACCESS to SCHOLARSHIP at Harvard Library, Office for Scholarly Communication (https://dash.harvard.edu/). Readers are invited to explore, and to comment and discuss.

CLINICO-ANATOMICAL CASED-BASED CHALLENGES

Challenge No. 1 – Locations of coronary lesions.

When reviewing coronary angiograms for education, research or clinical purposes, cardiologists and anatomists had no concern about the length, diameter nor the curvature of the artery. These differences were considered normal anatomic variations. More recently, variations in the patterns of the coronary arteries have been documented among diverse human populations (Anbumani, et al., 2016; Bhimalli et al., 2011; Ortale et al., 2005; Fazliogullari et al., 2010; Nguyen and Talarico, 2018; Ballesteros et al., 2011; Kalpana, 2003; Ortale et al., 2004; Nguyen and Talarico, 2019). Still further, there is some evidence that these coronary variations may be one factor that might influence the development or absence of lesions in the coronary arteries (Rossi et al., 1980; Saidi et al., 2010; Nguyen and Talarico, 2018; Nguyen and Talarico, 2019).

Data obtained from the coronary angiograms of patients for the present four-part series of manuscripts showed that when patients developed lesions in the coronary arteries, their coronary angiograms showed significant lesions in the proximal, mid, distal or very distal segment (Fig. 1). This gives rise to many interesting questions.

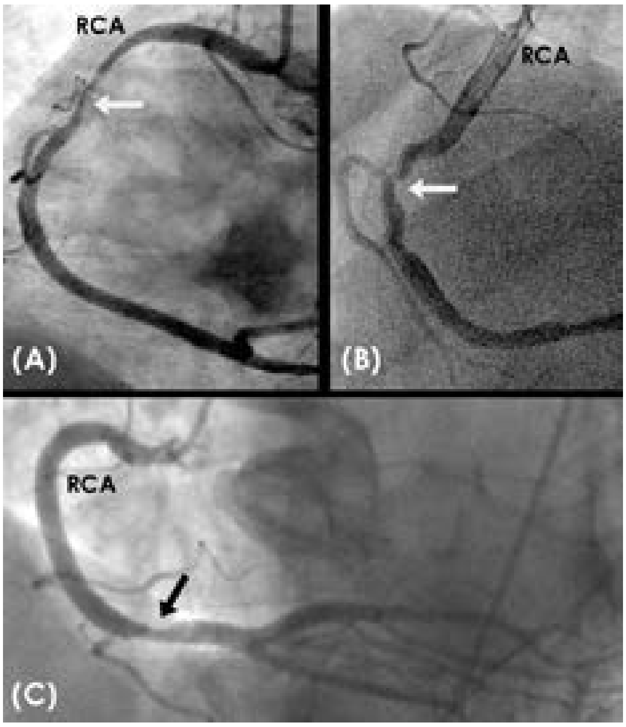

Fig. 1.- Angiograms of the Right Coronary Artery (RCA). (**A**) and (**B**) Sample angiograms from two different patients showing lesion development at the mid-segment (white arrow). (**C**) Angiogram of the RCA showing a lesion at the beginning of the distal segment (black arrow). Challenging questions are: WHY did the lesion happen at the mid-segment vs. the distal segment? COULD lesion formation occur more proximally or distally? DOES the location of lesion development reflect anatomical variations in the patterns of the RCA between patients, such as the presence (A and B) or absence (C) of the side branch?

Challenge No. 2 - Prognostic value of normal variant of right coronary ostium arising from the left sinus.

The right coronary artery (RCA) arises from a solitary coronary ostium and runs in the atrioventricular groove. The ostia of the left and right coronary arteries are located just above the aortic valve, as are the left and right sinuses of Valsalva. Thus, oxygenated blood is pumped into the aorta from the left ventricle and flows into the coronary artery ostia.

When reviewing RCA angiograms of patients with the ostium originating from the opposite sinus, cardiologists and anatomists in the present study agreed that they were a type of anatomical variation without severe prognosis unless the RCA went between the aorta and the pulmonary artery. In the case where the RCA coursed in front of the pulmonary artery, there was no constriction of the RCA during systole (Fig. 2). Relative to clinical/prognostic value, the investigators of the present work proposed a challenging question:

DID the orientation (i.e., anatomical variation) of the ostial and proximal RCA provide an environment suitable for plaque formation? (Fig. 2).

Challenge No. 3 - Diagnostic value of the size of the femoral vein.

Three patients arrived to the hospital with shortness of breath and dizziness. Ultrasound images of the femoral vein were obtained (Fig. 3). Vessels were within normal limits because they were variations of a normal femoral vein. Subsequently, one patient was diagnosed with heart failure, one with pulmonary embolism and one with gastro-intestinal bleeding. The challenging question for anatomists and cardiologists is:

HOW could the size of the femoral vein observed with ultrasound assist in the diagnosis of the above conditions?

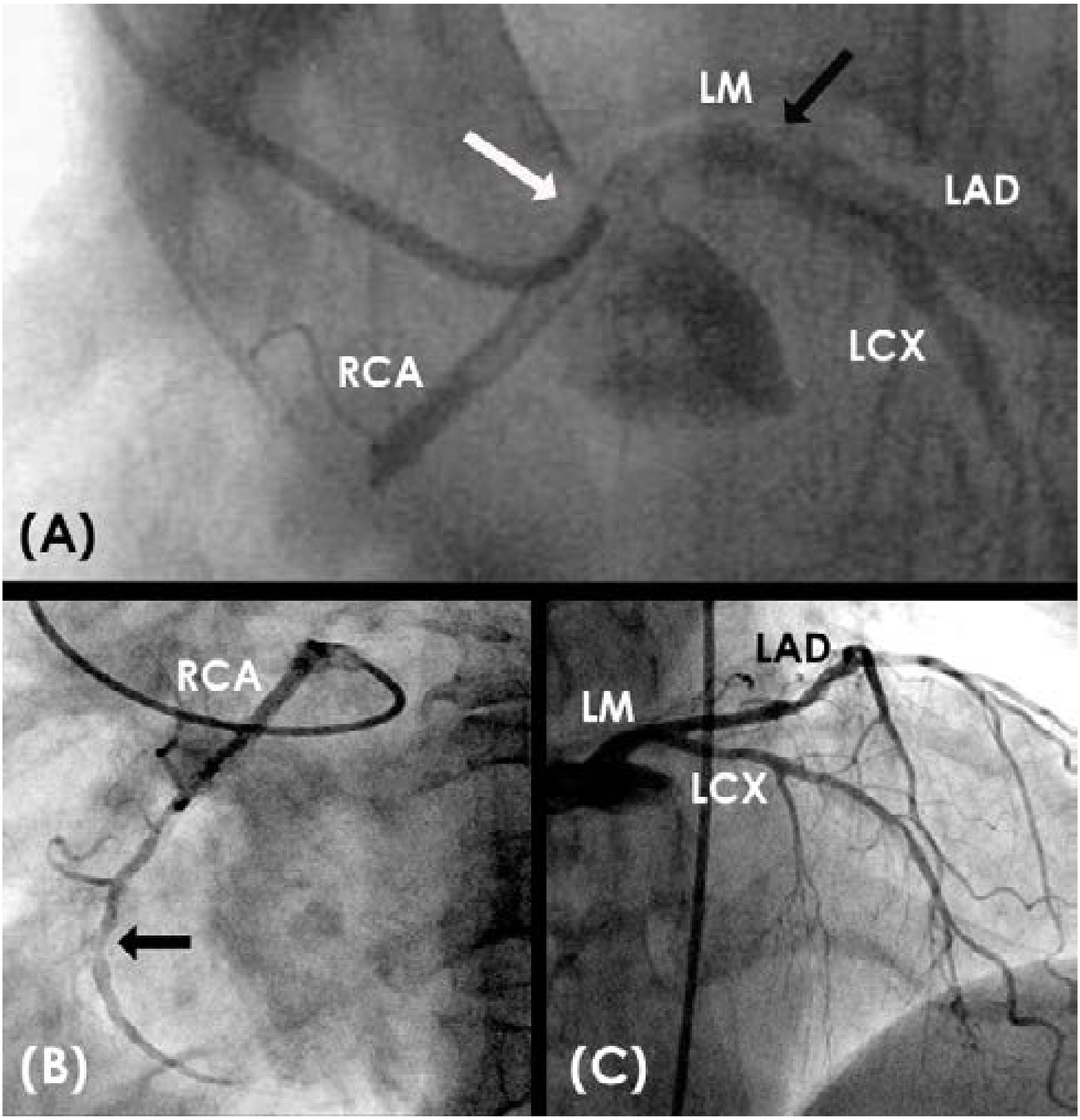

Fig. 2.- Variant of Right Coronary Ostium. (**A**)This is the angiogram of the right coronary artery (RCA) during acute myocardial infarction. The ostium of the RCA was anterior and superior to the ostium (white arrow) of the left main (LM) coronary artery (black arrow). The challenging question is: WHAT was the anatomical mechanism of vulnerable plaques in the proximal segment causing acute occlusion? (**B**) The RCA in the same patient was observed a few years later with a patent proximal stent and lesions in the distal part of the mid segment (arrow). Now, the question becomes: WHAT was the anatomical mechanism of developing new plaques in the mid segment of the RCA? (**C**) The left anterior descending (LAD) artery and the left circumflex (LCX) artery had only minimal lesion. All the three arteries were under the same effects of hypertension, high cholesterol level and smoking. Why did only the RCA have the new lesions?

DISCUSSION

In this four-part, manuscript symposium on anatomy, the authors raise novel questions and challenge anatomists and clinicians to look at anatomy *from a different and dynamic perspective*. The main question is: If I change the anatomy, does the function change? If yes, then the anatomy dictates the function. One example is the diameter of the artery or the pipe. The flow in a small diameter pipe is laminar, while the flow of the large diameter pipe (or artery) can have stagnant flow at the borders (i.e., boundary layers). If the anatomy of the artery (i.e., size, shape, number of branches and branching patterns) stays the same and the movement inside the artery (or pipe) changes, then it is not the anatomy that is essential for the function.

Throughout the presentations and discussions that follow in the subsequent papers, this international team of researchers present this new approach respective to arterial anatomy, and discuss and answer many of the challenges for anatomists, internists, cardiovascular surgeons, cardiologists, interventional cardiologists, radiologists and interventional radiologists, etc., in this modern era of anatomy and medicine (Table 1). As an addendum to this manuscript series, this investigative team stored detailed images of coronary angiograms of many first presentations in medical history at the DIGITAL ACCESS to SCHOLARSHIP at Harvard Library, Office for Scholarly Communication (https://dash.harvard.edu/). Clinical and research anatomists are invited to examine this depository and to discuss and shed new light on these questions and challenges from their perspectives.

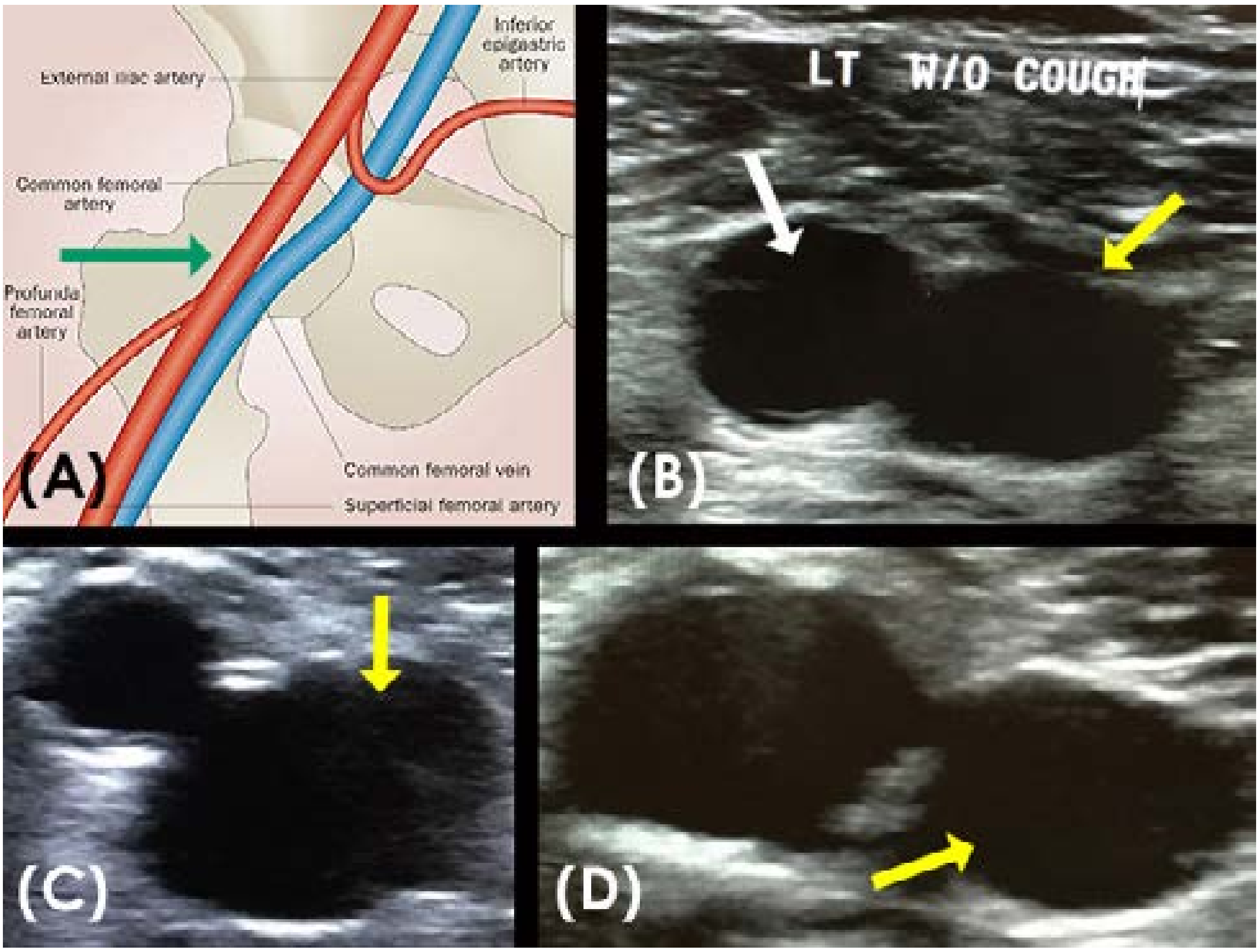

Fig. 3.- Ultrasound Imaging of the Left Femoral Vein. (**A**) Artistic Illustration. The common femoral artery and vein were measured at the level immediately proximal to the bifurcation of the superficial and deep (i.e., profunda) femoral artery (green arrow) (**B**) In this ultrasound image, the common femoral artery was identified as a round structure in the left (white arrow) and the common femoral vein in the right (yellow arrow). Without cough (W/O cough), the diameter of these vessels were of the same approximate size. The vein was easily identified because it collapsed when the probe was pressed down while the artery would stay the same (not shown here). Calcium deposits could be seen on the wall of the common femoral artery. (**C**) In the patient with shortness of breath, the diameter of the common femoral vein was larger, even twice or three times larger than the diameter of the femoral artery. (**D**) In contrast, in the patient with bleeding, the diameter of the common femoral vein was smaller than the diameter of the common femoral artery.

Table 1. List of Challenges and Questions for Modern Clinical Anatomy, Cardiology and Interventional Cardiology.

Challenges and Questions	Manuscript Series	Anatomy
Introduction to Novel Concepts in the Application of Anatomical Research Coronary arteries and lesions: Why? How? What?	Challenges of the 21st Century: Part 1 - Diagnostic, Prognostic and Interventional Anatomy	Descriptive Anatomy Predictive Anatomy Translational Anatomy Interventional Anatomy
Questions Based on Functional Anatomy Is a lesion easier to be developed in systole or in diastole? Does more turbulent flow happen in systole or diastole? Did stagnant flow happen in systole? If so, small lesions happened in systole, while big lesions happened in diastole. Why is this true? Did the stop line happen in systole or diastole?	Challenges of the 21st Century: Part 2 - Dynamic Angiography in the Investigation of Cavitation in Coronary Arteries	Descriptive Anatomy
Questions Based on Functional Anatomy Does a laminar flow predict the presence or absence of lesion in that segment? Does a peripheral contrast retention predict the presence of future lesion in that location? Does turbulent flow predict the development of future lesion in that location? What does the presence of a stop line predict? Questions Based on Cases With Anatomic Variations Can a small artery (diameter <1.5 mm) develop lesions? Does the abnormal orientation of the ostium of the RCA predict future lesions downstream? Does a RCA with the ostium coming from the left sinus have more future lesions downstream? Does the height of the aortic sinus predict the location in the left main, if there is?	Challenges of the 21st Century: Part 3 - The Anatomical Risk Factors Which Predict Future Disaster	Predictive Anatomy

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REFERENCES

ANBUMANI TL, DEEPTHI C, THAMARAI SELVI A, ANTHONY AMMAL S (2016) An anatomical study of the coronary arteries and their variations. *Int J Anat Res,* 4(1): 2114-2118.

BALLESTEROS LE, RAMIREZ ML, QUINTERO ID (2011) Right coronary artery anatomy: anatomical and morphometric analysis. *Rev Bras Cir Cardiovasc*, 26(2): 230-236.

BHIMALLI S, DIXI D, SIDDIBHAVI M, SHIROL VS (2011) A study of variations in coronary arterial system in cadaveric human hearts. *World J Sci Technol*, 1(5): 31-35.

CHOI AR, TAMBLYN R, STRINGER MD (2008) Electronic resources for surgical anatomy. *ANZ J Surg*, 78(12): 1082-1091.

ERKONEN WE, ALBANESE MA, SMITH WL, PANTAZIS NJ (1992) Effectiveness of teaching radiologic image interpretation in gross anatomy. A long-term follow-up. *Invest Radiol*, 7(3): 264-266.

FAZLIOGULLARI Z, KARABULUT AK, ULVER DUGAN N, UYSAL II (2010) Coronary artery variations and median artery in Turkish cadaver hearts. *Singapore Med J,* 51(10): 775-780.

GHOSH SK (2017) Cadaveric dissection as an educational tool for anatomical sciences in the 21st century. *Anat Sci Educ*, 10(3): 286-299.

KALPANA R (2003) A study on principal branches of coronary arteries in humans. *J Anat Soc India*, 52(2): 137-140.

MCNIESH LM, MADEWELL JE, ALLMAN RM (1983) Cadaver radiography in the teaching of gross anatomy. *Radiology*, 148(1): 73-74.

NGUYEN T, NGUYEN NMT, TRUONG VT, VO VM, RIGATELLI G (2018a) Cavitation phenomenon creating bubbles and their explosion in the coronary arteries caused damage to the endothelium and start the atherosclerotic process. *J Am Coll Cardiol*, 71(11 Supplement): A269. https://doi.org/10.1016/S0735-1097(18)30810-6

NGUYEN T, CHAU NBT, THUY LTP, DANG T, NGUYEN T NT, DARWISH T, RIGATELLI G, TALARICO JR EF (2018b) New discovery: New Technique of visualization of laminar, turbulent flow and measurement of velocity and dynamic coronary pressure. *J Am Coll Cardiol*, 72(16 Supplement): C200. doi: 10.1016/j.jacc.2018.08.872

NGUYEN T, DANG T, NGUYEN T NT, ANH CH, HOANG PLH, DARWISH T, RIGATELLI G, TALARICO JR EF (2018c) new discovery: gas bubbles rupture in the coronary arteries is most likely the mechanism breaking the thin cap of plaques causing acute coronary syndrome. *J Am Coll Cardiol*, 72(16 Supplement): C105. doi: 10.1016/j.jacc.2018.08.528

NGUYEN T, ZUNI M, LUAN NT, VY NNH, TRUONG K, DANG T, NGUYEN T NT, DARWISH T, RIGATELLI G, TALARICO JR EF (2018d) Demonstration of cavitation in the coronary arteries by computational fluid dynamics. *J Am Coll Cardiol*, 72(16 Supplement): C72. doi: 10.1016/j.jacc.2018.08.414

NGUYEN VH, TALARICO JR EF (2018) A morphometric anatomical study of the division of the left main coronary artery and myocardial bridges. *Eur J Anat*, 22(4): 355-365.

NGUYEN VH, TALARICO JR EF (2019) A morphometric anatomical study of the right coronary artery in Vietnamese. *Eur J Anat*, 23(5): 341-353.

ORTALE JR, FILHO JM, PACCOLA AMF, LEAL JGPG, SCARANARI CA (2005) Anatomy of the lateral, diagonal and anterosuperior arterial branches of the left ventricle of the human heart. *BJCVS/RBCCV*, 20(2): 149-158.

ORTALE JR, KEIRELLA LCB, CAMPINAS LS (2004) The posterior ventricular branches of the coronary arteries in the human heart. *Arqivos Brasileiros de Cardiologia*, 82(5): 468-472.

PETROU M, FOERSTER BR, REICH DS (2009) Translational research in radiology: challenges and role in a patient-based practice. *Acad Radiol*, 16(5): 593-596.

RIGATELLI G, ZUIN M, NGO TT, NGUYEN HT, NANJUNDAPPA A, TALARICO E, DUY LCP, NGUYEN T (2019) Intracoronary cavitation as a cause of plaque rupture and thrombosis propagation in patients with acute myocardial infarction: a computational study. *Transl Int Med*, 7(2): 69-75. doi: 10.2478/jtim-2019-0014.

ROSSI L, DANDER B, NIDASIO GP, ARBUSTINI E, PARIS B, VASSANELLI C, BUONANNO C, POPPI A (1980) Myocardial bridges and ischemic heart disease. *Eur Heart J*, 1(4): 239-245.

SAIDI, H, ONGERTI WK, OGENG'O J (2010) Morphology of human myocardial bridges and association with coronary artery disease. *Afr Health Sci*, 10(3): 242-247.

TALARICO JR EF (2010) A human dissection training program at Indiana University School of Medicine-Northwest. *Ana Sci Educ*, 3(2): 77-82.

TALARICO JR EF, PAINTER SD (2020) Small team-based medical imaging of human cadavers: an innovative tool for interdisciplinary learning in human gross anatomy and radiologic sciences. *Eur J Anat*, 24(2): 141-154.

ZUIN M, NGUYEN T, DANG T, VU A, LUONG P, DARWISH T, NGUYEN T, NGKUYEN T, BUI Q, CHE K, DANG T, RIGATELLI G, TALARICO JR ET (2018) Mechanism triggering acute coronary syndrome by rupturing plaque based on the cavitation phenomenon (bubble formation and explosion) at the distal left main bifurcation by computational fluid dynamic study. *J Am Coll Cardiol*, 72(13 Supplement): B126-B127. doi: 10.1016/j.jacc.2018.08.1447

WINKELMANN A (2007) Anatomical dissection as a teaching method in medical school: a review of the evidence. *Med Educ*, 41(1): 15-22.

Challenges of the 21ST Century: Part 2 - Dynamic angiography in the investigation of cavitation in coronary arteries: Standard description of coronary lesions and blood flow

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SUMMARY

There is no confirmed mechanism in the formation and growth of atherosclerotic plaques, or coronary artery disease (CAD). In all patients, the entire arterial tree is exposed to the atherogenic effects of systemic risk factors and yet only few arteries develop plaques. The hypothesis was that damage on the intima was caused by the cavitation phenomenon frequently seen in domestic/industrial pipes. Herein, a summary of hydraulic principles and cavitation phenomenon is presented. Then, a *novel* method is introduced for review and analysis of the coronary angiogram based on these principles and the underlying anatomic structure of the coronary vasculature. Coronary angiograms of patients with one or two de novo mild-to-moderate lesions in any of the coronary arteries were examined for correlation between types of flow and lesions. This novel technique allowed comparison of local factors effecting one coronary segment with local factors on other coronary segments in a same patient. The most frequent location (75%) of lesions was at the COLLISION LINE, where antegrade and retrograde flows collided during the transition from diastole to systole. Lesions at the collision line appeared earlier and grew faster compared with the lesions in other coronary arteries of a same patient in 76% of cases. There was a strong relation between the presence of lesions with the abnormalities of blood flow at the collision line or a side branch of mild-to-moderate size. The mechanism for formation of coronary lesions is most likely from explosion of air bubbles, injuring

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the intima and starting the atherosclerotic process. The new technique of angiography, review of the dynamic flows and their anatomical correlations opens new chapters in the clinical anatomy and interventional management of CAD.

Key words: Anatomical structure – Cavitation phenomenon – Coronary lesion – Dynamic pressure – Fluid mechanics – Laminar flow – Turbulent flow – Collision line – Vapor pressure

ABBREVIATIONS

Anterior-Posterior (AP)

Coronary Angiogram(s) (CAG/CAGs)

Coronary Artery Bypass Graft Surgery (CABG)

Coronary Artery Disease (CAD)

Dynamic Pressure ($P_{dynamic}$)

EPIC Electronic Health Record (EHR)

Heating, Ventilation and Air-Conditioning (HVAC)

Left Anterior Descending Artery (LAD)

Left Anterior Oblique (LAO)

Left Circumflex Artery (LCX)

Low-Density Lipoprotein (LDL)

Percutaneous Coronary Interventions (PCI)

Right Anterior Oblique (RAO)

Right Coronary Artery (RCA)

Thrombolysis in Myocardial Infarction (TIMI)

Vapor Pressure (P_{vapor})

INTRODUCTION

In Part 1 of this manuscript symposium, the challenges of diagnostic, prognostic and interventional anatomy were listed in the context of new and continued applications of anatomical research that are critical to maintain (and improve) the levels of medical care in humans and animals. Further, challenging questions and concepts were highlighted and presented that related to descriptive anatomy, predictive anatomy, translational anatomy and interventional anatomy. In Part 2 of this symposium, the authors present details of a *novel and groundbreaking* approach to examine coronary lesions based on the relationship between *anatomical structure and fluid mechanics*. This new perspective demonstrates the role of continued application of anatomical research in opening new doors or reaching new heights confronting anatomical sciences, medical, surgical or interventional cardiology during the second decade of the 21st century.

Questions for the Modern Interventional Anatomist (i.e., Interventional Cardiologist)

In the past 70 years, since the first coronary angiograms (CAGs) were done (Gensini et al., 1962; Sones and Shirey, 1962; Bruschke et al., 2009), investigators (i.e., cardiologists, interventionalists, angiographers, etc.) reviewed the CAG by looking at the shape of the lumen filled with contrast (i.e., luminogram). If there was an indentation or defect on the contrast filled arteriogram, the conclusion was that the patient had a lesion (Fig. 1). The identification of a lesion on angiograms did not provide an assessment of the risk level nor its prognosis. Still further, detailed description of a lesion could not clarify the *anatomic mechanism* of its formation and progression; thus, the clinician could not devise an effective strategy for treatment or prevention (Fig. 2). If the future appearance of a severe lesion could be predicted by reviewing the anatomy of an earlier CAG, the contribution of the anatomist community to the modern society could never be fully appreciated.

In this laboratory, recent research on coronary artery disease (CAD) hypothesized that coronary lesions were caused by the cavitation phenomenon (or bubble rupture) which is a well-proven and frequent cause of damage in domestic and industrial pipes in the plumbing or heating, ventilation and air-conditioning (HVAC) industries (Ferrari, 2017; Sathasivam et al., 2018; Wosnik and Arndt, 2013; Nguyen et al. 2018a-d; Zuin et al., 2018). The same principles of hydraulics and fluid mechanics were applied in the identification and explanation of different coronary flow patterns and their roles in the genesis of atherosclerotic plaques. The mechanistic pathologies were based on the anatomical structure and flows of the coronary arteries (i.e., vessel length and diameter;

degree of curving; orientation of the ostium and proximal segment; angles of bifurcation with side branches; flowing velocity and patterns; etc.).

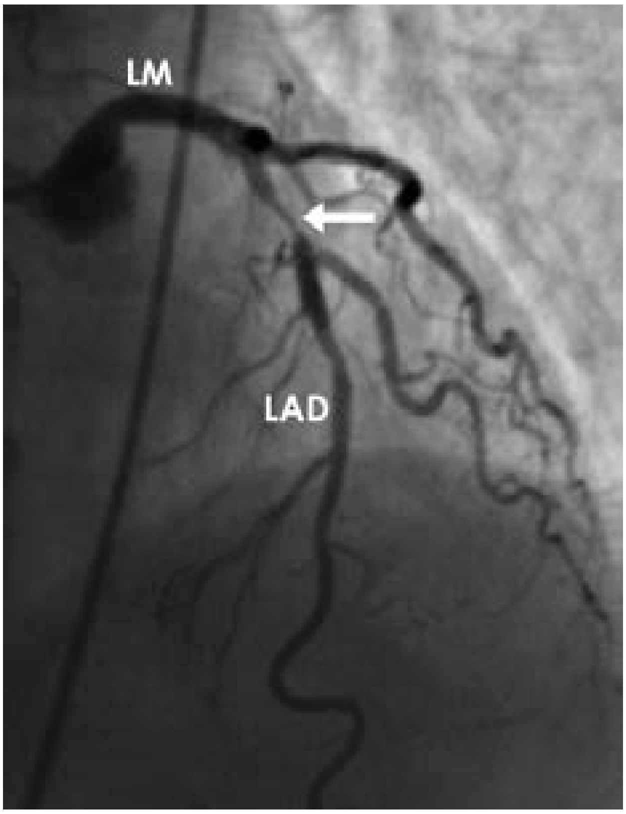

Fig. 1.- Left Coronary Artery Angiogram. In this coronary angiogram of the left coronary artery, there was a severe, subtotal lesion (arrow) on the proximal segment of the left anterior descending artery (LAD). This was a "widow maker" lesion. Why did it happen here? Could it be developed in another location with lower morbidity or mortality?

In this manuscript, an overview of the cavitation phenomenon is presented, especially its role in damage to domestic and industrial pipes and the engineering measures to prevent these damages. Then, a *novel* method of reviewing and analyzing CAGs is explained in detail (Nguyen et al. 2018a-d; Zuin et al, 0218) The goal is to search for elements that are needed for cavitation (i.e., laminar, turbulent or stagnant flow; separation or boundary layers; and areas of high and low velocity and corresponding pressure). At the end, the new discoveries that have never before been published in the medical literature are presented that focus on normal coronary dynamics, its timing, antegrade versus retrograde directions, and the new perspective on types of lesions, and different patterns of flows. In this symposium, details of complete angiograms (i.e., image-by-image; at 15 images per second) are stored in the established at the DIGITAL ACCESS to SCHOLARSHIP at Harvard Library, Office for Scholarly Communication (https://dash.harvard.edu/) for all investigators to verify and judge the results.

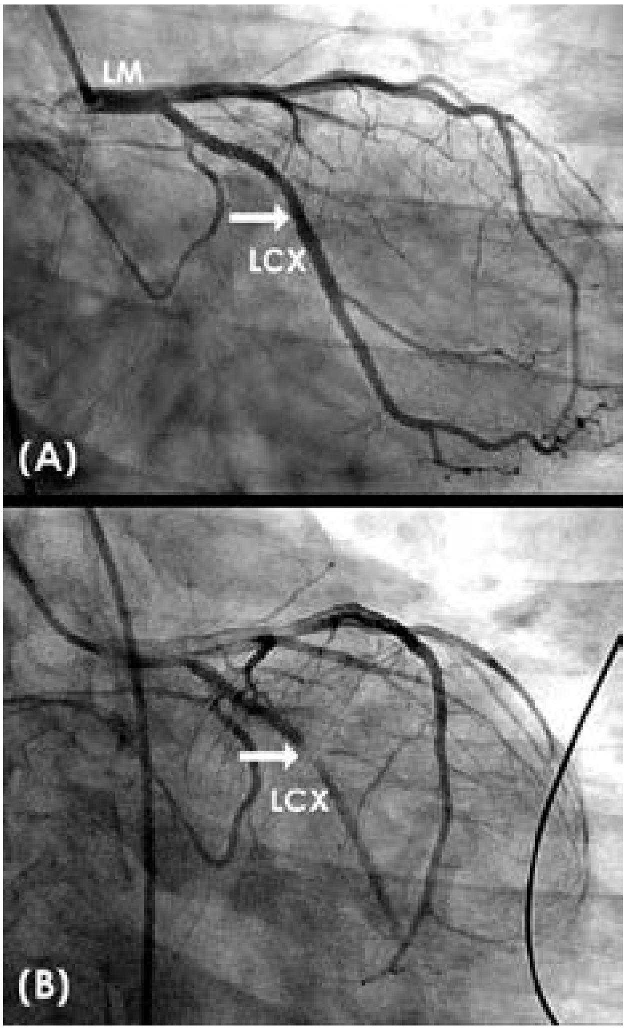

Fig. 2.- Left Coronary Artery Angiogram. **(A)** This is the left coronary angiogram with a patent left main (LM) and left circumflex (LCX) artery in a patient who underwent stenting for a severe lesion in the right coronary artery (not shown). **(B)** In this repeat angiogram of the same patient 3 months later, a severe lesion in the mid-segment was observed (arrow). The patient's low-density lipoprotein (LDL) cholesterol level was 170 mg/dL. Could the physician have predicted the appearance of the severe lesion by reviewing the anatomy of the earlier coronary angiogram?

CAVITATION IN PIPES AND ARTERIES

Observations in Coronary Arteries

At the present time, there is no confirmed mechanism for the development and growth of atherosclerotic plaques. In each individual, the entire arterial tree is exposed to the atherogenic effects of systemic risk factors and yet only a few arterial segments develop plaques. These plaques are frequently present in the coronary arteries, whereas fewer are seen in the arteries of the lower extremities, and far fewer are documented in the carotid, upper extremity or renal arteries. In the coronary arteries, plaques are observed to “cluster” in the proximal segment of the left anterior descending (LAD) or left circumflex artery (LCX), whereas they can be seen as frequently in the mid-segment of the right coronary artery (RCA). Why there is such a pattern of spatial distribution of coronary arterial plaques is not understood. Could these observations be explained relative to the underlying anatomy and blood flow?

Basic Principles of Applied Domestic and Industrial Hydraulics

In real-life hydraulic practice by domestic or industrial plumbers or HVAC specialists, the main goal is to have a smooth flow of fluid, water, oil, and hot or cold air, etc. This smooth flow is defined as laminar flow, when it flows in parallel layers with no disruption between each layer. The layers in the center flow faster, while those on the periphery flow more slowly. The differences in speed and pressure follow the rules of Bernoulli’s principle of energy conservation and are explained in Fig. 3.

The changes of pressure provide a favorable terrain for the cavitation phenomenon which subsequently causes extensive damage to pipes and pumps (Ferrari, 2017; Kumar and Pandit, 1999; Joseph, 1998; Brennen, 2005).

Mechanism of Cavitation in Pipes

Cavitation is defined as the process of formation of the vapor phase (i.e., vapor-filled cavities) which occurs when the dynamic fluid pressure decreases to a level lower than the vapor pressure of the gas diluted in the liquid. This results in the formation and growth of vapor bubbles (referred to as voids in the engineering industry). As bubbles are being transported along the pipes, when flowing through a zone of **low** dynamic pressure ($P_{dynamic}$) the bubbles will expand due to the pressure difference between the vapor (P_{vapor}) inside them and the surrounding liquid. When they expand too big in size, they become vulnerable and can explode. In contrast, when flowing through the zones of **high** $P_{dynamic}$, these bubbles will implode (Fig. 4).

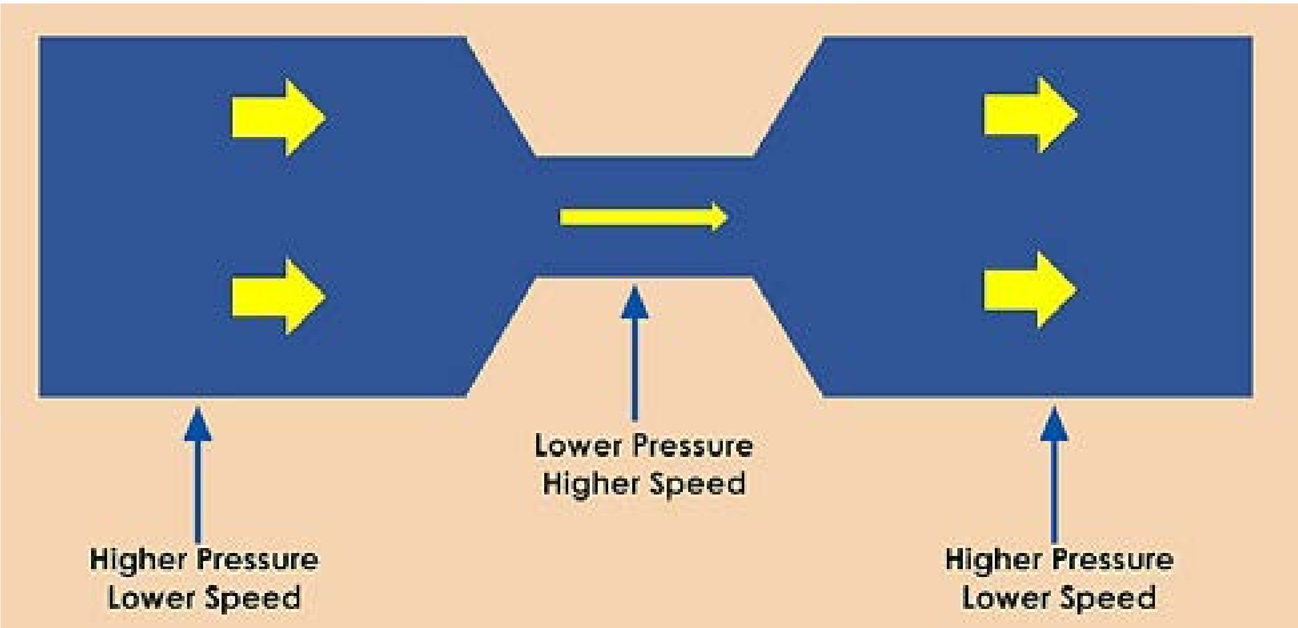

Fig. 3.- Bernoulli’s Principle. Bernoulli’s principle can be considered to be a statement of the conservation of energy principle appropriate for flowing fluids (i.e., changes in the flow and pressure according to the rule of constancy of total energy). The qualitative behavior that is usually labeled with the term “Bernoulli effect” is the lowering of fluid pressure in regions where the flow velocity is increased. Thus, an increase in the speed of a fluid occurs simultaneously with a decrease in static pressure or a decrease in the fluid’s potential energy. With respect to a pipe (or artery), the velocity is higher and the pressure is lower in the narrow area. Once outside the narrow area, upstream or downstream, the velocity is lower and the pressure is higher.

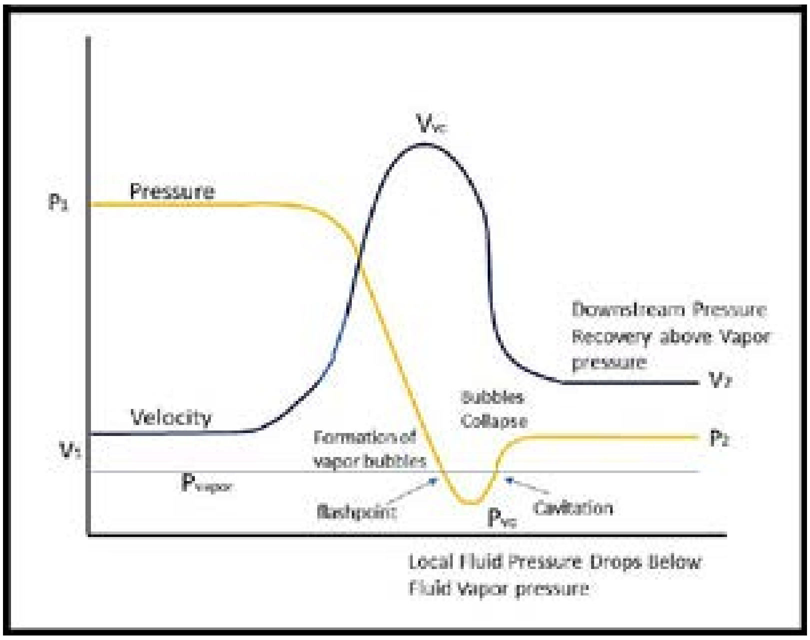

Fig. 4.- Graphical representation of Bernoulli's Principle in Cavitation and Bubble Formation. When the local dynamic pressure ($P_{dynamic}$) from the inlet becomes lower than the vapor pressure (P_{vapor}) in the liquid, such as in the narrow area of a pipe, where velocity (V) is high and $P_{dynamic}$ is low, then the bubbles form. When these bubbles move to an area with $P_{dynamic}$ higher than P_{vapor} (such as exiting the narrow area of a pipe and entering an area of greater size/diameter) then the bubbles will burst.

Bubble Implosion and Explosion Causing Micro-Jets

When the bubbles contract towards an infinitely small radius, they implode in a rather violent collapse (Fig. 5). This collapse is followed by a very localized pressure pulse that can give rise to small but powerful micro-jets (or shock waves), damaging the surfaces of pipes of the plumbing system of a house or a factory, or components of the valves inside a pump. The repeating insults on the surface of metal material which these domestic or industrial valves and pipes are constructed, could cause cyclic stress (i.e., the distribution of forces that change over time in a repetitive fashion). As result, the surfaces can become work-hardened, fatigued, brittle and so less resistant to local fracture and erosion with time (Brennen, 1995; Brennen, 2005; Ferrari, 2017; Fujisawa et al., 2018; Hsiao et al., 2014; Tomita et al., 2002; Kumar and Pandit, 1999).

Engineering Measures to Prevent Cavitation and Damage

In the plumbing, HVAC industries, cavitation is the most common culprit of mechanical damage, deterioration of pump performance and ultimately pump failure. In order to avoid or mitigate cavitation and its subsequent damage, various measures are applied by plumbers or HVAC specialists to

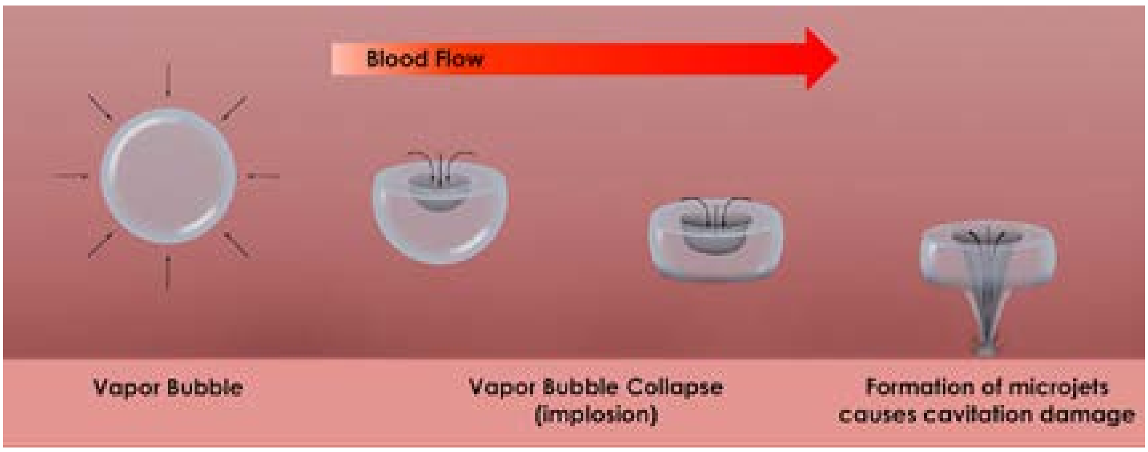

Fig. 5.- Bubble Formation and Implosion. As fluid flows through a pipe, bubbles form as vapor pressure becomes higher than dynamic pressure (1). When bubbles enter areas of the pipes where dynamic pressure increases above vapor pressure, bubbles deform (2 and 3). With increasing dynamic pressure on the bubble, surface tension of the bubble breaks and bursts creating micro-jets (4).

optimize flow performance in pipes (Table 1) (Chitnis et al., 2010; Zhao and Zhao, 2017; Xylem, Inc., 2015). These hydraulic recommendations were in turn used in the present research for better management of coronary and peripheral artery disease. They are listed in Table 1.

Hypothesis of the Cavitation Phenomenon in the Coronary Circulation

Based on the current understanding of coronary flow physiology, the blood flow during diastole is forward secondary to a positive gradient between the proximal and distal pressure. In systole, the coronary flow is at a standstill or even reverses backwards towards the ostium (Barral and Croibier, 2011; Carabello, 2006; Duncker et al., 2015). As the coronary flow is powered by distal lower pressure, there is high potential for bubbles to form when the $P_{dynamic}$ in the distal coronary flow drops too quickly, faster than the capability of the proximal coronary flow (at the LM artery level or the proximal RCA) to fill the void. If so, the flow at the LM may leave an area (or multiple tiny areas) of low $P_{dynamic}$ which is (are) a bubble(s) of gas. These bubbles expand as long as the P_{vapor} is higher than $P_{dynamic}$ (which happens in diastole). Then, bubbles implode when the local coronary $P_{dynamic}$ recovers above the P_{vapor} inside the bubbles (which happens in systole). Bubbles implosions create jet waves, damaging the tunica intima and triggering intimal thickening.

Because the intima is an avascular tissue, receiving O_2 and nutrients from the intra-luminal blood, the most distal intimal cell layers next to the media muscularis, could become hypoxic if the intimal layer becomes thickened enough. This hypoxia triggers the development of new vasa vasorum originated from the adventitia and media muscularis. From these neovascular channels, the blood moves in, carrying the low-density lipoprotein (LDL) cholesterol molecules into the sub-intimal space. Here, the LDL cholesterol molecules are trapped, without an exit, swallowed by macrophages, and form foam cells (i.e., lipid-laden macrophages). A multitude of foam cells becomes a lipid pool which is the core of a coronary plaque (Yu et al., 2013; Chistiakov et al., 2017).

Application of the Hydraulics Principles to the Coronary Circulation

To explain the mechanistic formation of CAD, hypothesis of cavitation, and detrimental or beneficial effects of different types of flow in the coronary circulation, the first task of anatomists,

Table 1. Engineering Measures in the Prevention of Cavitation in Pipes**.**

ANATOMICAL RELATIONSHIP	**MITIGATION MEASURES IN PIPES (VESSELS)**
Location of Main Pump and Anatomy and Sizes of Pipe Inlets and Outlets	<u>Connecting Pipes to Pumps</u> The source of the main pump should be at the lowest position (e.g. the basement of the house) while pumping the fluid up. From this position of high pressure from gravity, the chance to develop cavitation is low because the dynamic pressure is higher than the vapor pressure of the diluted air. The inlet of the pipes should be larger than the outlet because the fluid will fill all the spaces, without leaving empty pockets which are in fact the bubbles
Anatomical Structure - Diameter and Length of Pipes	<u>Pipes and Curves</u> From the inlet to a curve, the optimal distance should be 10 times the diameter of the pipe so the flow could become laminar if it is not so from the beginning
Anatomical Position of Curves	<u>Location and Angle of Curves</u> The angle of a curve should be smooth, not too acute so the flow could continue to be laminar, without pockets of recirculating flow.
Speed Relationship to Anatomical Structure	<u>Fluid Speed Coursing Through Pipes</u> LOW speed is better than a HIGH speed because a slow speed (= high pressure) would not allow the formation or growth of bubbles if the vapor pressure is low from the start

angiographers and cardiologists is to accurately identify the normal and abnormal flows and the different types of minimal-to-severe lesions in CAGs (Part 2 of this symposium which is this current article). The second task is to correlate the presence of abnormal flows with the presence of coronary plaques or the absence of abnormal flow with the absence of coronary plaques (Part 3 of this symposium: next article). Finally, the third task is to document the return of the laminar flow after restoration of the original coronary *anatomy with* medical treatment or percutaneous coronary interventions (PCI) (Part 4 of this symposium). In the beginning, the labeling of the types of coronary flow and lesion is done manually by the reviewers/anatomists/cardiologists/operators. However, in order to widely apply this technique to the hectic daily workload of the staff in cardiac catheterization laboratories, artificial intelligence programs to recognize these abnormal flows and their changes are needed (Nguyen, 2020; Vu , 2020; Do, 2020; Duong, 2020; Pham , 2020).

METHODS

Subject Cohort

Prior to the start of this study and subject recruitment, approval was obtained from the Internal Review Board of each participating hospital in the University Research Consortium. Patient consent was obtained.

All patients who underwent CAG were screened and the angiogram was selected if there were one or two de novo mild-to-moderate lesions. Fifty normal CAGs without left ventricular dysfunction nor valvular abnormalities served as control. Patients with prior coronary artery bypass graft surgery (CABG), ST segment elevation myocardial infarction, were excluded. If the lesion was very tight, with only Thrombolysis in Myocardial Infarction (TIMI) 0 or 1 flow, these patients were excluded. The reason was that the TIMI 0 and 1 flows are the terminal flows so they do not help in the mechanistic explanation of birth or growth of the lesion based on flow dynamics.

Image Research Depository. The complete database of images used in the development of this novel model and in this research investigation has been established at DIGITAL ACCESS to SCHOLARSHIP at Harvard Library, Office for Scholarly Communication (https://dash.harvard.edu/). Readers are invited to explore, and to comment and discuss.

Novel Technique of Dynamic Coronary Angiography. Because this is a *new approach* to examine the dynamics of coronary arteries based on anatomy and how this applies to the development and growth of coronary lesions, a detailed explanation of the method is given below.

Injection of Contrast Media and Recording of Images

Contrast was injected until the index coronary artery was completely opacified. When some contrast in “black” color was seen ejected back from the coronary ostium into the aorta, the manual injection was stopped. At that time, the blood in “white” color could be seen moving in and displacing the contrast. The shape, movements, directions and interactions of the blood flow in “white” color could be clearly observed above a “black” background.

The angiogram was recorded from the beginning of injection until all the contrast disappeared from the distal arterial vasculature (i.e., arterial phase) and ended after the contrast was gone from the coronary veins (i.e., venous phase). During the recording, the camera was positioned in an angle that could record the index artery in its full length, with all the images totally inside the screen, at 15 images per second. The left anterior oblique (LAO) caudal view was best for looking at the ostium, proximal and mid segment of the RCA (Fig. 6A). The right anterior oblique (RAO) caudal view was best when reviewing the LCX (Fig. 6B). The LAD was seen best with the anterior-posterior (AP) cranial view or LAO cranial view (Fig. 6C).

These views were selected because they could show all movements of the blood flow on a clean background of the lungs. The selected angles would avoid superimposing the arteriograms or venograms on the bony structures of the spine or on the myocardium filled with contrast at the end of the arterial phase and during the venous phase. The angiograms were saved and stored in the EPIC Electronic Health Record (EHR) System (*Epic Systems Corporation*, Madison, WI).

Review Protocol of Dynamic Coronary Angiogram

Each CAG was reviewed by two experienced angiographers. The reviewers accessed the data from the EHR, downloaded the entire angiogram, and selected the series to be examined. Then, on the keyboard, the reviewers made a “right” click, chose the Key Image option, and used the “Up and Down” arrow keys to move the images, one at a time (Fig. 7).

The time was calculated in second (sec) with 1 image = 0.06 second based on a speed of recording of 15 images per second. The images of the coronary angiography were de-identified with the name of the patients removed, given a new code number and saved in a Microsoft® PowerPoint file (*Microsoft Corporation*, Redmond, WA, USA). In this way, the sequential images of a coronary angiogram could be reviewed multiple times in hard copy without the need of re-accessing the security and firewall protected EHR.

Identification and Classification of Lesions

In all patients, the proximal, mid and distal segments of each coronary artery were searched and recorded for presence of lesions or normal borders without lesion. The mid-segments in each artery were especially focused. All the lesions were identified and classified as shown in Table 2 and Fig. 8.

Identification of Types of Flow

Similar to the classification in industrial piping, coronary flows can be divided into four types: (1)

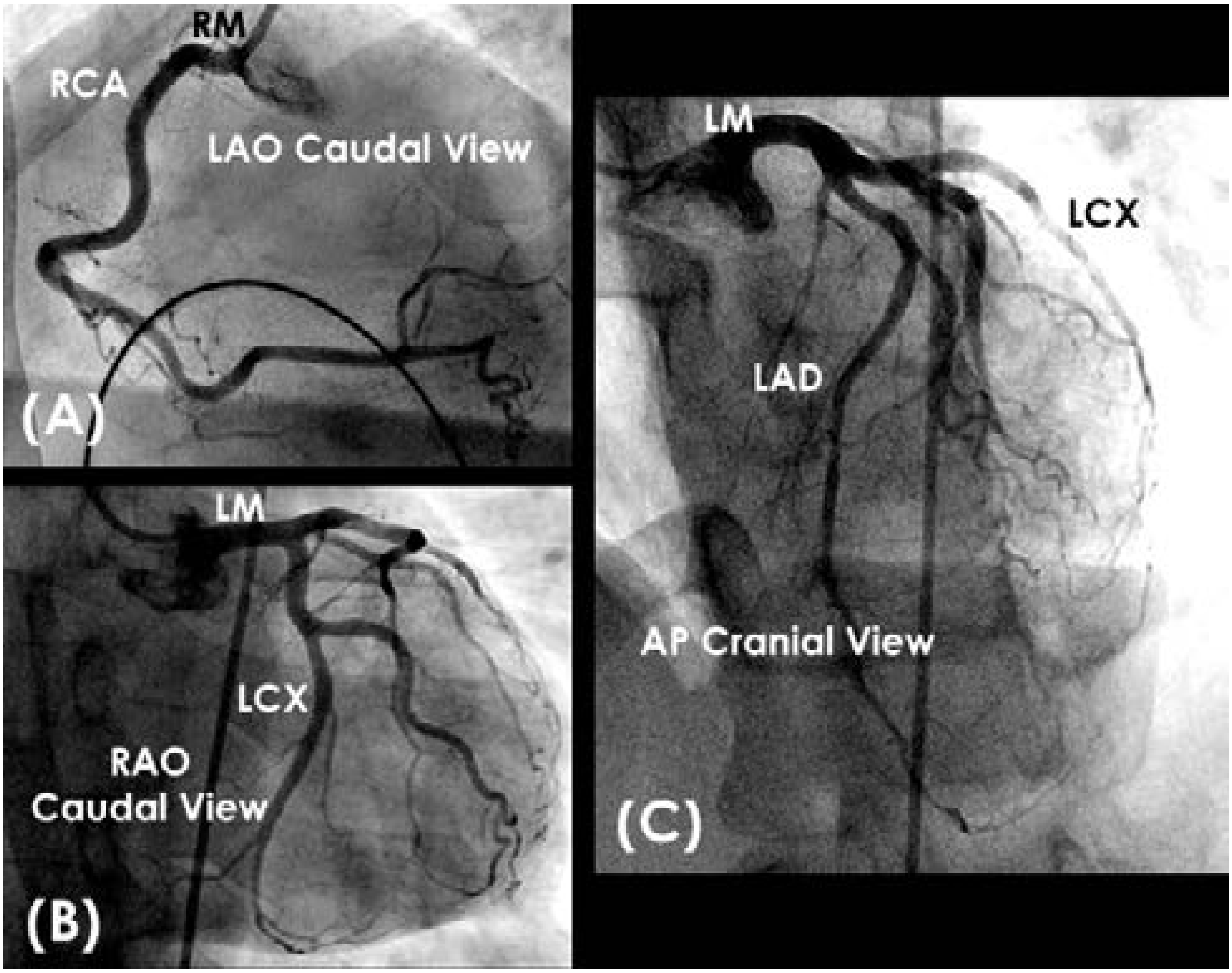

Fig. 6.- Best Angiographic Angles. **(A)** The left anterior oblique (LAO) caudal view was best for the right coronary artery (RCA). In this angle, the ostial and proximal segment was were projected on a clear background of the lungs. **(B)** The right anterior oblique (RAO) caudal view was best to see the bifurcation of the distal left main (LM) to the proximal curve of the left circumflex artery (LCX), and its mid and distal segment. **(C)** The anterior-posterior (AP) cranial view was best for the proximal, mid and distal segment of the left anterior descending artery (LAD).

laminar, (2) turbulent, (3) stagnant flow due to separation at the entrance of an artery (separation layer) and (4) stagnant flow due to high viscosity which forms a boundary layer. In laminar flow, the fluid layers slide in parallel, without eddies nor swirls, seen as homogenous white without of black contrast and white blood along the flow. (Fig. 9) (Table 3).

Fig. 7.- Reviewing Dynamic Coronary Angiograms. When reviewing the coronary angiogram, the reviewer makes a "right" click, selects the "Key Image" option (red arrow) and then uses the Up and Down arrow on the keyboard to move the images, frame-by-frame.

Table 2. Classification of Coronary Lesions.

LESION TYPE	DESCRIPTION
Type A	Severe subtotal lesion (**Fig. 8A**)
Type B	Moderate (**Fig. 8B**)
Type C	Mild (**Fig. 8C**)
Type D	Diffuse minimal lesion along the border of an arterial segment (**Fig. 8D**)

Turbulent flow occurs in three situations. One is at the site of collision between the antegrade flow (white) with the retrograde flow (black), seen as mixing of blood (white) and contrast (black) in a disorganized pattern**.** This location is called the collision site (Fig. 10). The second situation is at the ostium of the RCA or LM when the blood begins to enter the artery. It takes time for the flow to become organized. At the beginning, the flow is disorganized so it looks turbulent. The third situation happened when the diameter of the artery was large due to aneurysmal changes.

Other flow anomalies can also be observed using the novel approach. In the CAG shown in Fig. 11, contrast is seen persisting at the outer curve of a distal LM bifurcation, at the exit slope of the ostial LCX, opposite to the carina. The stagnant contrast is definitive for separation flow (Fig. 11A). The long and thick contrast retention along the inner curve of the RCA is typical for the presence of the boundary layer, most likely caused by high viscosity (Fig. 11B).

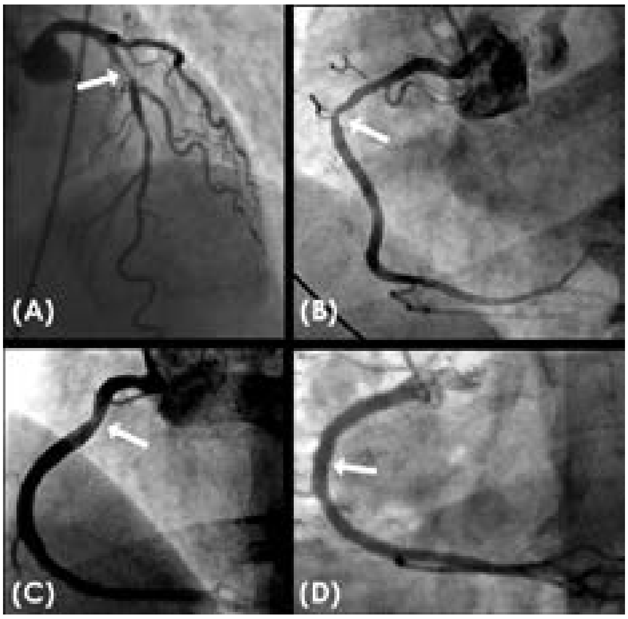

Fig. 8.- Classification of Coronary Lesions. **(A)** Type A lesion: Severe subtotal lesion (arrow). **(B)** Type B lesion: Short concise lesion of moderate severity. **(C)** Type C lesion: Short mild lesion. **(D)** Type D lesion: Minimal diffuse lesions.

Systolic and Diastolic Flow

The coronary circulation is a special system which is located on top of the myocardium to which the coronary arteries themselves supply oxygen and nutrients. The tissue layer which contains the coronary arteries is called the epicardium. This is why the major coronary arteries large enough to undergo stenting, are also known as epicardial coronary arteries. The epicardium is composed of both the outer layer of the myocardium and the inner layer of the serous visceral pericardium. The coronary arteries oxygenate the myocardium either by direct perforating septal vessels or by the network of arterioles or capillaries deep inside the myocardium. During systole, the contraction of the ventricle compresses these arterioles and capillary networks and denies the exit of the epicardial flow. The contraction of the ventricle (or myocardium) does not constrict the epicardial coronary arteries unless there is myocardial bridging (Nguyen and Talarico, 2019, Nguyen and Talarico, 2018; Lee and Chen, 2015; Mohlenkamp, et al., 2002; Ripa et al., 2007). Based on above current understanding, coronary perfusion occurs only during diastole. This understanding is confirmed by the new dynamic angiographic technique (Fig. 12). During CAG, after the coronary artery was totally opacified (i.e., black), the manual injection of contrast stopped, and the aortic valve was still opened (Fig. 12A). The image showed that the blood still coursed forward (i.e., distal, or away from the heart) with the contrast still at both borders of the ascending aorta (Fig. 12A). Then, in the next sequence, the aortic valve was observed closing; this was the end of systole (Fig. 12B). When blood (i.e., white) began to flow into the LM, this is the beginning of diastole (Fig. 12C).

RESULTS

Subjects

This study was conducted from January 2019 to December 2020, during which time 100 patients (mean age = 65, 56% female) met the inclusion criteria and were enrolled. The baseline demographic data for enrolled subjects are shown in Table 4.

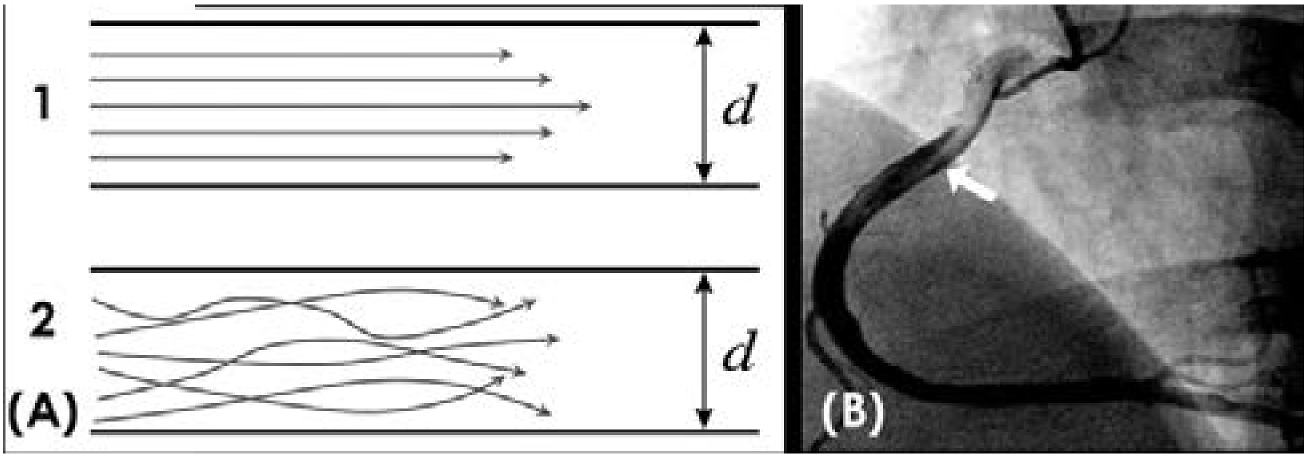

Fig. 9.- Flow Anomalies in Blood Vessels. **(A)** This schematic diagram shows laminar flow (1) vs. turbulent flow (2) as fluid courses downstream in a vessel (or pipe). Parallel, organized layers are seen in laminar flow in contrast to the disorganized (or chaotic) movement of fluid layers in turbulent flow (d = diameter of the vessel (or pipe)). **(B).** Sample angiogram of a coronary artery, where the blood (white) moved in and displaced the contrast (black). This is laminar flow because the flow is homogenously white with a pointed tip (white arrow).

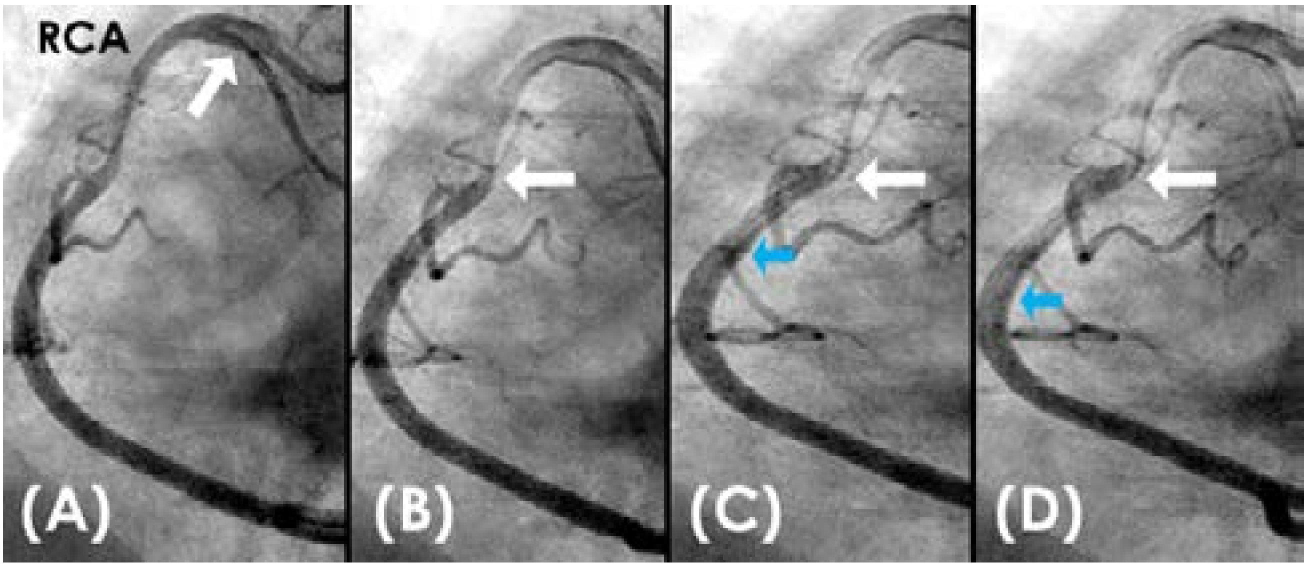

Fig. 10.- Turbulent Flow. In this patient, the angiogram was recorded at 15 images per second (0.06 second per image). These are four continuously sequential images. **(A)** The blood (white) is seen entering the proximal segment of the right coronary artery (RCA) (arrow). **(B)** In the next image (i.e., 0.06 second later), the blood arrived to the mid segment (arrow) and lost its pointed tip. **(C)** Here, the flood moved forward, more slowly (blue arrow), however there was dark contrast hanging at the mid segment, marking the location of collision between the antegrade and retrograde flow (white arrow). This location is called the COLLISION LINE. **(D)** Blood moved forward, more slowly (blue arrow). The dark spot with contrast hanging at the mid segment (the COLLISION LINE) was still quite black (white arrow).

Table 3. Classification of Flow Anomalies.

FLOW ANOMALY TYPE	DESCRIPTION
Type A	laminar flow (well-organized flow, seen as homogenously white, with a pointed tip) (Fig. 9 A1 and 9B)
Type B	turbulent flow presented as disorganized mixing of contrast (black) and blood (white) (Fig. 9A2 and 10 C-D)
Type C	Recirculating flow (stagnant contrast forming separation layers at the outer curve) (Fig. 11A)
Type D	Stagnant flow (stagnant contrast forming boundary layers at the inner curve) (Fig. 11B)

Normal Coronary Flow Dynamics

In normal patients, the coronary flow was antegrade in diastole which lasted about 0.24 second (4 images). During systole, the flow was also antegrade however at a slower speed. The systole lasted about 0.6 second or 10 images, based on a heart rate of 60 beats per minute. These data are summarized in Table 5. In all patients, the laminar flow was seen frequently at the proximal segment in diastole and in the distal segment during systole.

The flow in diastole was fast and reached the mid-segment of the RCA, LAD or LCX within 0.24 second, while the flow in systole was slower and covered the same distance in 0.6 second (10 images). In normal control patients, the reversed flow happened only at a short period (0.06 to 0.12 second) and flew backwards in short distance. The longer reversed flow in patients with different types of cardiovascular disease will be discussed separately later in this article.

Typical Normal Epicardial Flow in the RCA

Normally, the blood went in during diastole, flew forwards fast in 4 images or 0.24 second, and arrived at the mid-segment (Fig. 10B). Then, the flow stopped for 0.06 second (1 image) (Fig. 10C). This is the end of diastole and beginning of systole.

At the second (sequential) image of systole, turbulent flow was clearly visualized as a disorganized mixing of contrast (in black) and blood (in white). This location is called the COLLISION LINE (Fig. 10D). After, the blood continued to flow forwards, however more slowly, for 0.6 second (or 10 images). In the majority of CAGs, blood arrived at the distal segment, and then the flow accelerated again. This is the beginning of the second diastole, which lasted for 0.24 second, and then a new phase with slow pace of systole. The average arterial phase was 20-28 images or 1.2 - 1.68 seconds.

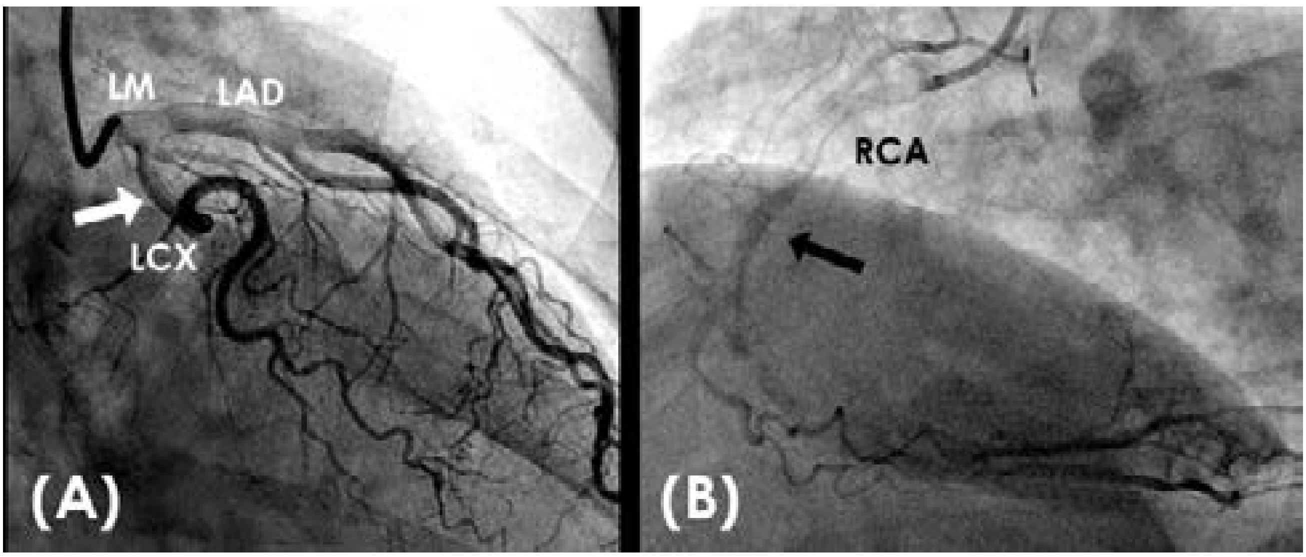

Fig. 11.- Flow Anomalies in Blood Vessels. **(A)** Sample angiogram showing peripheral retention flow (i.e., Type C). The blood (white) already reached the mid segment of the left anterior descending artery (LAD) while the blood was still seen at the proximal segment of the left circumflex artery (LCX). A thick layer of contrast (black) was seen stagnant at the outer curve, opposite to the carina (white arrow). This is the separation layer at the entrance of a pipe or an artery. **(B)** Sample coronary angiogram shown a large boundary layer at the inner curve of the right coronary artery (RCA; black arrow).

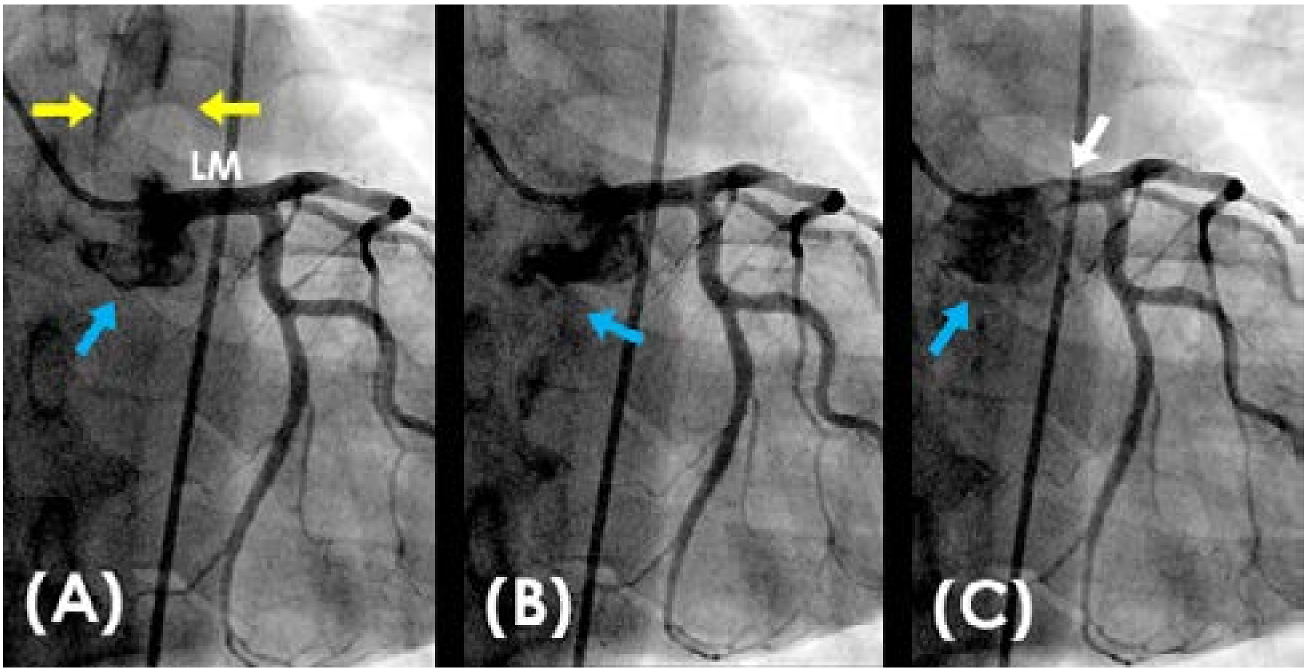

Fig. 12.- Systolic and Diastolic Flow Coronary Arteries Viewed on Dynamic Angiography. **(A)** During systole, the flow in the aorta was antegrade as it was seen going upwards (between the two yellow arrows), and the aortic valve was open (blue arrow). Because the ventricle was contracting in systole, no blood yet entered the left main (LM). **(B)** This is the next image in sequence at the end of systole, showing that the two aortic valve leaflets had begun to shut closely (blue arrow). There is no blood (white) in the LM. **(C)** As the diastole began with the aortic valve fully closed (blue arrow), the blood (white) moved into the LM (white arrow).

Table 4. Demographic Data and Clinical Features of Subject Cohort.

CLINICAL FEATURE	Mean ± SD or %
Age (years)	65 ± 7
Gender	
Male	44 %
Female	56 %
Cigarette smoking	30 %
Comorbidity	
Diabetes mellitus	35 %
Hypertension	43 %
Coronary artery disease	42 %
Previous heart failure	55 %
Anemia	6 %
Dyslipidemia	45 %

Typical Normal Epicardial Flow in the LAD

Blood entered the LM, arrived at the carina and preferentially flowed into the LAD (Fig. 13A-C) if the LAD had a larger diameter than the LCX. The flow usually arrived at the mid segment of the LAD after 0.24 second of diastole. The flow was usually laminar, with a thin boundary layer at the lateral border seen on the AP view (with or without a cranial angulation). The flow at the distal segment was usually laminar because of the small size of the artery.

Table 5. Normal Coronary Dynamics.

FLOW TYPE/ DURATION	DESCRIPTION USING NEW TECHNIQUE
Diastole (duration)	0.24 second or 4 images
Systole (duration)	0.60 second or 10 images
Antegrade Flow	in fast speed during diastole and slow speed in systole
Retrograde Flow	0.06 or 0.12 second or 1-2 images at the beginning of systole

Typical Normal Epicardial Flow in a normal LCX

At 0.06 second after entering the LAD, while the blood already reached the mid segment of the LAD, blood began to enter the proximal segment of the LCX (Fig. 13D). Usually, there was a thin layer of black contrast at the outer curve of the LCX, opposite to the carina. This is the separation layer while the flow was preparing to enter a new artery or major branch. After the 0.18 second of moving forward during diastole, then the blood went on to move into the mid- and distal segment of the LCX, at a slower speed. The difference between the LAD and LCX flow is that the flow to the LCX is 0.06 later than the flow in the LAD.

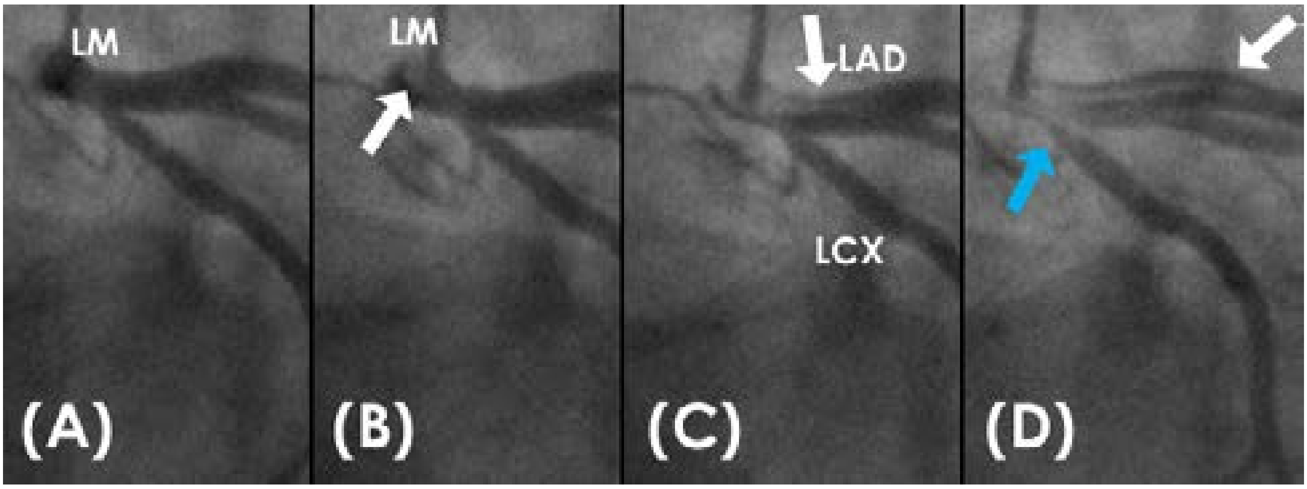

Fig. 13.- Flow in the Left Coronary System. This is the 4 sequential images separated by 0.06 second each (15 images per second) **(A)** At first, the arteries were filled with contrast (black). **(B)** At the beginning of diastole, there was some blood (white) which began to enter the left main (LM) (arrow). **(C)** The flow in the LM was clear, the pointed tip was at the proximal segment of the left anterior descending artery (LAD) (arrow). There was no flow to the left circumflex (LCX). **(D)** Now, 0.06 second (1 image) after, the blood began to enter the LCX (blue arrow), while the flow already reached the beginning of the mid-segment of the LAD (white arrow).

The complete CAGs of the LAD, LCX and RCA are stored, and can be viewed at the DIGITAL ACCESS to SCHOLARSHIP at Harvard Library, Office for Scholarly Communication (https://dash.harvard.edu/). Each angiogram showed all the images (filmed at 15 images per second) detailing the type of flow (laminar or turbulent), direction of flow (antegrade or retrograde), location of the stagnant contrast (separation or boundary layers), during systole or diastole and duration (1 image = 0.06 second).

Incidence of Turbulent Flow, Separation and Boundary Layer

The turbulent flow was seen in 3 situations: (1) at the collision line where the antegrade flow of diastole met the retrograde flow of systole (Fig. 10); (2) at the ostium of the LM or RCA when the flow entered the artery (entrance flow) and was preparing to become laminar (Fig. 14); (3) at the exit from the inlet segment with enlarging diameter due to aneurysm (Fig. 15).

The separation flow was seen commonly at the proximal LCX, at the outer curve, opposite to the carina. Separation layers were also seen frequently upstream at the same side of the large side branch or at the lateral border of the LAD on the AP view, especially if the LAD was large. The thick boundary layers were seen frequently at the inner curve of the mid segment of the RCA, especially if the RCA was large. The difference between the separation and boundary layers was that the separation layer was located opposite to the direction of the main flow (most of the times at the outer curve), while the boundary layer was located at the same direction with the main flow (most of times at the inner curve).

Antegrade and Retrograde Flows and Collision Line

During diastole, the flow was normally antegrade (Fig. 13). At the beginning of systole, the flow stopped for 0.06 second and moved forward at a lower speed. Some flows were reversed for about 0.06 -0.18 seconds (1-3 images). This retrograde coronary blood was longer in patients with severe uncontrolled hypertension, severe aortic stenosis or with the RCA originated from the left sinus and running between the aorta and pulmonary artery (or the LM coming from the right sinus). In many cases, the flow returned up to the ostium and spilled contrast out of the coronary ostium into the aortic sinus (Fig. 16) (Chung et al., 2020; Ngo et al., 2018).

When there was collision between the antegrade and retrograde flow, this location is called the collision line. This observation was seen at the mid RCA, junction between the proximal with the midsegment of the LAD and at the proximal segment of the LCX (Fig. 10) (Nguyen, 2020). However, the collision of the antegrade with the retrograde flow could also be observed in the iliac artery (images not shown herein, but can be seen at the DIGITAL ACCESS to SCHOLARSHIP at Harvard Library, Office for Scholarly Communication (https://dash.harvard.edu/).

Flow at Bifurcation

When arriving at a bifurcation, the flow will hit the carina and the primary flow will follow the path of the larger (diameter) branch. From the LM, in the majority of cases, the flow would primarily enter the LAD (0.06 second earlier and/or with the large part of the flow), because of the direct path (i.e., the anatomy) from the LM to the LAD. As a result, there was less separation flow in the LAD and almost always there was a separation layer at the outer curve of the LCX, opposite to the carina. This is the finding in the LM-LAD-LCX bifurcation. As always, there were exceptions. In one case (Fig. 17), it was unclear how the flow from the proximal LCX preferentially entered the obtuse marginal branch

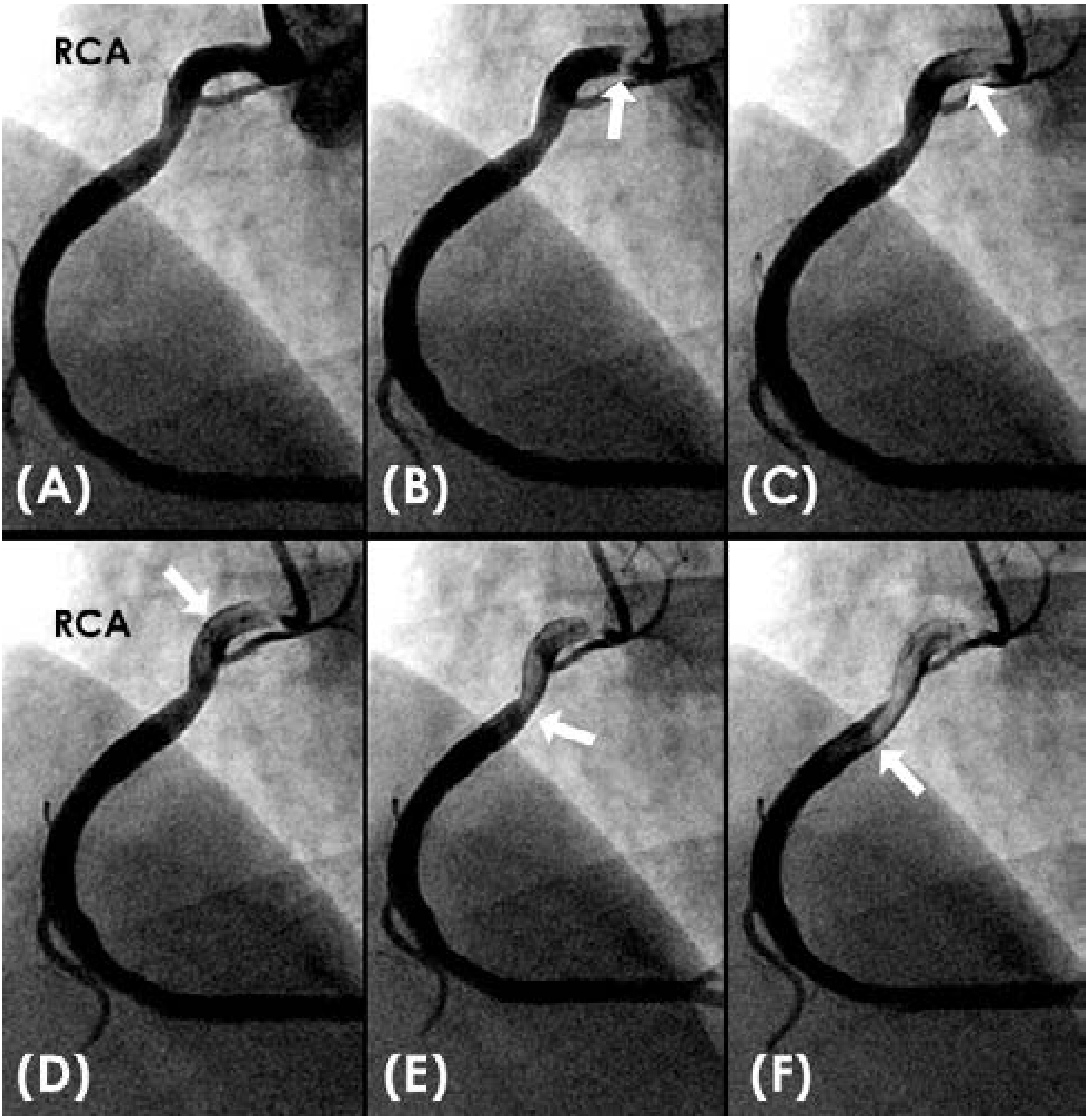

Fig. 14.- Turbulent Flow at the Ostium. These are the 6 sequential images separated by 0.06 second each (15 images per second). **(A)** At first, the right coronary artery (RCA) was completely filled with contrast (black). (**B)** At the beginning of diastole, there was some blood (white) which began to move into the proximal segment of the RCA (arrow). **(C)** The flow continued to move in, without a pointed tip (arrow). **(D)** Now, the flow was at the proximal segment of the RCA, turbulent with unorganized mixing of contrast with blood. **(E)** At this time, the flow began to appear with an almost pointed tip. At the ostium, the flow was clearly turbulent. **(F)** Here, the flow was clearly laminar with a pointed tip. There was a large and short separation layer (arrow). It took 0.24 second or 6 images for the flow to be organized (i.e., laminar).

or the distal LCX. If the blood flowed primarily to the main vessel, then the separation layer would be at a location which was at the same side and upstream of the large side branch. If the blood flowed primarily to the side branch, then the separation layer would be at the lateral wall of the main vessel, opposite to the origin of the side branch.

DISCUSSION

Summary of Results

In this study, at first, the results detailed the description of (1) normal coronary flow, in diastole and systole and (2) flow patterns (normal laminar,

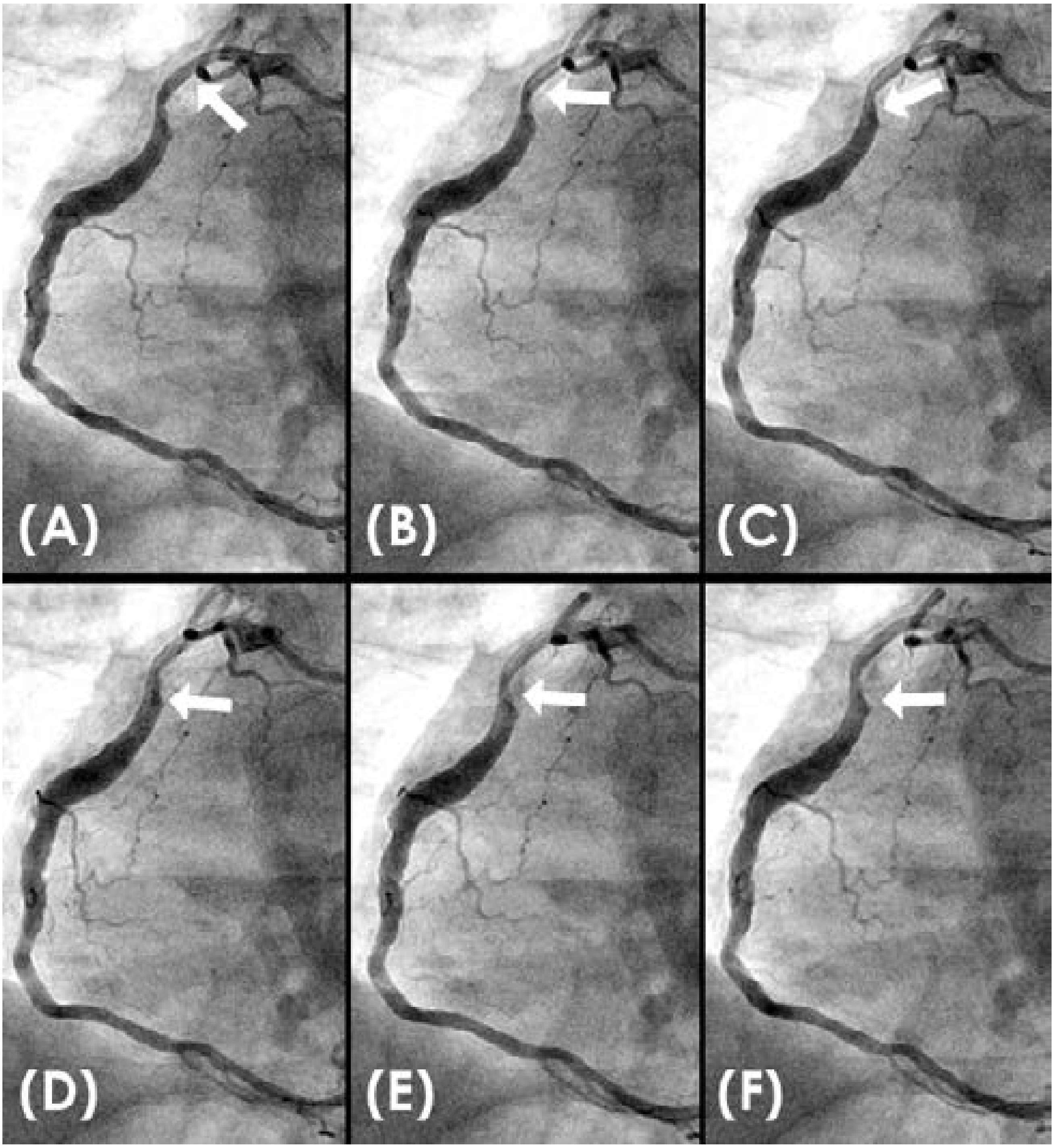

Fig. 15.- Turbulent Flow at the Aneurysmal Segment. This is the 6 sequential images separated by 0.06 second each (15 images per second) at an aneurysm. Contrast is seen in black, and blood is seen in white. **(A)** At first, the arteries were filled with contrast. **(B)** At the beginning of diastole, the blood moved in and reached the beginning of the mid-segment (arrow). **(C)** The blood began to enter the aneurysmal sac where there was random mixing of contrast and blood. **(D)** In the proximal segment of the aneurysmal sac flow, the blood was seen more homogenous at the outer curve, while at the inner curve, the area was unorganized or turbulent. **(E)** At the proximal segment of the aneurysmal sac flow, the blood was seen more homogenous at the outer curve, but at the inner curve, the area began to be mildly more homogenous. **(F)** Now, at the proximal segment of the aneurysmal sac flow, the blood was seen more homogenous at the outer curve, while at the inner curve, near the entrance of the aneurysmal sac, the area was still prominent with contrast. This is the separation layer or recirculation flow.

or turbulence or stagnant). Then, the results confirmed definitively the normal antegrade direction of fast flow in diastole and slow flow in systole. The retrograde flow was an exception which happened in patients with severe CAD, aortic stenosis, coronary anomalies with origin from the opposite site. Finally, an important result was the identification of the location of the COLLISION LINE where the antegrade flow collides with the retrograde flow (Nguyen 2020). These results could be evidenced by a *novel* method reviewing the CAG by using blood as a white medium in an artery full of black contrast as background. The types of data that can be collected using this innovative approach are summarized in Table 6.

In the past, the early pioneers used smoke or dye to show the flow in experimental tubes full of air, fluid or oil (Reynolds, 1883; Taylor, 1929). The novel technique presented herein used the same principle in reverse with arteries full with black contrast and the blood as the white medium. An extensive literature survey showed that regarding flow in the coronary arteries, many investigators examined flow by Doppler Ultrasound and Magnetic Resonance Angiography, however, there was *no prior* published report of direct visualization of the coronary flow as in the present study.

In the applications of Bernoulli principles in areas of low and high velocity, the pressure was speculated to be high and low, respectively. The measurements of these pressures in arteries have never done before, especially in the coronary arteries. The first reason was because the majority of studies were done in mounted arterial

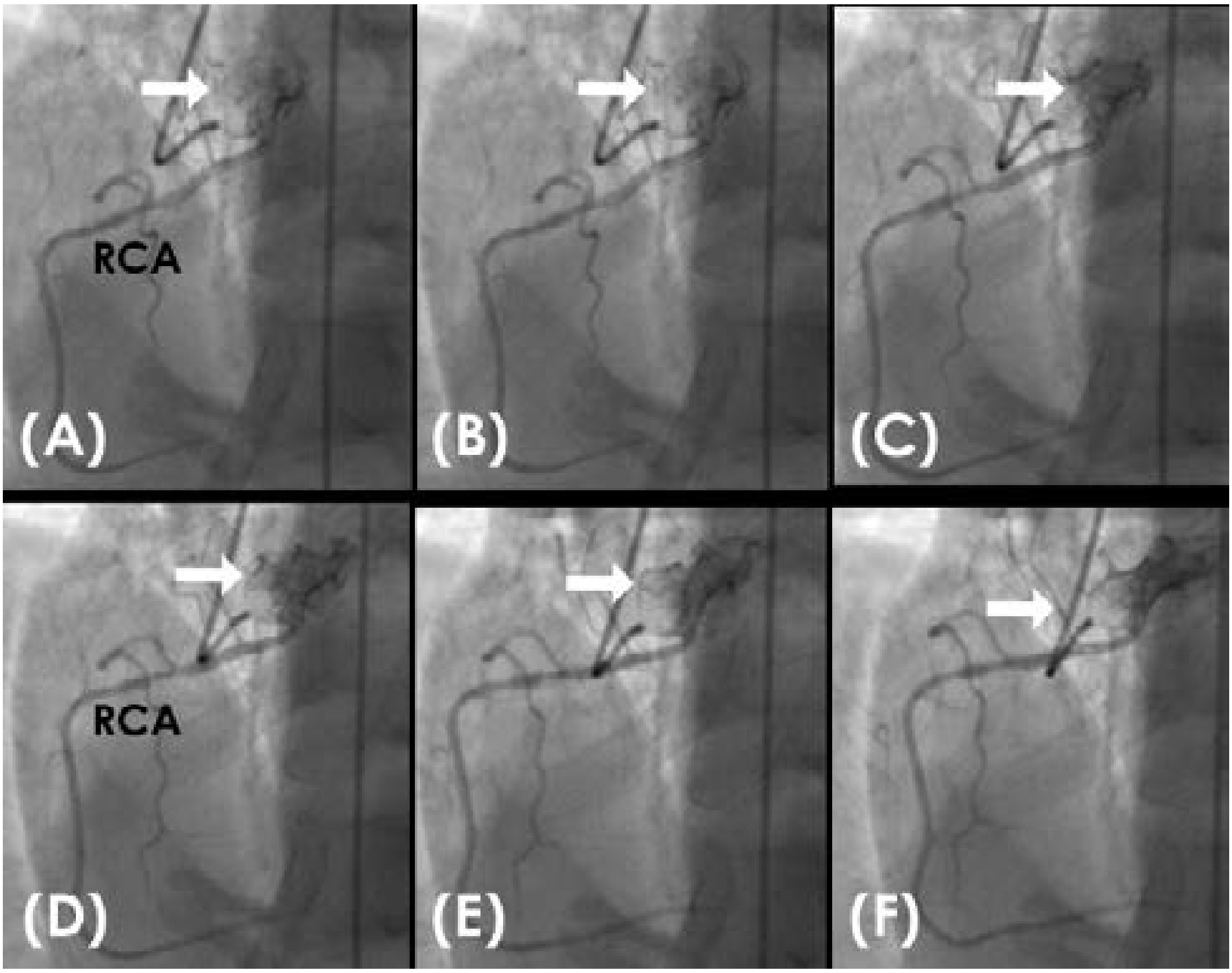

Fig. 16.- Reversed Flow in the Right Coronary Artery. This is a series of six sequential images separated by 0.06 second each (15 images per second). **(A)** The right coronary artery (RCA) originated from the left sinus. The contrast filled completely the RCA. The diagnostic catheter flipped out. Contrast (black) could be seen coming out of the RCA ostium, spilling in the aortic sinus (arrow). **(B) and (C)** The area of spillage became darker and darker because more contrast was spilling out (arrow). **(D)** Contrast (black) could be seen coming out of the RCA ostium, and spilling into the aortic sinus in a disorganized fashion (i.e., turbulent) (arrow). **(E)** The cloud of contrast expanded (arrow). **(F)** The area of contrast became larger and darker because more contrast was spilled (arrow). The entire angiogram can be observed in the Image Depository.

specimens, and not on living subjects. The second reason was because in live animals or humans, the arterial wall is moving, constricting or dilating based on stimulation on the arterial wall. The third reason was that the boundary layer or separation layers are very thin (0.1 mm or 100 microns) so it is very difficult to measure the pressure in these layers.

With respect to the turbulent, laminar or separation boundary layers, and cavitation phenomenon in pipes, the physic and hydraulics community have made numerous videos showing these important observations in pipes (Mountain States Engineering and Controls, 2015). In the cardiovascular arena, the presence of adaptive intimal thickening (AIT), speculated to be the

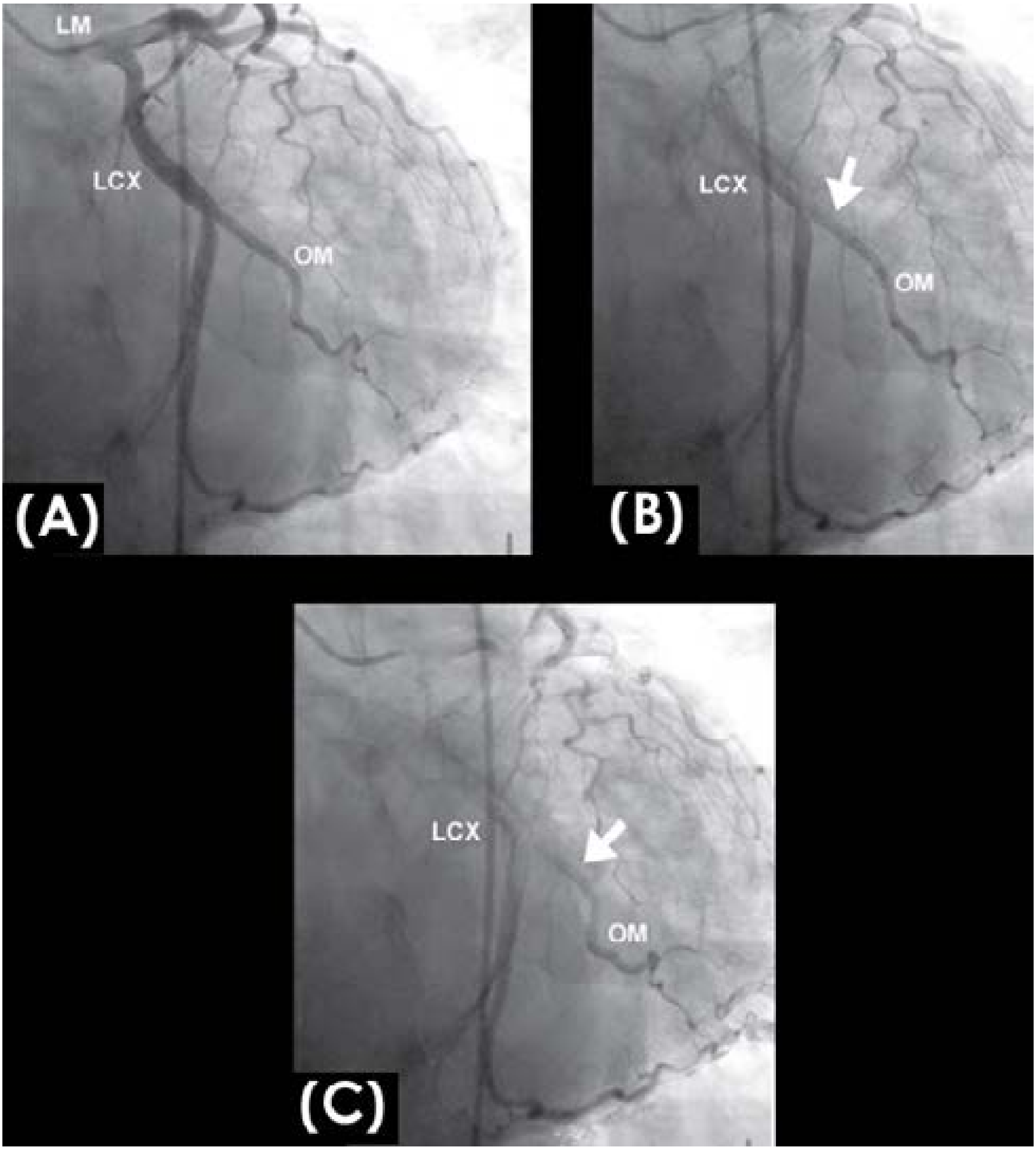

Fig. 17.- Flow at Bifurcations. This is the right anterior oblique (RAO) view angiogram of the left circumflex artery (LCX) with a large obtuse marginal (OM) side branch. **(A)** In this angiogram, an OM (a side branch) forms a straight line with the proximal LCX. Even though the OM is much smaller than the mid LCX, the dominant flow can go towards the side branch rather than the distal vessel. The contrast filled all the arteries and branches. **(B)** The flow cleared at the OM first, and before the flow cleared at the mid LCX. **(C)** While the contrast is almost cleared at the OM, there is still contrast at the outer curve of the proximal to mid LCX.

results of turbulent flow, could be seen in fetuses and newborns (Otsuka et al., 2015). The most common area of AIT seen in autopsies of middle-aged American was at the outer curve of the proximal segment of the LCX. It seems that it took 50 years to develop 0.2 mm of intimal thickening. This is why it is almost impossible to make the videos featuring the cavitation phenomenon in arteries of live animals or humans.

Table 6. Collected Data.

DATA ITEM	DESCRIPTION
Time	beginning of blood coming in until complete clearing of all contrast
Type of Flow	laminar versus turbulent
Direction of Flow	antegrade versus retrograde
Movement	moving, stopping or staying stand-still at the peripheries
Morphology of “Tip” of Flow	pointed, disorganized (no tip) or flattened on a sharply demarcated horizontal line
Speed and Duration of Flow	measured by number of images, one image = 0.06 second
Vessel Branching	presence of side branch
Size of the Coronary Segment	stenosis or dilation (aneurysmal change)

What’s New in the Results of the Present Study?

The first, most important result of the present study is that this novel technique accurately showed the normal antegrade coronary flow in both diastole and systole. The only difference is the speed which is fast in diastole and slow in systole. The second important information is the incidence of laminar flow, turbulent flow and retention flow (or separation and boundary layers) in coronary vessels are clearly documented. The third most important finding is the identification of location of the collision line where the antegrade and retrograde flows collide at the beginning of systole. The results suggest that anatomy affects flow. Thus, as anatomists and interventional cardiologist/anatomists, morphology of the coronary arteries and their anatomical variations (i.e., the number of side-branches and branching patterns) require consideration in this model (Anbumani, et al., 2016; Bhimalli et al., 2011; Ortale et al., 2005; Fazliogullari et al., 2010; Nguyen and Talarico, 2018; Ballesteros et al., 2011; Kalpana, 2003; Ortale et al., 2004; Nguyen and Talarico, 2019). These are new and important discoveries for anatomists that will be examined and discussed in Part 3 of this manuscript symposium. The mechanisms of normal and abnormal findings will be explained from the perspective of fluid mechanics (or hydraulics) or the effect of cavitation relative to the anatomy of the coronary arteries in clinical cases. Then, in the final article (i.e., Part 4), the clinical/pathological relevance of the above findings will be thoroughly investigated, and how clinicians and interventionalists can apply these new discoveries in their daily practice.

The results of this study have never been published in full papers with comprehensive supportive data, as shown herein. In this symposium, the complete angiograms of many the above findings, image-by-image, at 15 images per second, are stored at the DIGITAL ACCESS to SCHOLARSHIP at Harvard Library, Office for Scholarly Communication (https://dash.harvard.edu/) available to all readers to examine, comment upon and make suggestions. However, for the present work, a limiting factor is that the results came from a limited number of patients (<200). This study, the new technique and the depository at the DIGITAL ACCESS to SCHOLARSHIP at Harvard Library, Office for Scholarly Communication (https://dash.harvard.edu/) set the stage for more advanced and in-depth confirmations by current and future investigators.

CONCLUSION

The mechanism of formation of coronary lesions is most likely due constant injuries from explosion of air bubbles, injuring the intima and starting the atherosclerotic process. The most common location of these coronary lesions is likely at the collision line where the antegrade flow collided with the retrograde flow. The new technique of angiography, review of the dynamic flows and their anatomical correlations opens new chapters in the clinical anatomy and interventional management of CAD.

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REFERENCES

ANBUMANI TL, DEEPTHI C, THAMARAI SELVI A, ANTHONY AMMAL S (2016) An anatomical study of the coronary arteries and their variations. *Int J Anat Res,* 4(1): 2114-2118.

BALLESTEROS LE, RAMIREZ ML, QUINTERO ID (2011) Right coronary artery anatomy: anatomical and morphometric analysis. *Rev Bras Cir Cardiovasc*, 26(2): 230-236.

BARRAL JP, CROIBIER A (2011) Chapter 3 – Homeostasis of the cardiovascular system. In: Visceral Vascular Manipulations, *Churchill Livingstone*, pp 46-60.

BHIMALLI S, DIXI D, SIDDIBHAVI M, SHIROL VS (2011) A study of variations in coronary arterial system in cadaveric human hearts. *World J Sci Technol*, 1(5): 31-35.

BRENNEN CE (1995) Cavitation and Bubble Dynamics. Oxford University Press, Inc., New York.

BRENNEN CE (2005). Cavitation. In: *Fundamentals of Multiphase Flow.* Cambridge University Press, Cambridge, pp 97-115. doi:10.1017/CBO9780511807169.006

BRUSCHKE AVG, SELDON WC, SHIREY EK, PROUDFIT WL (2009) A half century of selective coronary arteriography, *J Am Coll Cardiol*, 54: 2139-2144.

CARABELLO BA (2006) Understanding coronary blood flow – the wave of the future. *Circulation*, 114(14): 1721-1722.

CHISTIAKOV DA, MELNICHENKO AA, MYASOEDOVA VA, GRECHKO AV, OREKHOV AN (2017) Mechanisms of foam cell formation in atherosclerosis. *J Mol Med (Berl)*. 95(11): 1153-1165.

CHITNIS PV, MANZI NJ, CLEVELAND RO, ROY RA, HOLT RG (2010) Mitigation of damage to solid surfaces from the collapse of cavitation bubble clouds. ASME, *J Fluids Eng*, 132(5): 051303. https://doi.org/10.1115/1.4001552

CHUNG D, NGO L, NGUYEN T, RIGATELLI G (2020) No flow in the distal coronary segment and reversed flow at the proximal segment are the mechanisms of chest pain in patients with aortic stenosis and patent coronary arteries. *J Am Coll Cardiol*, 75(11 Supplement): 2158. doi:10.1016/S0735-1097(20)32785-6

DO NN Q (2020) Using machine learning to quantify the level of collision by antegrade and retrograde flow causing rupture of culprit lesion in ACS. Oral Presentation at the *Joint Coronary Revascularization Meeting*, Busan, Korea.

DUNCKER DJ, KOLLER A, MERKUS D, CANTY JM JR (2015). Regulation of coronary blood flow in health and ischemic heart disease. *Prog Cardiovasc Dis*, 57(5): 409-422.

DUONG DNH (2020) Application of machine learning to observe the angiogram for matching the time and length of stagnant flow. Oral Presentation at the *Joint Coronary Revascularization Meeting*, Busan, Korea.

FAZLIOGULLARI Z, KARABULUT AK, ULVER DUGAN N, UYSAL II (2010) Coronary artery variations and median artery in Turkish cadaver hearts. *Singapore Med J*, 51(10): 775-780.

FERRARI A (2017) Fluid dynamics of acoustic and hydrodynamic cavitation in hydraulic power systems. *Proc Math Phys Eng Sci*, 473(2199): 20160345. doi:10.1098/rspa.2016.0345

FUJISAWA N, FUJITA Y, YANAGISAWA K, FUJISAWA K, YAMAGATA T (2018) Simultaneous observations of cavitation collapse and shock wave formation in cavitating jet. *Exp Therm Fluid Sci*, 94: 159-167.

GENSINI GG, DI GIORGI S, MURAD-NETTO S, BLACK A (1962) Arteriographic demonstration of coronary artery spasm and its release after the use of a vasodilator in a case of angina pectoris and in the experimental animal. *Angiology*, 3: 550-553.

HSIAO C, JAYAPRAKASH A, KAPAHI A, CHOI J, CHAHINE G (2014) Modelling of material pitting from cavitation bubble collapse. *J Fluid Mech*, 755: 142-175.

JOSEPH D (1998) Cavitation and the state of stress in a flowing liquid. *J Fluid Mech,* 366: 367-378.

KALPANA R (2003) A study on principal branches of coronary arteries in humans. *J Anat Soc India*, 52(2): 137-140.

KUMAR PS, PANDIT AB (1999) Modeling hydrodynamic cavitation. *Chem Eng Tech*, 22(12): 1017-1027.

LEE MS, CHEN CH (2015) Myocardial bridging: an up-to-date review. *J Invasive Cardiol*, 27(11): 521-528.

MOHLENKAMP S, HORT W, GE J, ERBEL R (2002) Update on myocardial bridging. *Circulation*, 106(20): 2616-2622.

MOUNTAIN STATES ENGINEERING CONTROLS, INC. (2015) Cavitation in a water pump and valve. YouTube (January 13, 2015), https://www.youtube.com/watch?v=0dd6AlyOnfc

NGO LM, CHUNG D, NGO AN, NGUYEN T, RIGATELLI G (2020) Persistent reversed flow and antegrade slow flow of the right coronary artery with anomalous origin from the left sinus are the mechanisms for chest pain and sudden death. *J Am Coll Cardiol*, 75(11 Supplement): 1354. doi:10.1016/S0735-1097(20)31981-1

NGUYEN T (2020) Violent coronary flow collision triggers the formation of coronary plaques updates of recent research results. Oral Presentation at the *Northern Coronary Forum*, Shenyang, China.

NGUYEN TN, NGUYEN NMT, TRUONG VT, VO VM, RIGATELLI G (2018a) Cavitation phenomenon creating bubbles and their explosion in the coronary arteries caused damage to the endothelium and start the atherosclerotic process. *J Am Coll Cardiol*, 71(11 Supplement): A269. https://doi.org/10.1016/S0735-1097(18)30810-6

NGUYEN T, CHAU NBT, THUY LTP, DANG T, NGUYEN T NT, DARWISH T, RIGATELLI G, TALARICO JR EF (2018b) New discovery: new technique of visualization of laminar, turbulent flow and measurement of velocity and dynamic coronary pressure. *J Am Coll Cardiol*, 72(16 Supplement): C200. doi: 10.1016/j.jacc.2018.08.872

NGUYEN T, DANG T, NGUYEN T NT, ANH CH, HOANG PLH, DARWISH T, RIGATELLI G, TALARICO JR EF (2018c) New discovery: gas bubbles rupture in the coronary arteries is most likely the mechanism breaking the thin cap of plaques causing acute coronary syndrome. *J Am Coll Cardiol*, 72(16 Supplement): C105. doi: 10.1016/j.jacc.2018.08.528

NGUYEN T, ZUNI M, LUAN NT, VY NNH, TRUONG K, DANG T, NGUYEN T NT, DARWISH T, RIGATELLI G, TALARICO JR EF (2018d) Demonstration of cavitation in the coronary arteries by computational fluid dynamics. *J Am Coll Cardiol*, 72(16 Supplement): C72. doi: 10.1016/j.jacc.2018.08.414

NGUYEN VH, TALARICO JR EF (2018) A morphometric anatomical study of the division of the left main coronary artery and myocardial bridges. *Eur J Anat*, 22(4): 355-365.

NGUYEN VH, TALARICO JR EF (2019) A morphometric anatomical study of the right coronary artery in Vietnamese. *Eur J Anat*, 23(5): 341-353.

ORTALE JR, KEIRELLA LCB, CAMPINAS LS (2004) The posterior ventricular branches of the coronary arteries in the human heart. *Arqivos Brasileiros de Cardiologia*, 82(5): 468-472.

ORTALE JR, FILHO JM, PACCOLA AMF, LEAL JGPG, SCARANARI CA (2005) Anatomy of the lateral, diagonal and anterosuperior arterial branches of the left ventricle of the human heart. *BJCVS/RBCCV*, 20(2): 149-158.

OTSUKA F, KRAMER MC, WOUDSTRA P, YAHAGI K, LADICH E, FINN AV, DE WINTER RJ, KOLODGIE FD, WIGHT TN, DAVIS HR, JONER

M, VIRMANI R (2015) Natural progression of atherosclerosis from pathologic intimal thickening to late fibroatheroma in human coronary arteries: A pathology study. *Atherosclerosis*, 241(2): 772-782.

PHAM TD (2020) General principles for using AI for detect the change of blood flow based on the change of pixel intensity value in angiogram. Oral Presentation at the *Joint Coronary Revascularization Meeting*, Busan, Korea.

REYNOLDS O (1883) An experimental investigation of the circumstances which determine whether the motion of water shall be direct or sinuous and the law of resistance in parallel channels. *Phil Trans R. Soc*, A174: 935-982.

RIPA C, MELATINII MC, OLIVIERI F, ANTONICELLI R (2007) Myocardial bridging: a forgotten cause of acute coronary syndrome – a case report. *Int J Angiol*, 16(3): 115-118.

SATHASIVAM M, THAARRINI J, KUMAR NS, SANJEYKUMARAN SJ (2018) Review on cavitation analysis in pipes. *IJCIET*, 9(10): 1231-1238.

SONES FM, SHIREY EK (1962) Cine coronary arteriography. *Mod Concepts Cardiovasc Dis*, 31: 735-738.

TAYLOR GI (1929) The criterion for turbulence in curved pipes. *Proc Roy Soc*,124: 243-249.

TOMITA Y, ROBINSON P, TONG R, BLAKE J (2002) Growth and collapse of cavitation bubbles near a curved rigid boundary. *J Fluid Mech,* 466: 259-283.

WOSNIK M, ARNDT REA (2013) Measurements in high void-fraction bubbly wakes created by ventilated supercavitation. *J Fluids Eng*, 135(1): 011304. https://doi.org/10.1115/1.4023193

VU TL (2020) Using AI technique in detection of the high risk area in angiogram. Oral Presentation at the *Joint Coronary Revascularization Meeting*, Busan, Korea.

XYLEM (2015) Pump cavitation and how to avoid it: best practices in pump system design. *Xylem Applied Water Systems*, available online at https://www.xylem.com/siteassets/support/case-studies/case-studies-pdf/cavitation-white-paper_final-2.pdf

YU XH, FU YC, ZHANG DW, YIN K, TANG CK (2013) Foam cells in atherosclerosis. *Clin Chim Acta*, 424: 245-252.

ZHAO W, ZHAO G (2017) An active method to control cavitation in a centrifugal pump by obstacles. *Adv Mech Eng*, 9(11): 1-15.

ZUIN M, NGUYEN T, DANG T, VU A, LUONG P, DARWISH T, NGUYEN T, NGKUYEN T, BUI Q, CHE K, DANG T, RIGATELLI G, TALARICO Jr ET (2018) Mechanism triggering acute coronary syndrome by rupturing plaque based on the cavitation phenomenon (bubble formation and explosion) at the distal left main bifurcation by computational fluid dynamic study. *J Am Coll Cardiol*, 72(13 Supplement): B126-B127. doi: 10.1016/j.jacc.2018.08.1447

Challenges of the 21st Century: Part 3 - The anatomical risk factors which predict future disaster

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SUMMARY

A novel approach using dynamic angiography to study cavitation in coronary arteries as related to anatomical structure and fluid dynamics was applied to patient cases. Cases were evaluated to determine if vessel anatomy/variations (i.e., length, diameter, curves, side branches, ostia, branching patterns, etc.) that affected blood flow could be used as predictive factors of future lesion formation or events. Laminar flow through arterial segments and smooth curves was predictive of absence of lesion. Anatomical variations, arterial size that affected boundary layers, turbulent flow, stop line; location of ostium and height of aortic sinus, were found to be predictive factors of lesion formation. This demonstration of how anatomy (1) changes blood flow, (2) influences lesion formation via cavitation and bubble explosion; and (3) can be used as a predictive factor in the formation of coronary lesions is new and critical knowledge for anatomists, cardiologists and interventional cardiologists (i.e., interventional anatomists). Still further, this new perspective and knowledge applies to all vessels in the body, and may translate into new and effective management of patients with vessel disorder or disease.

Key words: Anatomical structure – Anatomical variation – Boundary layer – Cavitation phenomenon – Coronary artery – Coronary lesion – Laminar flow – Collision line – Turbulent flow

ABBREVIATIONS

Coronary Angiography/Angiogram (CAG)

Coronary Artery Anomalies (CAAs).

Left Anterior Descending (LAD)

Left Circumflex Artery (LCX)

Left Main Coronary Artery (LM)

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Low Density Lipoprotein (LDL)

Obtuse Marginal (OM)

Posterior Descending Artery (PDA)

Right Coronary Artery (RCA)

Side Branch (SB)

Sinus of Valsalva (SV)

INTRODUCTION

In Part 2 of this manuscript symposium, the authors presented detailed research and explanation of a new approach using dynamic angiography to describe the flow and lesions in coronary arteries based on fluid mechanics, especially the cavitation mechanism or bubble rupture. Now, in Part 3, the research team elevated this concept further by correlating the injuries caused by the flows with formation of lesions. In this new research, at first, the standard coronary anatomical structure was studied in isolation and with the associated blood flow. Then, with the multiple variations in the coronary anatomy, different types of blood flows with their beneficial and detrimental effects were identified and correlated for presence or absence of lesions. The mechanisms and the predisposing factors facilitating these changes were also identified and searched for correlations. The problems are discussed in clinical case-based format using fluid mechanics principles to explain the anatomical/structural cause-effect mechanism and future risk stratification.

Dynamic Coronary Anatomy

In general, there are three main epicardial coronary arteries, (1) the right coronary artery (RCA) and the left main coronary artery (LM) which bifurcates into (2) the left anterior descending (LAD) artery and (3) the circumflex artery (LCX). The LM originates from the left sinus of Valsalva (SV), while the RCA originates from the right SV.

The LAD artery runs in the anterior interventricular sulcus, providing the penetrating septal branches. The LCX courses along the left atrioventricular sulcus and gives rise to at least one obtuse marginal (OM) branch, while the RCA lies in the right atrioventricular sulcus and most of the time gives rise to the posterior descending (PDA) branch.

The artery that supplies the posterior descending artery (PDA) determines coronary dominance. Approximately 70% - 80% of the general population is right-dominant (i.e. supplied by the RCA), while 5% - 10% is left-dominant (i.e. supplied by the LCX) and 10% - 20% is co-dominant (i.e. supplied by both the RCA and LCX) (Moore et al., 2018).

Typically, there are two coronary ostia. The ostium, or opening, of the RCA is in the right aortic sinus and that of the LM is in the left aortic sinus. However, in some cases where the LM is absent, three ostia can be detected. In individuals with such a condition, the LAD and LCX originate from separate ostia.

Coronary arteries can be anatomically categorized into three groups based on their anatomical features: normal coronary anatomy (described above), anatomic variations of the coronary arteries and coronary artery anomalies (CAAs). Anatomical variations of coronary arteries include (1) the number of side-branches; (2) branching patterns; (3) the presence/absence and location of ostia, and (4) myocardial bridges (Anbumani, et al., 2016; Bhimalli et al., 2011; Ortale et al., 2005; Fazliogullari et al., 2010; Nguyen and Talarico, 2018; Ballesteros et al., 2011; Kalpana, 2003; Ortale et al., 2004; Nguyen and Talarico, 2019). CAAs, which are congenital disorders in the coronary anatomy are observed in less than 1% of the general population (Altin et al., 2015). However, in cardiology, the coronary arteries are considered normal or of normal variations in spite that they are long, short, curved, or straight, etc.

As a river without water is not a river, the research of the coronary arteries without the consideration of circulating blood is the investigation of an inert structure taken out of context. In health or disease, the flow in the coronary artery is programmed depending on the structural design of the arterial system. In this article, besides the dynamic anatomical study, the aim was to correlate the coronary flow patterns with the presence or absence of coronary lesions and offer a mechanistic explanation based on fluid mechanics. From this perspective, anatomical variations that affect flow patterns could be identified as risk factors predictive of future lesions or events. The coronary flow patterns and anatomical variations to be discussed are listed in Tables 1 and 2.

Table 1. Anatomical Variations to be Discussed.

ANATOMICAL VARIATIONS	QUESTION(S) REGARDING ANATOMICAL VARIATIONS
Orientation of the ostium of the left main and right coronary artery	Do the *orientation and angle of the entrance of the ostium* at the LM or RCA cause different flow patterns and predict the presence of future ostial or proximal lesion? Why and how? Does the *abnormal orientation of the ostium* of the RCA predict future lesions downstream? Why and how? Does an RCA with the *ostium coming from the left sinus* have more future lesions downstream? Why and how?
Lesions Related to Flow: Aortic Sinus	Does the *height of the aortic sinus* predict the location of lesions in the LM, if there is a lesion present? Why and how?
Angle at distal left main bifurcation	How are the *flows* at the end of the LM and at the ostium of the LAD and LCX? Which one is the primary flow and which one is the secondary flow?
Angle of separation of the left circumflex	What was the clinical relevance of the *recirculation flow forming the separation layer* at the outer curve, opposite to the carina at the proximal segment of the LCX? Why and how?
Location of the left anterior descending artery and right coronary artery	As the LAD stays on *top of the myocardium*, does the artery need a lot of receptors to keep *its vasomotor tone*? As the distal RCA stays below the ventricle, *under the weight of the myocardium,* does the artery need *a lot of receptors to keep its vasomotor tone*?
Lesions Related to Flow: Arterial Size	Can a *small artery* develop lesions? Why and why not? How does a large *artery* develop lesions? Why and why not?

Table 2. Coronary Flow Patterns to be Discussed.

CORONARY FLOW PATTERN	QUESTION(S) REGARDING ANATOMICAL VARIATIONS
Laminar Flow	Does a *laminar flow* predict the presence or absence of lesion in that arterial segment? Why and how?
Laminar Flow at a Curve	In an artery with many smooth curves, why does the laminar flow *follow the peak* of each curve and *avoid the valley (lowest point)* of the curve? Why and How?
Turbulent Flow	Does *turbulent flow* predict the development of future lesion in that location? Why and how?
Recirculating Flow	Does a *peripheral contrast retention (separation layer)* predict the presence of future lesion in that location? Why and how?
Collision Flow	What does the presence of a *collision line* predict? Why and how?
Stagnant Flow	What does the presence of a *boundary layer* predict? Why and how?

METHODS

Subject Cohort

Prior to the start of this study and subject recruitment, approval was obtained from the Internal Review Board of each participating hospital of the University Research Consortium. Patient consent was obtained.

In Part 3 of this manuscript symposium, the authors tried to answer the questions why and how the lesions were developed in the coronary arteries. In the past, all studies compared one group of patients to other groups with blind randomization so the demographic and risk profiles (hypertension, diabetes, etc.) would be similar in both groups. The goal was to have near perfect similarity in the background so the study was only to compare different anatomical or interventional factors. In reality, there would never be two groups of patients with identical baseline.

In order to overcome the problem of biases by clinical confounders, the design of the present study was to compare the data of one epicardial coronary artery (i.e., the LAD) with the data of the other epicardial artery (i.e., the LCX or RCA) of the same patient. The data to be compared included: (1) the presence or absence of lesion, (2) the types of lesion, (3) the types of flow at the location of the lesion, and (4) the mechanism of developing a lesion. In this design, there was perfect baseline similarity of hypertension, diabetes mellitus, level of testosterone, of C-reactive protein, or of any clinical factors. The reason was that the demographic background was of a same patient. Therefore, the study design compares the mechanisms causing the lesion in the LAD with the possible mechanisms in the LCX or the RCA

(Fig. 1 and Fig. 2). This study also investigates factors which may protect the artery from having a lesion such as the LCX or the distal RCA (Fig. 1 and Fig. 2), again in the right and left coronary angiograms (CAGs) of a same patient.

Image Research Depository. The complete database of images used in the development of this novel model and in this research investigation has been established at DIGITAL ACCESS to SCHOLARSHIP at Harvard Library, Office for

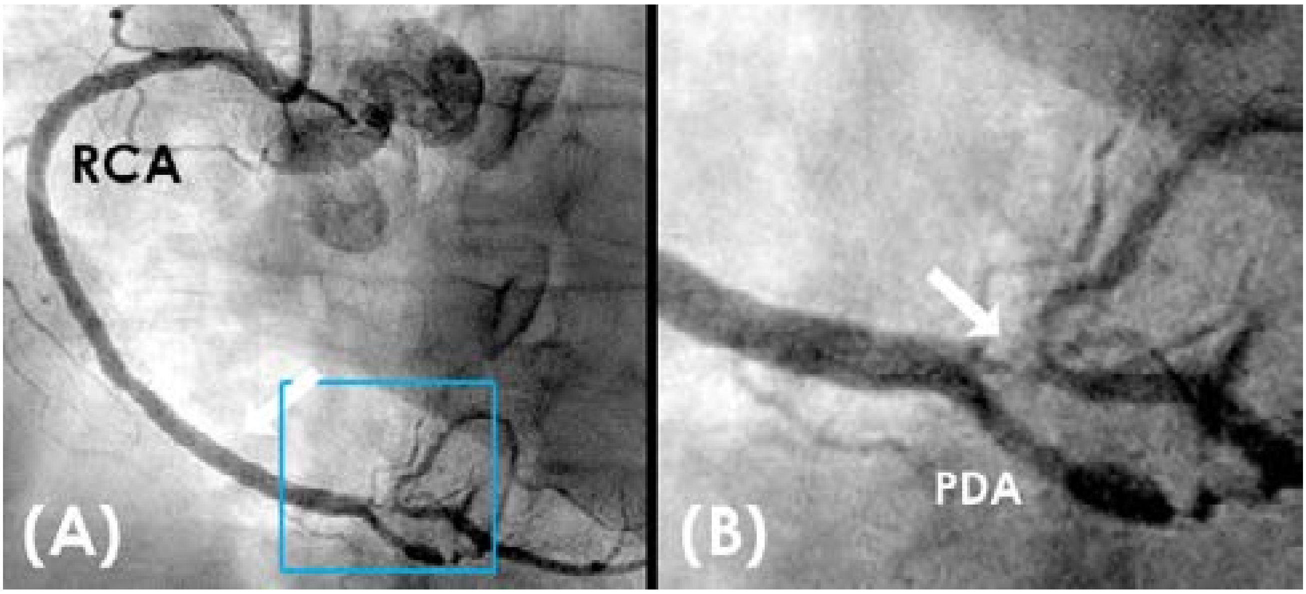

Fig. 1.- Right Coronary Artery Angiogram. **(A)** The right coronary artery (RCA) had diffuse disease along its wall from the proximal segment to the mid-segment. The distal segment had less lesions (arrow) until it arrived to the end, after the bifurcation with the posterior descending artery (PDA). *Why and how did the proximal and mid-segment have so many minimal lesions along its border?* **(B)** Magnification of the distal segment of the RCA (blue box in "A") showing subtotal lesion distal to the PDA (arrow). *Why and how did the lesion develop here?*

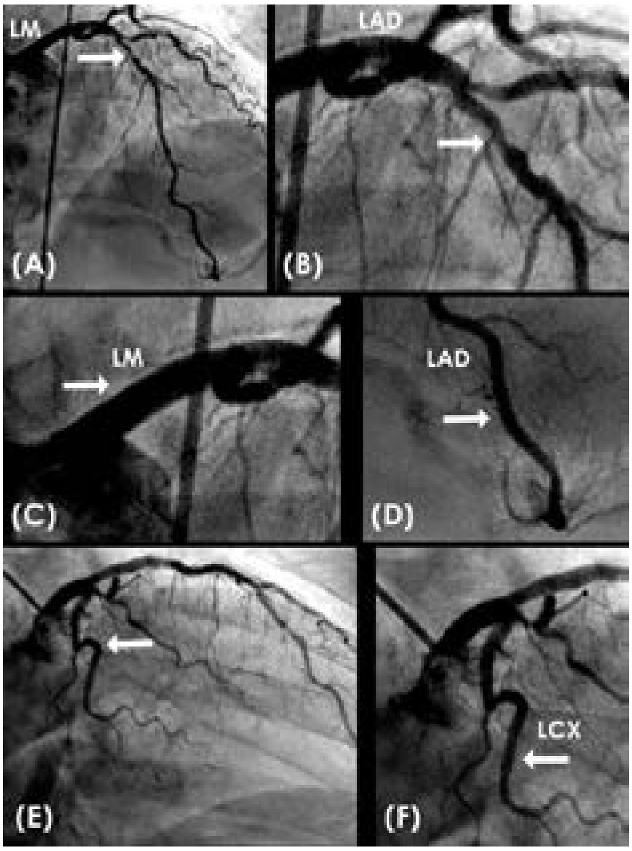

Fig. 2.- Sample Angiograms in the Same Patient. **(A)** The left anterior descending artery (LAD) had a severe lesion at its mid-segment, distal to the origin of a large diagonal. **(B)** Magnification of the lesion in "A". Why and how was a severe lesion developed here? **(C)** *Why was the left main (LM) clean of lesion (arrow), while a severe lesion appeared in the mid-segment of the LAD?* **(D)** Segment of the LAD distal to the lesion shown in "B". *Why and how was the distal segment (arrow) of the LAD devoid of lesion?* **(E)** The left circumflex artery (LCX, arrow) had no lesion. **(F)** Magnification of the LCX shown in "E". *Why and how was the LCX clean of lesion, while a severe lesion appeared in the midsegment of the LAD?*

Scholarly Communication (https://dash.harvard.edu/). Readers are invited to explore, and to comment and discuss.

CORONARY FLOW PATTERNS

Laminar Flow

Clinical Presentation and Relevance. A 57-year-old, diabetic patient came to the emergency room because of a near syncopal episode after hemodialysis. Her blood pressure was >100 mm Hg on arrival to the emergency room. Her electrocardiogram showed ST segment elevation in the leads 2, 3 and AVF (Fig. 3). The ST segment elevation in select leads is more common with myocardial infarction, in contrast to ST elevation in all leads (diffuse convex upward ST elevation) that is more common with acute pericarditis. Her electrolytes and glucose level were normal. She denied any chest pain (which could be silent in diabetic patients). Because of the history of near syncope, ST segment elevation, she underwent an emergent CAG (Fig. 4A).

There was no lesion in the RCA (Fig. 4A). Was there any other way to confirm the absence of lesion in the RCA? Could the new technique of dynamic angiography, with applied principles of hydraulics/fluid dynamics, looking at the coronary flow help to confirm the absence of lesion? Could the patient develop lesions in the near or far future?

Observing blood (white) coursing into the RCA and displacing the contrast (black), the flow was well-organized or laminar (Fig. 4B). The flow was homogenous, well-organized and was considered to be laminar. What does this laminar flow correlate with?

Fluid Mechanics Perspective. In laminar flow pattern: (1) there is orderly organization of fluid layers, (2) the speed is steady throughout the length of the segment, and (3) the boundary layers are absent or only minimal. In this ideal situation, the probability for cavitation (from rupture of bubbles and resulting micro-jet waves) is low because the pressure is steady and stable in the whole length of the pipe (or artery). There are no localized areas with different high or low pressures favorable for the formation of new bubbles and their final demise downstream by implosion or explosion. The flow shown in Fig. 4B - 4D fulfilled all the characteristics of a laminar flow so the fact of no minimal nor mild lesion seen by the conventional CAG was credible.

Coronary Anatomy Perspective. The CAG of the patient showed the blood in homogenously white color. The blood followed swiftly the curves, along the peaks and valleys. Its borders showed sharp demarcation line with the contrast in the boundary layers. Based on the above angiographic descriptions, the flow was considered to be laminar. At the present time, the current literature documents that there is no severe or obvious lesion if the flow is laminar (Chiu and Chien, 2011). The absence of coronary lesion could also be confirmed in this case because the angiogram was done in an older patient. If the angiogram showed no lesion in a young patient, the negative results could be explained because the artery has not had enough time to develop a lesion (i.e., not enough time to

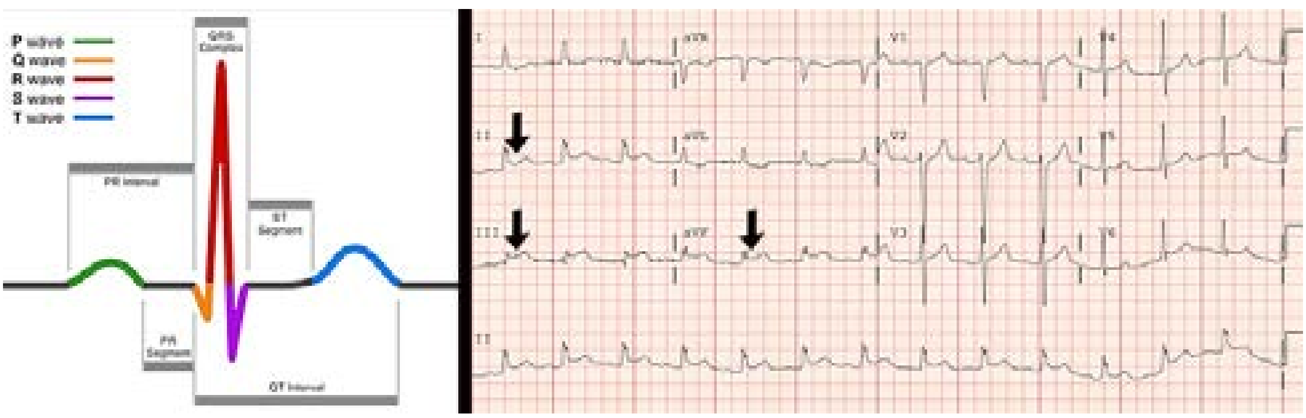

Fig. 3.- Electrocardiogram (EKG) of Patient with ST Segment Elevation. A “reference” EKG with labels is shown (left). The patient’s EKG (right) showed ST segment elevation in leads 2, 3 and AVF (black arrows) suggestive of acute inferior myocardial infarction. Her troponin level was 115 ng/L.

reach the threshold number of bubble explosions and micro-jet waves needed to result in endothelial damage and initiate plaque formation).

Advanced Fluid Mechanics Interpretations.
When the fluid flows steadily and without turbulence rounds a bend (i.e., curve), every element of it must change its direction of motion. Thus, it must have a component of acceleration at right angles to its flow direction (Caro et al., 2012). The rules of fluid dynamics dictate that, like a single particle moving in a circle, every element of the fluid must experience a force in that direction – acting from the outside bend towards the inside bend (Caro et al., 2012). This will act uniformly over the whole cross-section of the pipe (or artery), and all fluid elements will experience approximately the same sideways force (aka sideways acceleration) to make them turn the corner. But, this means that faster moving elements will change their direction less rapidly than slower moving ones, because they have more inertia. Thus, the faster moving fluid which originally occupied the center of the pipe (or an artery in biological systems) will tend to be swept out towards the outside of the bend, being replaced by slower moving fluid from near the walls. This is exactly what was observed in RCA CAG (Fig. 4C, black arrow). The RCA has five (1-5) smooth curves and minimal side branching (Fig. 4). Upon entrance from the ostium, the blood (in white color) twisted and turned along the curve, followed the apex (outside bend) in each of the four curves because of its faster speed. At the same time, the contrast (in black color) moved from the

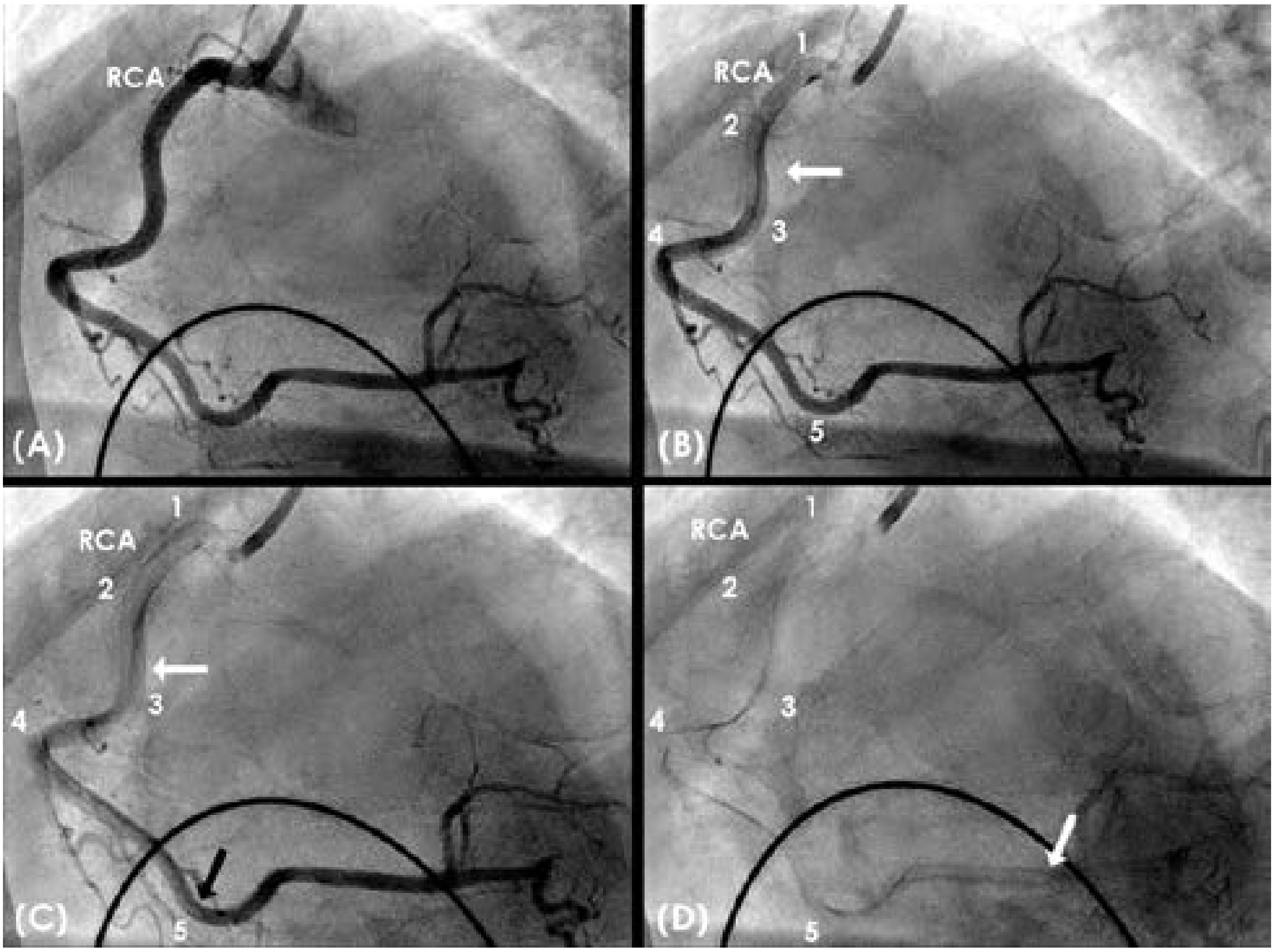

Fig. 4.- Coronary Angiogram. **(A)** This is the CAG of the RCA of a 57-year-old female patient with diabetes mellitus, end stage renal disease on hemodialysis, peripheral vascular disease, and bilateral below knee amputation. Before the coronary angiogram, the calculation for probability of significant disease was high, however the angiogram showed no lesion. *Can we trust the results? Should the patient have intravascular ultrasound to be sure that there was no lesion?* **(B)** The RCA angiogram showed the blood (white) with characteristically homogenous color, considered to be laminar that twisted and turned along the curves (1-5). The contrast was black. **(C)** In this isolated image of the same, continuously sequential CAG, the RCA continued to show the blood (white) in laminar flow which twisted and turned along the curves. The main flow of blood (white) followed the peak (apex) of the curves (white arrow) while the slow flow of contrast (black) occupied the valleys (or lowest point) of the inner curves (black arrow). The tip of the blood flow is pointed because the flow was laminar. **(D)** Blood flow (white) continues to be laminar and has replaced most of the contrast along all 5 curves. Now, the main flow of blood has arrived at the distal segment (past curve 5, arrow) with a pointed tip, again characteristic of laminar flow.

inner curve to the center of the flow because of its slower speed (black arrow). This phenomenon repeated itself at the five curves of the RCA. In this case, the anatomy (structure and pattern) of the RCA has determined the flow dynamics with the blood in well-organized laminar fashion.

Real Life Comparisons. The fact that the blood moves along the curve by following the peaks is seen in car racing at Daytona or Indy 500 (Fig. 5). In order for the car not to slow down, the driver needs to select path 2 (Fig. 5), follow the outer curve or peak of a circle with a wider radius. This is the path where the blood follows (Fig. 4B). In the case the driver selects path 1 (Fig. 5), the speed has to be lower and the car could follow the valley or inner curve as the black contrast in the CAG (Fig. 4B). In the coronary artery, it is simpler if there is no need to decrease the speed and change direction because sudden and excessive deceleration or change of direction require energies and create turbulence. The blood preferentially selects the most economical path for its flow.

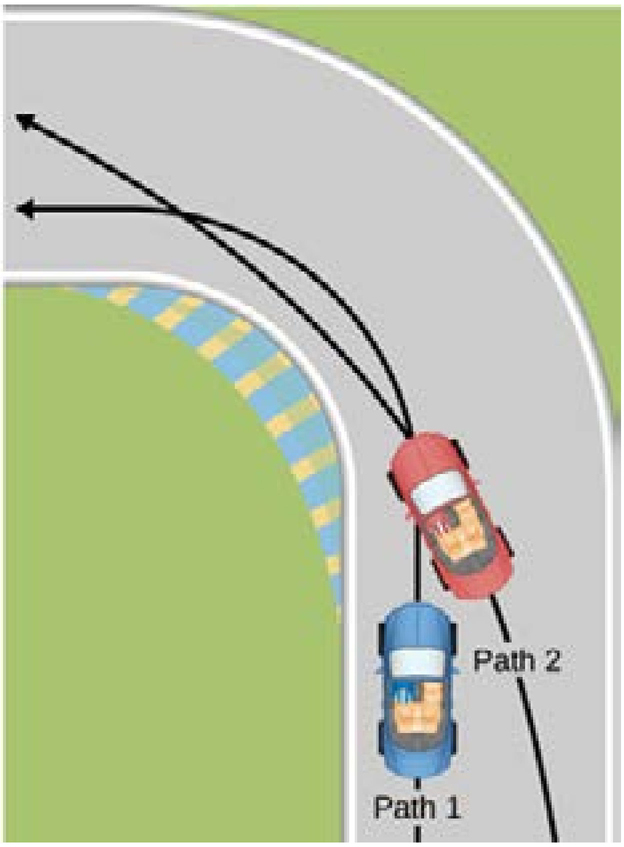

Fig. 5.- Racing Cars Curving Around the Track. In car racing, in order to keep high speed, the driver could select path 2 following the peak of the curve. In this way, the driver selects a wider radius. If the driver selects the path 1, he has to slower the speed of the car. If not, the car will be ejected out of the driveway. Surprisingly, the blood in the right coronary artery selects path 2 and follows all the peaks because this is the most economical pathway.

Clinical Presentations and Relevance. Many patients came to the emergency room with chest pain, and their CAGs showed the majority of the lesions were in the mid-segment of the LAD, RCA or LCX (Fig. 6). Why?

Anatomical Perspective. In the CAG of the patient in Fig. 6, at first, the blood (white) entered the artery in laminar fashion during diastole (Fig. 6A). Once inside the LM, the blood continued to move in on an antegrade direction, in laminar fashion with a point tip displacing the contrast (Fig. 6B, arrow). During diastole which lasted 0.24 second, the flow was brisk. Then, the flow became turbulent (a disorganized mixing of black and white) signaling the beginning of a collision between the diastolic antegrade flow and the systolic retrograde flow (Fig. 6C). The flow came to a strong stop marked by a sharp horizontal line. This location was called the COLLISION LINE, and it was important because the majority of lesions happened here (Fig. 6C-D).

Fluid Mechanics Perspective. The turbulent flow is defined as irregular, disorganized flow in which vortices, eddies and wakes make the flow unpredictable. Turbulent flow occurs at high flow rates and with larger pipes. Still further, the number, size and arrangement of side-branches of pipes in industrial pumping systems can cause alterations in pressure, speed, friction and fractional (and oscillatory) flow rates (Sakamoto et al. 2015).

Coronary Anatomy Perspective. The turbulent flow is observed as diffuse mixing of contrast (black) and blood (white) in an angiogram (Fig 6C). Turbulent flow could be seen at (1) the entry of the LM or RCA, (2) the mid segment of the RCA or proximal or mid segment of the LAD and (3) at the exit of an opening from a smaller diameter segment to a much larger aneurysmal segment.

Just like a complex network of industrial pipes, changes in structure of vessels, number of branches and branching patterns affect blood flow suggesting that local geometry (i.e., anatomy) has important effects on flow (Caro et al., 2012; Zarandi et al., 2012). Turbulent flow may be the result of these “anatomical” interactions.

In search for the cause-effect mechanism of lesions, is turbulent flow the only cause of formation of lesion? If so, then why can there be an absence of lesions at the ostial LM or RCA, when the majority of the times, there was turbulent flow? To answer this question, the authors investigate and discuss the formation of lesion at the collision line, and then the flow at the ostium of the LM or RCA.

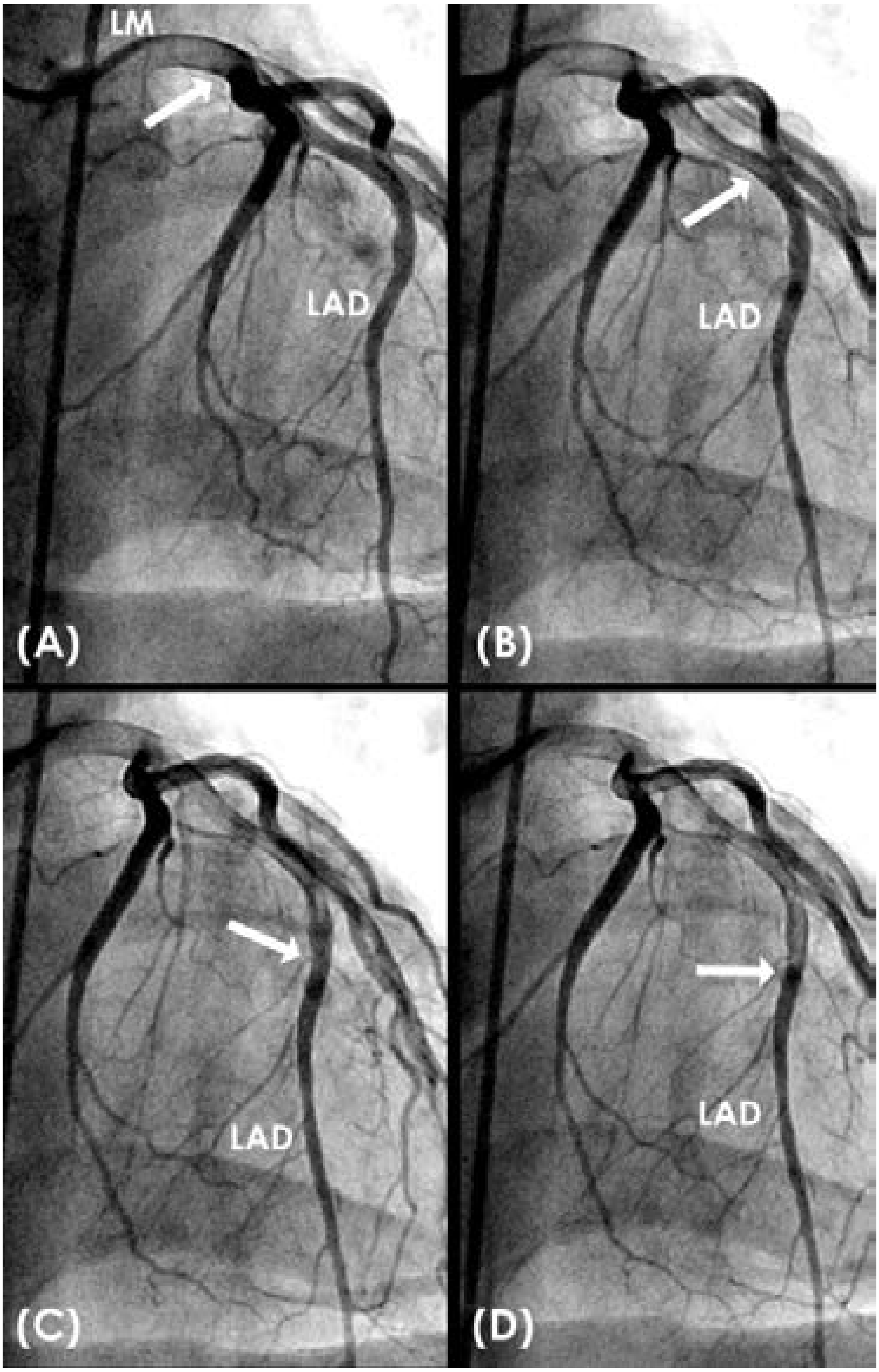

Fig. 6.- Turbulent Flow. The images A-D are of the CAG are in continuous sequence. **(A)** During diastole, the flow was brisk. The blood reached the ostium of the left anterior descending artery (LAD). **(B)** With only one image (0.06 second), the blood jumped from the left main (LM) to the end of the proximal segment of the LAD (arrow). **(C)** Next, the flow slowed down because it was the end of diastole and the beginning of systole. There was intense mixing of blood (white) and contrast (black), marking the turbulence in this area (arrow). **(D)** There was a sharp horizontal demarcation line suggestive of the intensity of the collision between the antegrade flow of diastole and retrograde flow of systole. This location was called the Collision Line (arrow) where lesions were observed by conventional CAG.

Collision Line

Clinical Presentations and Relevance. In the review of CAGs, the majority of stenting procedures were done at the midsegment of the RCA, LCX or LAD. Why? (Fig. 7)

Fluid Mechanics Perspective. The Collision Line is the location where there is the collision between antegrade and retrograde coronary flows during the change from diastole to systole. Because of this collision, the flow becomes turbulent, seen on CAGs as a mixing of contrast (black) and blood (white) (Fig. 6C). In the review of CAGs, the presence of many lesions at different levels of severity at the collision line is the indirect evidence that the lesions were caused by the turbulence from collision of the antegrade and retrograde flows. There are however locations with turbulent flow and no lesion as seen at the ostium of the LM and RCA, or the location distal to a stenosis (i.e., vena contracta). What else is needed?

Advanced Fluid Mechanics Perspective - Shock Wave Bubbles Interaction. In the coronary artery, at the end of diastole, the reversed systolic flow returns violently, stops the antegrade flow abruptly, and is seen with a sharp (Fig. 6D). At that time, if there are some bubbles wandering at the location where the diastolic flow stops, the systolic flow could hit the resting bubbles like a shock wave. These bubbles will be almost completely reflected due to the sharp increase in acoustic impedance at the bubble wall. The resulting momentum transfer accelerates the bubble wall and starts the collapse from this side (Brujan, 2011). Together, with focusing effects during the collapse stage, this situation finally leads to the formation of a fast liquid jet in the direction of wave propagation time (Brujan, 2011; Brennen, 1995; Brennen, 2005; Ferrari, 2017; Fujisawa et al., 2018; Hsiao et al., 2014; Tomita et al., 2002). This liquid jet damages the intima and starts the genesis of coronary plaques (Yu et al., 2013; Chistiakov et al., 2017) (Fig. 8). These observations explain why turbulence alone could not cause severe lesions, as seen in the ostium of the LM or RCA. There is a need of cavitation or bubble rupture caused by the shock wave from reversed systolic flow. The combination of *Turbulence plus Shock Wave and Cavitation* is the perfect formula for new lesions in the cardiovascular system (i.e., for both coronary and systemic arteries).

*Coronary Anatomical Perspective***.** In this case of a newly developed lesion, the usual static black and white images of the CAG could not explain the

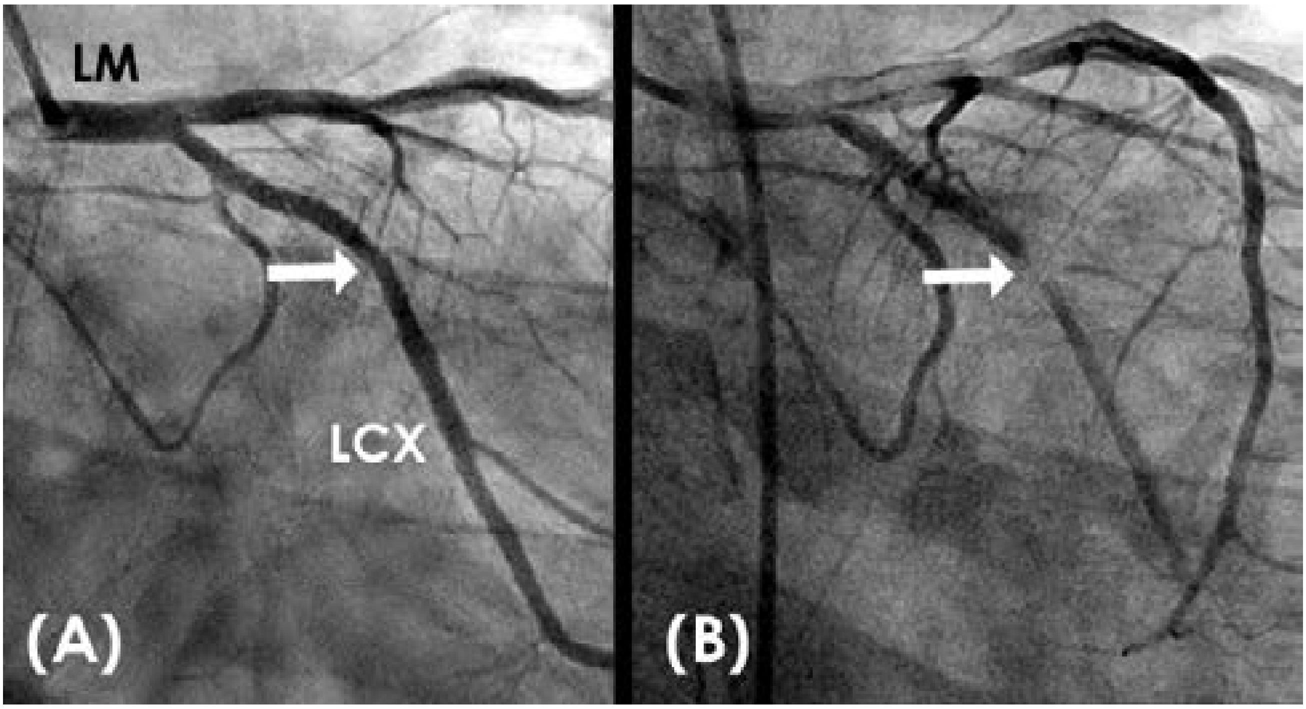

Fig. 7.- Left Coronary Artery Angiograms. These images are from a left CAG of a male patient with low density lipoprotein (LDL) cholesterol level of 170 mg/dl, who underwent stenting for a severe lesion of the RCA (not shown) in June 2020. **(A)** At that time, the left main (LM) and left circumflex artery (LCX) were patent. **(B)** A follow-up CAG in November 2020, showed a severe lesion in the mid-segment of the LCX. How could the physician not predict the problem of severe lesion by reviewing the coronary angiogram of 6/2020?

mechanism of quick change (Fig. 7A). However, the coronary flow study could explain the pathological mechanism of the event. What happened to the flow at the LCX? (Fig. 8). The patient had the usual turbulent flow pattern with collision of the antegrade and retrograde flow at the collision line (Fig. 8C). In addition to the turbulent flow, there were repeating collisions causing cyclic stress and cavitation, and all combined together for the growth of the atheroslerotic plaques.

In the case of the patient in Fig. 8, because his level of low density lipoprotein (LDL) cholesterol was very high at 170mg/dL, the body had enough cholesterol particles for the plaque to quickly develop in a few months. The anatomists or cardiologists could not predict the development of the lesion based on the conventional CAG. With this new technique of dynamic angiographic review, the investigators may be able to predict the location of new and severe lesion if all of the favorable conditions fall in place and at the correct anatomical location along the vessels (Caro et al., 2012; Zarandi et al., 2012, Nguyen et al., 2020, Nguyen et al., 2021).

Recirculating Flow (Separation Layer)

Clinical Presentations and Relevance. In many CAGs of asymptomatic patients, there was no obvious lesion in the LAD and RCA, except a small narrowing at the proximal segment of the LCX, at the outer curve, opposite to the carina. Why are there many mild lesions here**?** (Fig. 9).

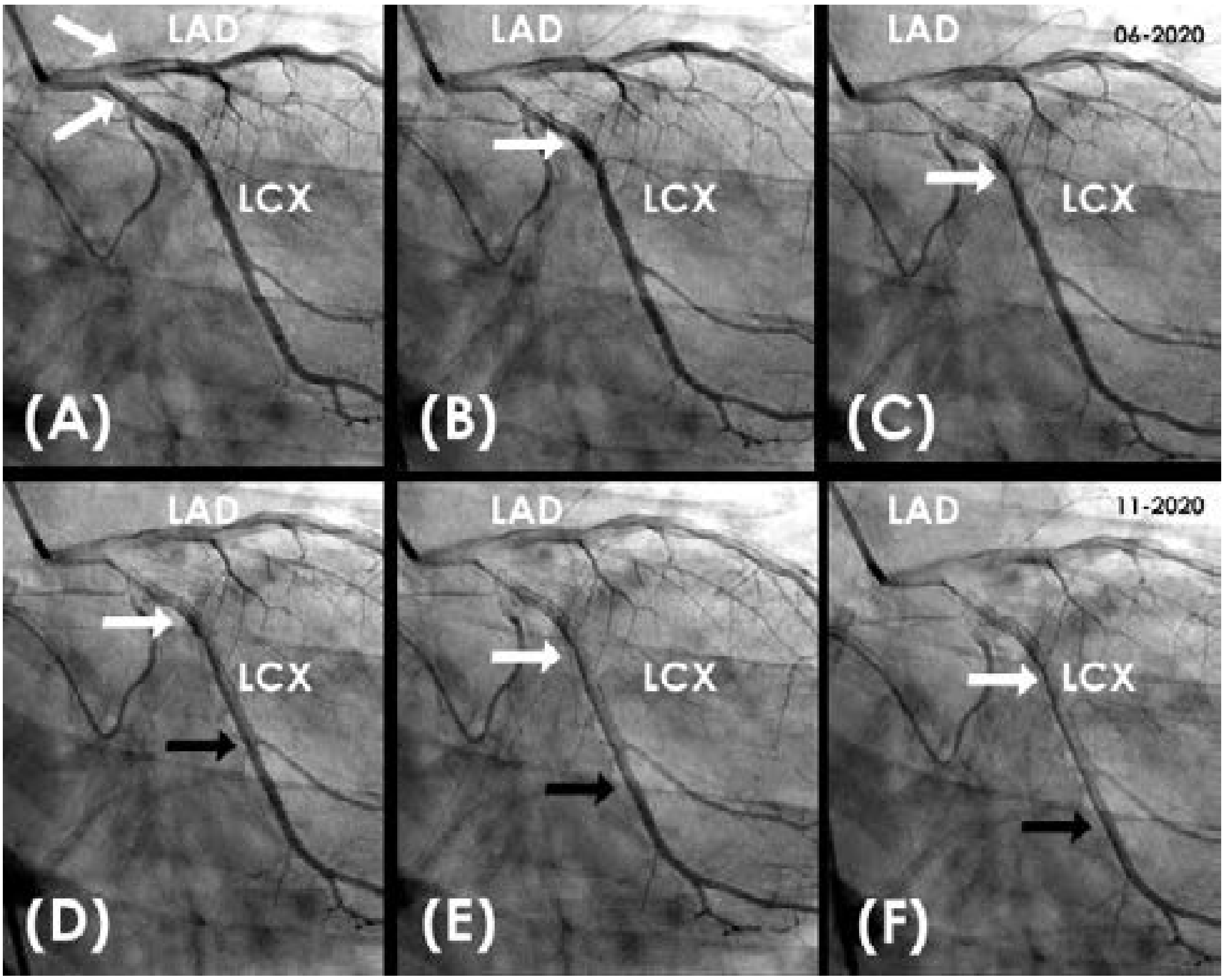

Fig. 8.- Coronary Angiogram of a Patient that Came for a Stenting Procedure. **(A)** This is the baseline left CAG of June 2020 with a patent left circumflex artery (LCX). This patient came for stenting for a severe lesion in the right coronary artery. The blood (white) was seen entering the proximal segments of the LCX and the left anterior descending artery (LAD) (white arrows). **(B)** The blood was seen to move in a proximal-to distal fashion through this segment and in laminar fashion with a thin boundary layer. **(C)** Blood is observed to flow further downstream, but only a minimal distance. **(D)** The flow stopped and seemed to be disorganized. This is the Collision Line (white arrow). The distal flow moved forward (black arrow). **(E)** There was disorganized mixing between contrast (black) and blood (white). The flow here was turbulent (white arrow). The distal flow moved forward (black arrow). **(F)** In this image, the flow was still turbulent (white arrow), with a large boundary layer.

Fluid Mechanics Perspective. When the blood arrived at the end of the LM, the layers at the centerline will go straight towards the carina and a major part of the blood turns towards the LAD. At the proximal segment of the LCX, because this was the beginning of a developing laminar flow, the separation layer was formed at the outer curve of the proximal segment, opposite to the carina (Fig. 9A) (Zarandi et al., 2012). Based on Bernoulli's principle, the pressure at the separation layer is high because the speed is low. If any bubbles wander into the area, they burst secondary to cavitation. There is a difficulty in imaging the cavitation event causing the first injury starting the atherosclerotic process and the presence of a coronary plaque (Zarandi et al., 2012). The reason is that more than 50 years were required for an average American patient to develop a lesion in this ostial location. In contrast, if the cholesterol level was very high (600 mg%) as in severe familial hypercholesterolemia, a 10-years-old child could develop similar lesions at a much higher severity by the same mechanism (Fig. 9C).

Coronary Anatomical Perspective. The separation layer is defined as a retention of contrast at the border frequently seen after the LM distal bifurcation on the exit shoulder toward the LCX (Fig. 9A). This slow or no speed flow happened at the beginning of the formation process of an antegrade laminar flow. At the same time, in this particular

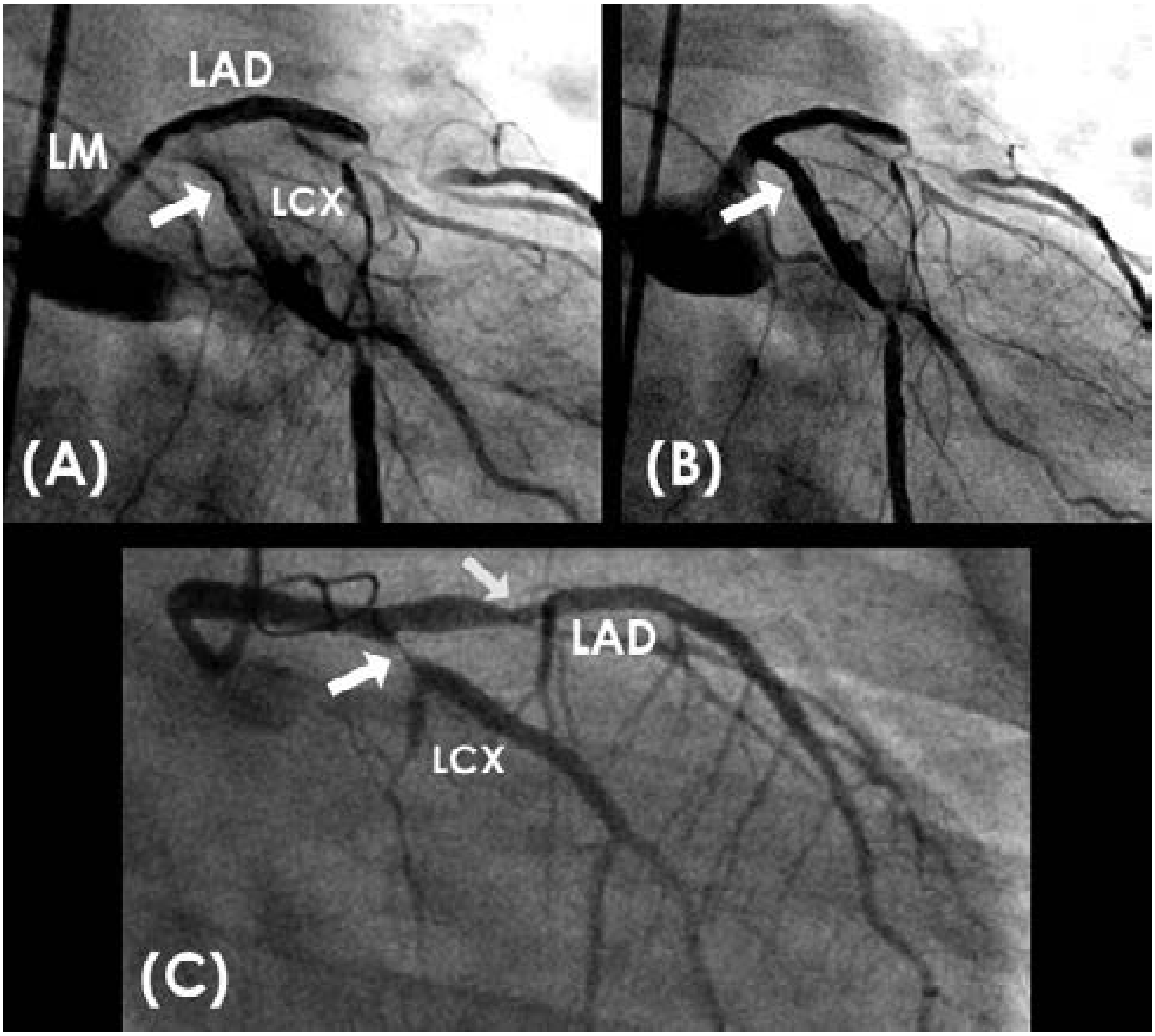

Fig. 9.- Left Coronary Arterial System Angiogram and Separation Layer. **(A)** CAG of patient with showing when the blood entered the left circumflex artery (LCX) there was a boundary layer or stagnant flow at the outer wall of the proximal segment of the LCX (arrow). **(B)** In this CAG, at the outer wall of the LCX, opposite to the carina, there was a lesion (arrow) which coincided with the location of the separation layer. **C.** This angiogram belonged to a 10-year-old boy with history of familial hypercholesterolemia. There is a severe lesion in the proximal segment of the LCX (arrow) and a mild lesion in the mid-segment of the LAD (arrow).

location (at the outer curve of the LCX opposite to the carina (i.e., outer wall of the side branch), many lesions of slow growth and mild severity lesions are frequently seen by the conventional CAG. The lesions here were the first to appear in middle-aged patients while there was no lesion in other coronary arteries of the same patient (Fig. 9A). It is reasonable to suggest that the recirculating flow at the separation layer was a fertile ground for cavitation or rupture of bubbles, injuring the intima and starting the formation of plaques.

Anatomical Difference of the Coronary Artery at the Proximal Segment of the LCX. Why was the separation layer so prominent at the proximal segment of the LCX and not at other locations? One of the reasons why there are only rare lesions in young patients is because the coronary arteries dilate and constrict based on the flow. If there is lower fluid input from the veins, such as in bleeding, the artery will constrict in order to maintain a stable blood pressure. If there is too much fluid intake, the artery will dilate in order to accommodate the extra amount of fluid. In these situations, the flow would stay laminar because there is harmony and concordance between the amount of the blood and the size of the container (i.e., artery). By the same token, the separation layer would be minimal and not the basis for severe cavitation and plaque formation. In the case of the LCX, its proximal segment is stiff and non-accommodating by being encased in the muscular segment of the proximal left atrioventricular sulcus. This is why interventional cardiology practice, the bifurcation from the LM to the LCX and the proximal segment of the LCX are the areas which are most difficult for advancing a metallic stent, especially when there is calcification from old age or chronic kidney disease. The second caveat is when there is an arterial dissection in the proximal segment of the LCX, the artery will not expand much because it is encased inside a muscular channel. In this situation, the patient will show more symptom of ischemia. The fact that the proximal segment of the LCX is encased in the muscular segment of the left atrioventricular sulcus sets the LCX aside and is different from the proximal segment of the LM or RCA, unless the RCA is originated from the left sinus. In this case, the type, and intensity or frequency of the flow were changed by the *anatomical interactions*.

Stagnant Flow - Boundary Layer

Clinical Presentations and Relevance. In many patients who underwent the non-invasive CT angiograms, the calcium scores were high. When they underwent conventional CAGs the results showed patent coronary arteries. Why?

Fluid Mechanics Perspective. According to principles in fluid mechanics, the presence of the boundary layers depends on the viscosity of the fluid (or blood) (Caro et al., 2012). This condition happened when the patients were older, smoked or had uncontrolled diabetes, infections or had recent surgeries.

Coronary Anatomy Perspective. In clinical cardiology, patients with acute coronary syndrome or who smoke could have high viscosity in the blood. The boundary layer could be quite thick as in the RCA (Fig. 10A). Will treatment with

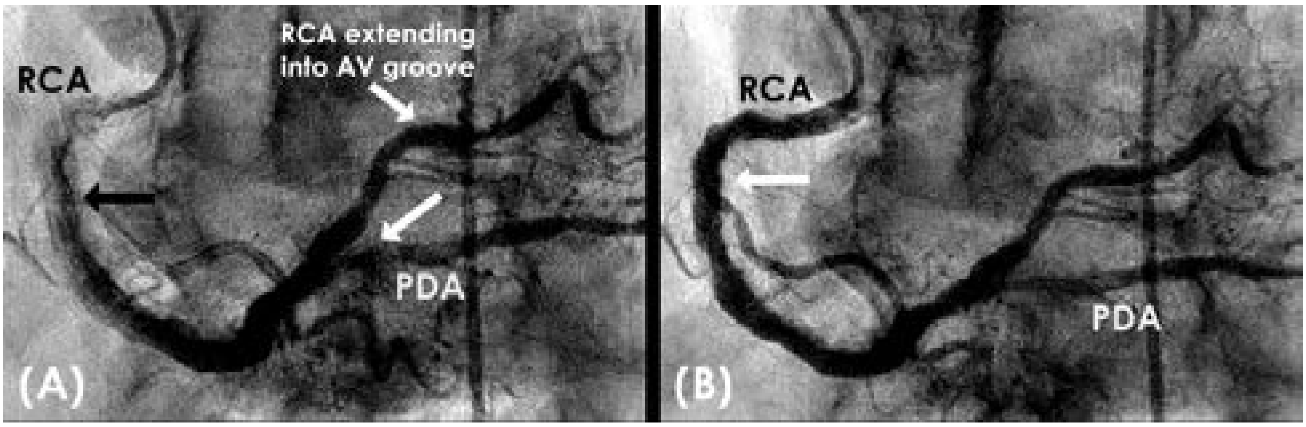

Fig. 10.- Thick Boundary Layer. **(A)** This is the right coronary angiogram (RCA) of a 93-year-old patient with non-ST segment elevation myocardial infarction. The culprit lesion was at the origin of the large posterior descending artery (PDA) (white arrow). In the mid segment of the RCA, the coronary blood flow (white) followed the outer curve while there was a thick layer of stagnant contrast (black) at the inner curve (black arrow). This thick area of contrast retention is called the boundary layer. **(B)** At all the segments where the boundary layer was seen as in Fig. 10A, many mild and diffuse lesions were observed (white arrow).

anti-inflammatory drugs (i.e., aspirin, P2Y12 inhibitors, statins), result in these thick boundary layers becoming smaller? This question will be answered in Part 4 of this manuscript symposium (Nguyen et al., 2020; Nguyen et al., 2021).

Side Branches

Clinical Presentations and Relevance. In patients with CAD, the majority of lesions were seen at the location or near a side branch. Why?

Fluid Mechanics Perspective. In the practice of hydraulics or HVAC, there are needs for bends, T or side tubes. The changes in direction of the original laminar flow would create different types of flows which effect the formation of lesions (Caro et al., 2012).

Coronary Anatomy Perspective. The anatomical presence of a side branch (SB) or pattern of branches can be variable, and can have an impact on the development of lesions. In the presence of a SB at a mid-segment, where collision occurs, it can be suggested that lesions could grow faster and become more unstable (Fig. 11). The reason is that the SB diverts the blood away from the main branch and causes more cavitation and also affects the collision line (Caro et al., 2012; Zarandi et al., 2012).

Small Diameter

Clinical Presentations and Relevance. A 53-year-old patient came with severe chest pain. The main risk factor was heavy smoking (>2 pack per day). The electrocardiogram showed non-specific ST-T change in lead 3. The LDL level was 57. The baseline CAG showed severe disease and the patient underwent successfully stenting in 2 arteries. The diameter of the RCA was 1.6 mm based on the size of the 5 French right diagnostic catheter (Fig. 12). The diameter of the LCX was 3 mm and of the LAD was 2.75 mm. The patient underwent successfully a plain angioplasty of the RCA with a balloon of 1.5 mm diameter and stenting of the mid-segment of a dominant LCX (not shown). It seemed that the RCA was spared (i.e., not requiring stenting) because of its small diameter (i.e., its anatomy). Is it true? WHY?

Anatomical Perspective. In general, in the small arteries observed in CAG, the flow was frequently laminar while there was turbulence in large arteries. Just like in industrial pipes, arteries (i.e., pipes) of smaller diameter have higher speed and lower pressure – more conducive to laminar flow – than arteries of larger diameter (Caro et al., 2012; Zarandi et al., 2012; Sakamoto et al., 2013; Ferrari, 2017).

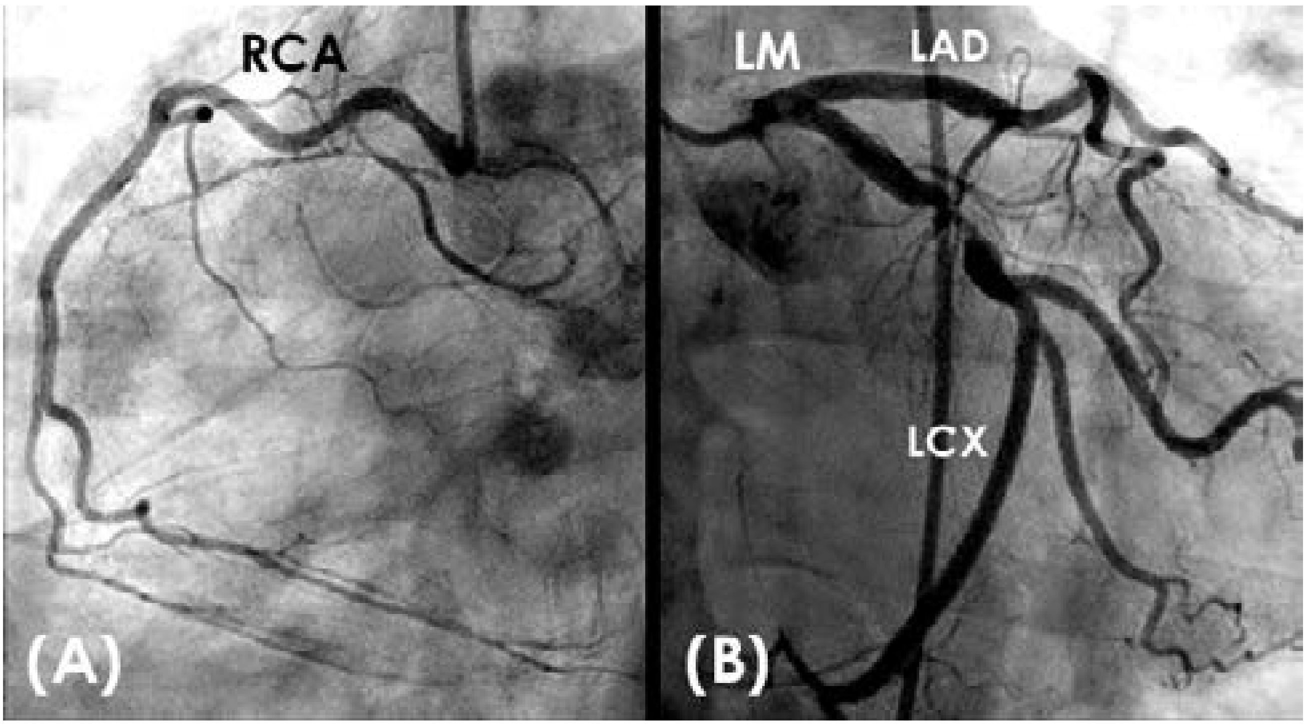

Fig. 11.- Coronary Arteries with Variability in Number and Pattern of Side Branches. The above angiograms were done after stenting of 2 arteries in the same patient. **(A)** This image shows an angiogram of the right coronary artery (RCA). **(B)** This is the left coronary angiogram. The diameters of the RCA, left circumflex (LCX) and left anterior descending (LAD) were 1.6 mm, 2.75 mm and 3.0 mm, respectively. The number/presence of side branches arising from the LCX is more, and the lesion is more severe. The LCX underwent successfully stenting of the proximal segment.

This is why the majority of lesions happened in large arteries. A small diameter is considered to be protective of the arteries from developing plaques.

Ostial Anomalies

Clinical Presentation and Relevance. Occasionally, a coronary artery can become obstructed or totally occluded in fetal or neonatal life due to ostial hypoplasia or atresia (Villa et al., 2016). In this case, the distal coronary bed is supplied by collateral circulation from an ostium on the opposite side. This condition can be associated with ischemic manifestations (Villa et al., 2016). The question is WHY?

Anatomical Perspective. Using the new approach, analysis of CAG showed that in coronary arteries with anomalies of the coronary ostium, there were more minimal lesions downstream (Fig. 13A). In coronary arteries with anomalies due the ostium that originated from the opposite sinus, there were diffused lesions downstream (Fig. 13B). The reason is that the abnormal orientation (i.e., change from the normal coronary arterial geometry/anatomy) causes turbulent flow and triggers the cavitation phenomenon (Fig. 13C).

Height of Aortic Sinus

Clinical Presentation and Relevance. In patients with lesions in the LM, the lesions could develop at the ostial, mid or distal location (Villa et al., 2016; Holm and Christiansen, 2014). The lesions could also develop at the superior or inferior border of the artery (Villa et al., 2016; Angelini et al., 2010). An unprotected LM leaves the majority of the myocardium susceptible to death if significant stenosis is present. (Ramadan et al., 2018).

Anatomical Perspective. Which factor dictates the presence of lesion in the superior or inferior border of the LM? Anatomy is the foundation of the answer, because the anatomy (or geometry) of the artery and sinus effect the blood flow (Caro et al., 2012; Zarandi et al., 2012; Angelini et al., 2010). Based on computational dynamic flow study, the height of the left aortic sinus dictates the angle of entry at the LM (Angelini et al., 2010). Applying the present model, if the height of the aortic sinus was short, the blood will enter from below and hit the superior border of the LM (Fig. 14). In this way, the lesion will happen at the lower border.

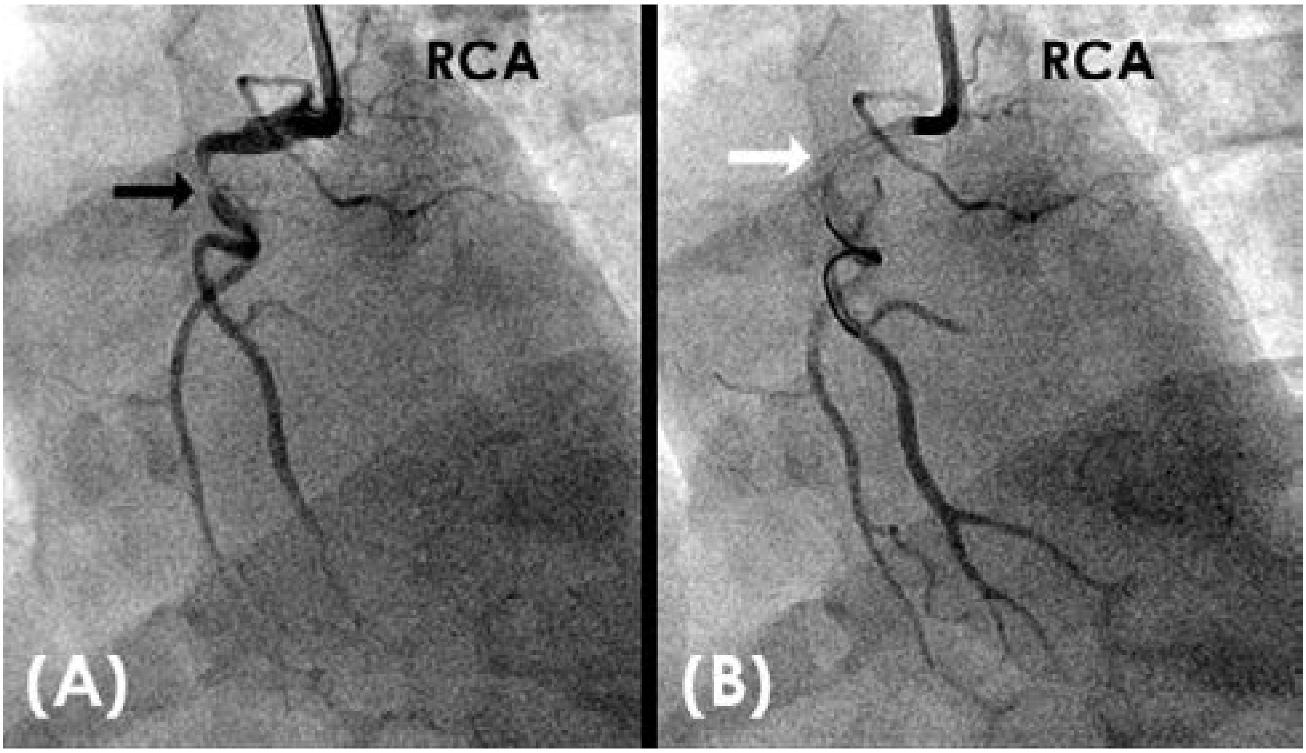

Fig. 12.- Small Right Coronary Artery. **(A)** In this patient, the right coronary artery (RCA) was a diminutive artery with the diameter at the mid segment equal to 1.6 mm (based on the diameter of the tip of the catheter). There was a small lesion (black arrow). **(B)** The RCA was short and had plain balloon angioplasty with a 1.5 mm balloon, and no stent. Blood flow (white arrow) was restored.

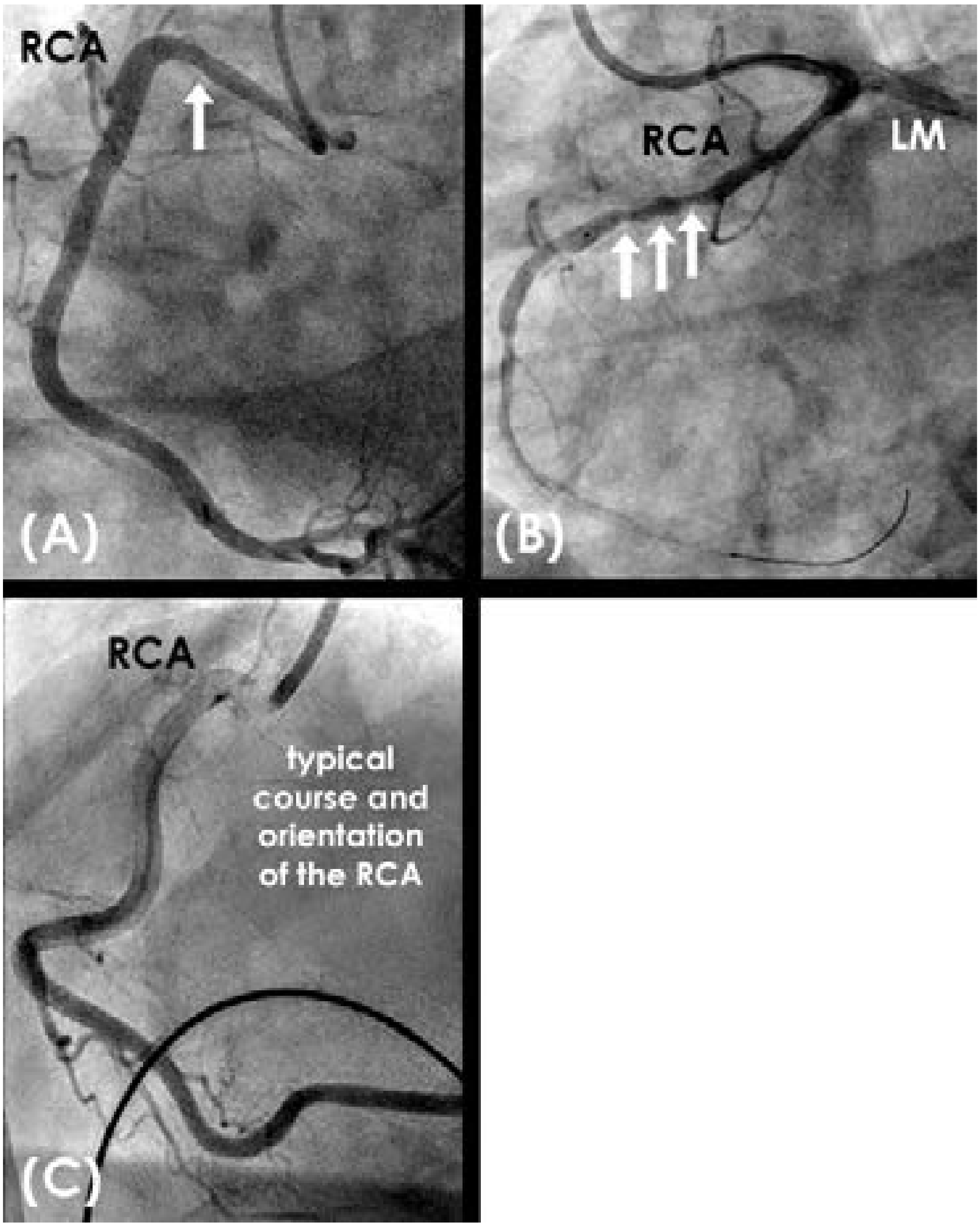

Fig. 13.- Ostial Anomalies of the Right Coronary Artery. **(A)** Abnormal orientation of the right coronary artery (RCA) is the cause of the presence of diffuse minimal lesions the mid segment. There was tubular stenosis at the proximal segment (arrow). The distal segment was normal. **(B)** CAG showing the ostium of the RCA was from the left sinus, next to the ostium of the left main (LM). Abnormal orientation of the right coronary artery (RCA) was the cause of the lesions (arrows). There were no lesions in the left anterior descending and left circumflex arteries. **(C)** This CAG is representative of the typical course and orientation of the RCA. Normal, laminar flow can be observed.

DISCUSSION

In this investigation, the authors examined anatomical variations in the coronary arterial system that affect blood flow patterns using a novel approach of dynamic coronary angiography applied to actual patient cases. In each case, this model showed that the anatomical structure of the coronary arteries was not only a risk factor, but also those anatomical variations that affect flow patterns could be predictive risk factors of future lesions. When flow coursed through arterial segments and curves with the characteristics of orderly organization, steady speed and minimal (or absent) boundary layers, then flow was laminar and explained absence of lesions in older patients. In arteries that showed areas of peripheral contrast retention, these boundary layers were predictive of lesion because the anatomy provided the structural influence on flow for cavitation or bubble rupture to occur. Changes in structure of vessels, number of branches and branching patterns affected blood flow suggesting that local geometry (i.e., anatomy) may induce turbulent flow (Caro et al., 2012; Zarandi et al., 2012). Even further, with this new technique the collision line in a coronary vessel could be clearly identified. The collision line is a “generation point” where colliding flows (antegrade and retrograde coronary flows) results in bubble collapse and micro jet wave propagations that damage the tunica intimal and begin the process of lesion development (Brujan, 2011; Brennen, 1995; Brennen, 2005; Ferrari, 2017; Fujisawa et al., 2018; Hsiao et al., 2014; Tomita et al., 2002; Yu et al., 2013; Chistiakov et al., 2017). Fewer or no lesions were observed in arties of smaller diameter, suggesting that the “anatomy” of smaller diameter is more conducive to laminar flow (Caro et al., 2012); just like industrial pipes (Sakamoto et al., 2013; Ferrari, 2017). Finally, study of ostial location/anomalies and height of the aortic sinus with this new model and flow studies showed that the coronary atrial anatomy can cause changes in flow direction, turbulence, and can be used as predictors of where future lesions will form.

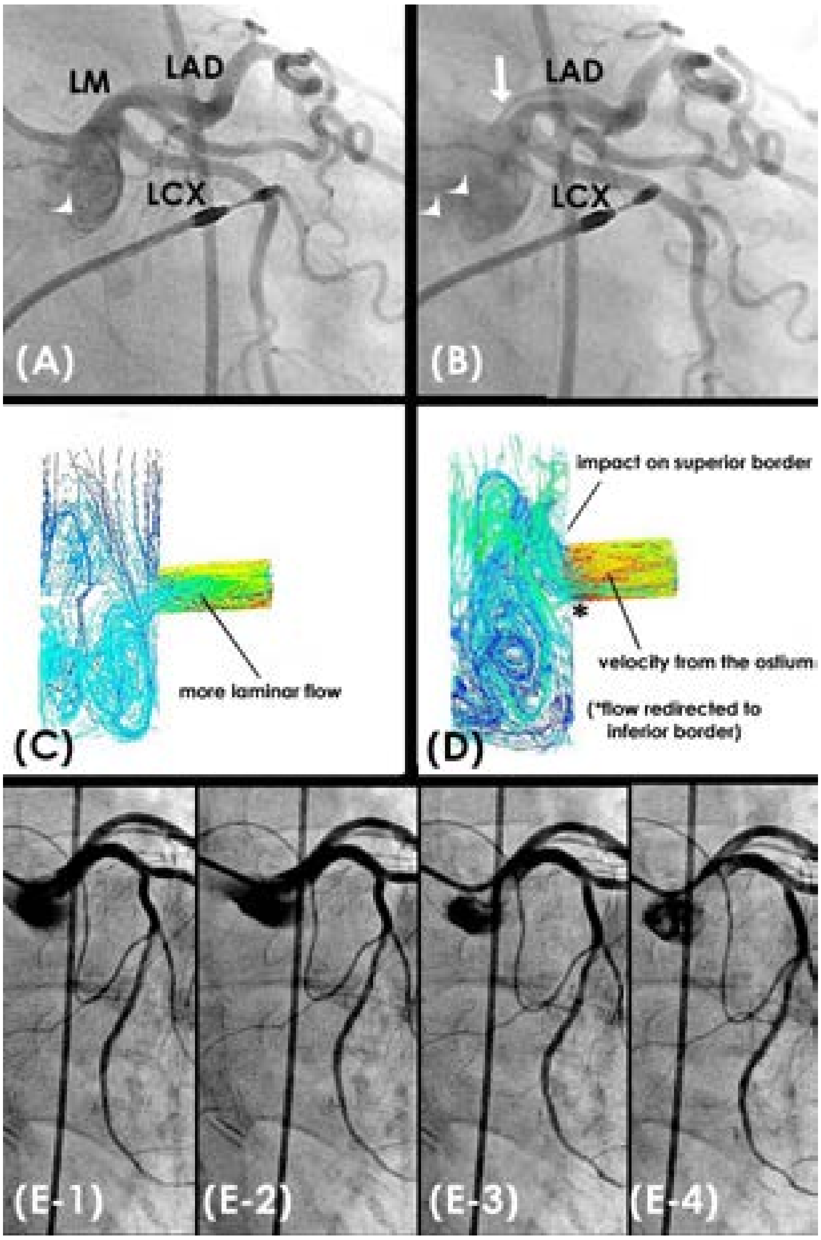

Fig. 14.- Blood Flow Relative to the Anatomy of the Aortic Sinus. **(A)** In this sample CAG, the left main (LM), the left descending (LAD), left circumflex (LCX) arteries were full with contrast (black). The height of the aortic sinus was short. This image was near the end of systole with the aortic valve near its closed position (single arrowhead). **(B)** The blood (white) was seen entering the LM and LAD, by following the upper border (white arrow). The lower half of the LM and LAD was still full with contrast (boundary layer). The aortic valve was closed now (double arrowhead). The explanation was that the blood was expelled from the left ventricle to the aorta. During diastole, the blood stroke down the aortic sinus (which was shallow), hit the aortic valve, moved up to the LM ostium and entered the LM along the upper border. **(C)** Flow diagram of blood during diastole entering the LM with normal height the aortic sinus. **(D)** Blood flow diagram during diastole of blood entering the LM with short height of the aortic sinus. The anatomy of the vessel (i.e., change in height and angle of ostium) results in impact on the superior border and redirection to the inferior border of the LM ostium. **(E1-4)** Left CAG of sequential images (0.06 second) showing blood (white) entering the LM. During diastole, the blood stroke down the aortic sinus (which was shallow), hit the aortic valve, moved up to the LM ostium and entered the LM along the upper border.

This demonstration of how anatomy (1) changes blood flow, (2) influences lesion formation via cavitation and bubble explosion; and (3) can be used as a predictive factor in the formation of coronary lesions is new and critical knowledge for anatomists, cardiologists and interventional cardiologists (i.e., interventional anatomists). Still further, this new perspective and knowledge applies to all vessels in the body. So the questions now are:

1. HOW can this knowledge and this new approach of dynamic coronary angiography be used to help cardiac patients?
2. COULD the anatomy underlying changes in blood flow patterns and lesion formation be changed?
3. HOW can this be applied to lesions in other vessels outside of the coronary arterial system (i.e., femoral, iliac, basilar, etc.)?

The answers to these questions will be discussed in Part 4 of this manuscript symposium, when this research team focuses on the impact of this anatomical research on medicine or mechanical interventions (i.e., angioplasty, stenting, medications) in order to restore the natural anatomical structure (i.e., interventional anatomy).

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REFERENCES

ALTIN C, KANYILMAZ S, KOC S, GURSOY YC, BAL U, AYDINALP A, YILDIRIR A, MUDERRISOGLU H (2015) Coronary anatomy, anatomic variations and anomalies: a retrospective coronary angiography study. *Singapore Med J*, 56(6): 339-345.

ANBUMANI TL, DEEPTHI C, THAMARAI SELVI A, ANTHONY AMMAL S (2016) An anatomical study of the coronary arteries and their variations. *Int J Anat Res,* 4(1): 2114-2118.

ANGELINI P (2002) Coronary artery anomalies - current clinical issues: definitions, classification, incidence, clinical relevance, and treatment guidelines. *Tex Heart Inst J*, 29: 271-278.

ANGELINI P, WALMSLEY R, CHEONG BYC, OTT DA (2010) Left main coronary artery originating from the proper sinus but with acute angulation and an intramural course, leading to critical stenosis. *Tex Heart Inst J*, 37(2): 221-225.

BALLESTEROS LE, RAMIREZ ML, QUINTERO ID (2011) Right coronary artery anatomy: anatomical and morphometric analysis. *Rev Bras Cir Cardiovasc*, 26(2): 230-236.

BHIMALLI S, DIXI D, SIDDIBHAVI M, SHIROL VS (2011) A study of variations in coronary arterial system in cadaveric human hearts. *World J Sci Technol*, 1(5): 31-35.

BRENNEN CE (1995) Cavitation and Bubble Dynamics. *Oxford University Press, Inc.*, New York.

BRENNEN CE (2005) Cavitation. In: *Fundamentals of Multiphase Flow*. Cambridge University Press, Cambridge, pp 97-115. doi:10.1017/CBO9780511807169.006.

BRUJAN AE (2011) Cavitation in non-newtonian fluids with biomedical and bioengineering applications. *Springer,* New York.

CARO CG, PEDLEY TJ, SCHROTER RC, SEED WA (2012) *Mechanics of Circulation*, 2nd edition. Cambridge University Press, Cambridge, UK.

CHISTIAKOV DA, MELNICHENKO AA, MYASOEDOVA VA, GRECHKO AV, OREKHOV AN (2017) Mechanisms of foam cell formation in atherosclerosis. *J Mol Med (Berl)*, 95(11): 1153-1165.

DI GUGLIELMO L, MONTEMARTINI C (1975) Anatomical variations and congenital anomalies of the coronary arteries. Personal experience (author's transl). *Ann Radiol (Paris)*, 18: 255-257.

FAZLIOGULLARI Z, KARABULUT AK, ULVER DUGAN N, UYSAL II (2010) Coronary artery variations and median artery in Turkish cadaver hearts. *Singapore Med J*, 51(10): 775-780.

FERRARI A (2017) Fluid dynamics of acoustic and hydrodynamic cavitation in hydraulic power systems. *Proc Math Phys Eng Sci*, 473(2199): 20160345. doi:10.1098/rspa.2016.0345

FUJISAWA N, FUJITA Y, YANAGISAWA K, FUJISAWA K, YAMAGATA T (2018) Simultaneous observations of cavitation collapse and shock wave formation in cavitating jet. *Exp Therm Fluid Sci*, 94: 159-167.

GARG N, TEWARI S, KAPOOR A, GUPTA DK, SINHA N (2000) Primary congenital anomalies of the coronary arteries: a coronary: arteriographic study. *Int J Cardiol*, 74: 39-46.

HOLM NR, CHRISTIANSEN EH (2014) Left main coronary artery lesions and optical coherence tomography. *Interv Cardio Rev*, 1-4. RadcliffeCardiology.com

HSIAO C, JAYAPRAKASH A, KAPAHI A, CHOI J, CHAHINE G (2014) Modelling of material pitting from cavitation bubble collapse. *J Fluid Mech*, 755: 142-175.

KALPANA R (2003) A study on principal branches of coronary arteries in humans. *J Anat Soc India*, 52(2): 137-140.

MOORE KL, DALLEY AF, AGUR AMR (2018) Clinically Oriented Anatomy, 8th edition. Wolters Kluwer, Alphen an den Rijn, Netherlands.

NGUYEN T, LUAN NT, LE V, CHUNG D, NGO T, NGO L, NGUYEN PM, NGUYEN PT, TRUONG T, NGUYEN H, NGO AT, QUANG D NN, DUONG DN H, VU TL, NHAN TPH, THINH CV, DUNG HT, RIGATELLI G, NANJUNDAPPA A (2020) In patients with acute coronary syndrome, the collision line is the location of vulnerable plaques caused by violent collision between antegrade and retrograde coronary flow. Presented at the *Great Wall International Conference on Cardiology*, Beijing, China.

NGUYEN T, VU L, RIGATELLI G, TALARICO, JR. EF, CAO T, HO D, DUONG HH, PHAM D, CHUNG D, NGO L, NAGO T, TRUONG D (2021) Measuring the boundary layers in patients with ACS by dynamic angiography and machine learning program. Accepted for Presentation at the *American College of Cardiology Scientific Meeting*, Atlanta, GA, USA.

NGUYEN VH, TALARICO JR EF (2018) A morphometric anatomical study of the division of the left main coronary artery and myocardial bridges. *Eur J Anat*, 22(4): 355-365.

NGUYEN VH, TALARICO JR EF (2019) A morphometric anatomical study of the right coronary artery in Vietnamese. *Eur J Anat*, 23(5): 341-353.

ORTALE JR, KEIRELLA LCB, CAMPINAS LS (2004) The posterior ventricular branches of the coronary arteries in the human heart. *Arqivos Brasileiros de Cardiologia*, 82(5): 468-472.

ORTALE JR, FILHO JM, PACCOLA AMF, LEAL JGPG, SCARANARI CA (2005) Anatomy of the lateral, diagonal and anterosuperior arterial branches of the left ventricle of the human heart. *BJCVS/RBCCV*, 20(2): 149-158.

RAMADAN R, BODEN WE, KINLAY S (2018) Management of left main coronary artery disease. *J Am Heart Assoc*, 7(7): e008151.

SAKAMOTO D, YOUN C, KAGAWA T (2013) Pressure change in tee branch pipe in oscillatory flow. *Adv Mech Eng*, Article ID 257283. http://dx.doi.org/10.1155/2013/257283

TOMITA Y, ROBINSON P, TONG R, BLAKE J (2002) Growth and collapse of cavitation bubbles near a curved rigid boundary. *J Fluid Mech,* 466: 259-283.

VILLA ADM, SAMMUT E, NAIR A, RAJANI R, BONAMINI R, CHIRIBIRI A (2016) Coronary artery anomalies overview: the normal and the abnormal. *World J Radiol,* 8(6): 537-555.

YU XH, FU YC, ZHANG DW, YIN K, TANG CK (2013) Foam cells in atherosclerosis. *Clin Chim Acta*, 424: 245-252.

ZARANDI MM, MONGRAIN R, BERTRAND OR (2012) Determination of flow conditions in coronary bifurcation lesions in the context of the medina classification. *Modelling and Simulation in Engineering*, Article ID 419087. https://doi.org/10.1155/2012/419087

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Challenges of the 21st Century: Part 4 - Interventional Anatomy: a case-based discussion

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SUMMARY

Dynamic coronary angiography applies the principles of hydraulics to blood flow and examines the relationship between anatomical structure of the artery and fluid mechanics. Both normal anatomy and anatomic variation in the coronary arteries change blood flow, and can produce an environment favorable for cavitation phenomenon and the development of coronary lesions. Thus, the anatomy of the coronary arteries in a patient can be used as a predicative factor (i.e., predictive anatomy) of where lesion formation will occur. Anatomical preservation by medicine, or restoration of natural anatomy by advance anatomical intervention, restores laminar flow patterns and lessens the chances for vessel injury. This novel model presented in this manuscript symposium represents a new and provocative way of thinking for anatomists and cardiologists, and demonstrates how anatomy research continues to be important in the modern era.

Key words: Anatomy – Anatomical preservation – Anatomical restoration – Coronary artery

ABBREVIATIONS

Acute Myocardial Infarction (AMI)

Aspirin (ASA)

Beta-blockers (BB)

Blood Pressure (BP)

Cerebral Vascular Accident (CVA)

Coronary Angiogram(s) (CAG/CAGs)

Coronary Artery Bypass Surgery (CABG)

Coronary artery Disease (CAD)

Diabetes Mellitus (DM)

Hypertension (HTN)

Left Anterior Descending Artery (LAD)

Left Circumflex Artery (LCX)

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Left Main Coronary Artery (LM)

Low Density Lipoprotein (LDL)

Percutaneous Coronary Intervention (PCI)

Peripheral Arterial Disease (PAD)

INTRODUCTION

Thus far in this manuscript symposium, the authors have (1) discussed the challenges of diagnostic, prognostic and interventional anatomy in the modern era; (2) presented a novel and groundbreaking approach to examine coronary lesions based on the relationship between anatomical structure and fluid mechanics; and (3) correlated injuries caused by flow anomalies with formation of lesions and then used principles of fluid mechanics to explain the anatomical/ structural cause-effect mechanism and future risks.

From an anatomical perspective, there are many patterns of variation in the coronary arteries (Moore et al., 2018; Anbumani, et al., 2016; Bhimalli et al., 2011; Ortale et al., 2005; Fazliogullari et al., 2010; Nguyen and Talarico, 2018; Ballesteros et al., 2011; Kalpana, 2003; Ortale et al., 2004; Nguyen and Talarico, 2019). In cardiology, the coronary arteries are considered normal or of normal variations if they are long, short, curved, or straight, etc. If the arteries are within the 90% of these extremes, then the artery is considered to be normal or normal variations. However, anatomical variations coronary arteries could lead to pathological problems. Results in Part 3 of this symposium showed how the anatomy/geometry of coronary arteries affects flow dynamics and could be used to predict where lesions would form (i.e., predictive anatomy). Even further, it was suggested that these results applied not only to the coronary arterial system, but to the peripheral arteries, as well. This leads anatomists and cardiologist to an intriguing question: Does restoration of the *anatomy* restore the function? This is the question that will be examined in this, the final article, of this symposium. The approach taken herein is a case-based format, where each situation (or condition) is illustrated with a real-life problem.

What is the ultimate goal of guideline directed medical therapy (GDMT) or mechanical interventions in coronary and peripheral arterial disease? The ultimate goal is to preserve or restore the original anatomy in order to maintain optimal function. For example, in a specific situation, what does Aspirin (ASA) do to the coronary artery? ASA helps to keep the lumen of the artery constantly open, without encroachment of the lumen by the platelet rich white thrombus. Thus, the blood flow is “controlled” secondary to the principles of fluid dynamics because the lumen (i.e., the anatomy) is restored to normal as possible. In another example, it can be asked, “What does a statin do to the coronary artery?” Statins, also known as HMG-CoA reductase inhibitors, are a class of lipid-lowering medications that reduce illness and mortality in those who are at high risk of coronary artery disease (CAD). By lowering cholesterol levels in the blood, statins prevent enlargement of a plaque encroaching the lumen of the artery. Similarly, what does a stenting procedure do to a patient? A stent is a tiny tube that is inserted into a blocked passageway and expanded in order to keep it open. The stent restores the flow of blood where it is placed. Thus, stenting restores the natural anatomy of a coronary lumen in order for the artery to fulfill its function of channeling blood to the distal myocardium.

Image Research Depository. The complete database of images used in the development of this novel model and in this research investigation has been established at DIGITAL ACCESS to SCHOLARSHIP at Harvard Library, Office for Scholarly Communication (https://dash.harvard.edu/). Readers are invited to explore, and to comment and discuss.

ANATOMICAL PRESERVATION BY MEDICINE

In the care of patients with confirmed CAD, three important medications are included in the GDMT: ASA, statin and beta blockers (BB). The role of ASA is to block the formation of thromboxane which is responsible for the aggregation of platelets. Its main role in all patients with proven CAD (secondary prevention) is to prevent the formation of a platelet rich white thrombus in the first phase of the coagulation cascade. Is there a role of ASA in primary prevention based on the new discoveries on turbulent flow or boundary or separation layers discussed in this symposium? What is the indication of ASA in asymptomatic patients with aneurysmal coronary arteries? For betablockers and statin, what are their interference in turbulent flow, collision line, reversed flow and laminar flow? The answers to the above questions will be discussed in this article.

Antiplatelet Therapy in Coronary Artery Disease

Physicians and scientists do not question the efficacy of ASA in patients with proven CAD, after percutaneous coronary intervention (PCI) or coronary artery bypass surgery (CABG). However, in asymptomatic patients without any history of CAD, peripheral arterial disease (PAD), or stroke, is ASA effective in primary prevention?

Based on the incidence of turbulent flow and presence of boundary layers at the borders, it is reasonable to suggest that ASA may help to prevent the aggregation of platelet without changing the disease process. In patients with hypertension (HTN), if the blood pressure (BP) is well controlled, the chance of acute myocardial infarction (AMI) and cerebral vascular accident (CVA) will be much lower. The benefits come from a lower BP and rate of rise (which is defined as the change of pressure over time, or dp/dt) creating an attenuated collision due to a weaker reversed systolic flow. If the collision was weaker in a coronary artery, then there is lower incidence of AMI. If the collision is weaker in the carotid or mid-cerebral artery, then there is lower incidence of CVA. If weaker collision happens in the iliac or femoral artery, then the incidence of PAD would be lower. ASA would not change the profile of AMI, CVA, PAD if blood pressure is elevated. HTN puts an extra strain on all the blood vessels in the body. This can make a AMI, CVA and PAD more likely, because HTN damages blood vessels and makes them become stiffer and more narrow (Hörnsten et al., 2016; Gaciong et al., 2013).

In case of smoking, uncontrolled diabetes (DM), old age, infection, or recent surgery, the patients may have thick boundary layer due to high viscosity. These thick boundary layers caused mild damage to the intima, mostly as a weaker version of cavitation. The coronary angiograms (CAGs) of these patients showed multiple minimal to mild diffuse lesions along the arterial wall (Fig. 1). The reason for no severe lesion is speculated because of the absence of repeated shock waves from cavitation. Thus, with the presence of multiple diffuse minimal to mild lesions, the use of ASA may be beneficial for this high risk group of patients.

ASA for Aneurysmal Artery

In a huge artery, the flow could be turbulent and creates intertwining areas of high or low

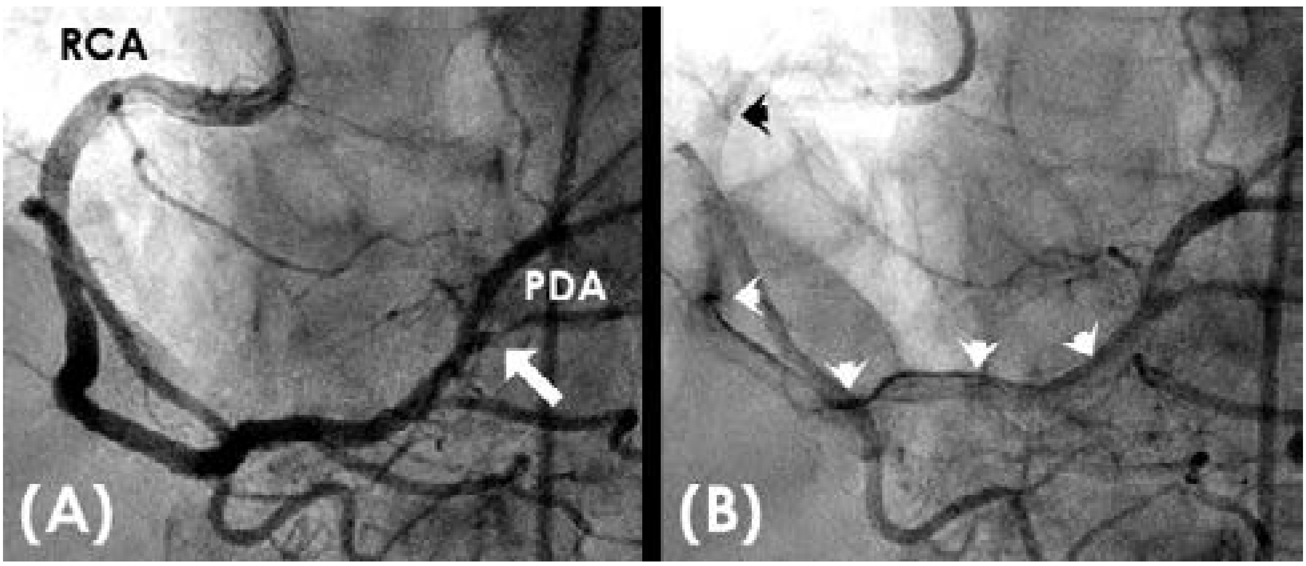

Fig. 1.- Right Coronary Artery Angiogram. **(A)** This was the right coronary artery (RCA) CAG of a patient with uncontrolled diabetes, smoking and high level of low-density lipoprotein (LDL)-cholesterol. Her troponin level was high. There was a severe lesion in a posterior descending artery (PDA) branch (arrow). **(B)** There was a moderately thick boundary layer along the inner curve due to high viscosity of the blood (short arrows).

pressure favorable for the bubbles to rupture if they venture between these areas (i.e., the cavitation phenomenon) (Fig. 2). Because of many areas with recirculation and stagnant flow, the probability of thrombotic formation is high, ASA is used to prevent the formation of the thrombi. If the patient developed recurrent chest pain and elevated cardiac enzyme level, in spite of ASA, full dose of anticoagulation with new oral anticoagulant drugs is suggested (Su et al., 2014).

Preservation of the Natural Lumen by Statin

In patients with CAD, statins lower the low density lipoprotein (LDL) cholesterol level and prevent more acute myocardial infarction than PCI (Boden et al., 2007). Statin prevents the growth of the cholesterol plaques which encroach the arterial lumen. Consider the case of a 70-year-old, male patient having PCI of the proximal LAD. CAG documented that the distal RCA had a fairly significant lesion (Fig. 3). Because the patient was asymptomatic, he declined any intervention. The patient was on statin, BB and ASA. A recent echocardiography showed normal function of the inferior wall in the 2-chamber view. Statin and ASA preserved the arterial lumen (i.e., the anatomy), and this is why the patient was asymptomatic.

The Effects of Betablockade

In general, betablockade was associated with lower mortality in patients with anterior wall infarction (3.9% vs 13.4%, $p < 0.0001$) whereas nonsignificant benefits were observed in nonanterior wall infarct location (2.0% vs 3.3%, p = NS) (De Luca et al. 2005). Applying the novel model of this symposium, some interesting questions arise. What was the exact mechanism of this benefit? Could bradycardia caused by BB offer the protection to the coronary arteries? Was the speed in the coronary arteries slower with BB so that the BB offered protection from plaque rupture? Below, selections of images are reviewed showing the size of the artery, the speed of the coronary flow and the extent of the recirculation flow after a bifurcation are presented in patients after treatment with BB.

Vasoconstriction. In 2011, a patient with PCI of the LAD, the LAD showed a diameter >2 mm in the left anterior oblique cranial view, after PCI. In 2019, the same patient now on BB underwent PCI of the left circumflex (LCX), and a diagnostic CAG of the LAD was performed (Fig. 4). Compared with the angiogram of 2011, the diameter of the LAD was smaller. Because BB caused distal vasoconstriction, BB could provide an anatomy

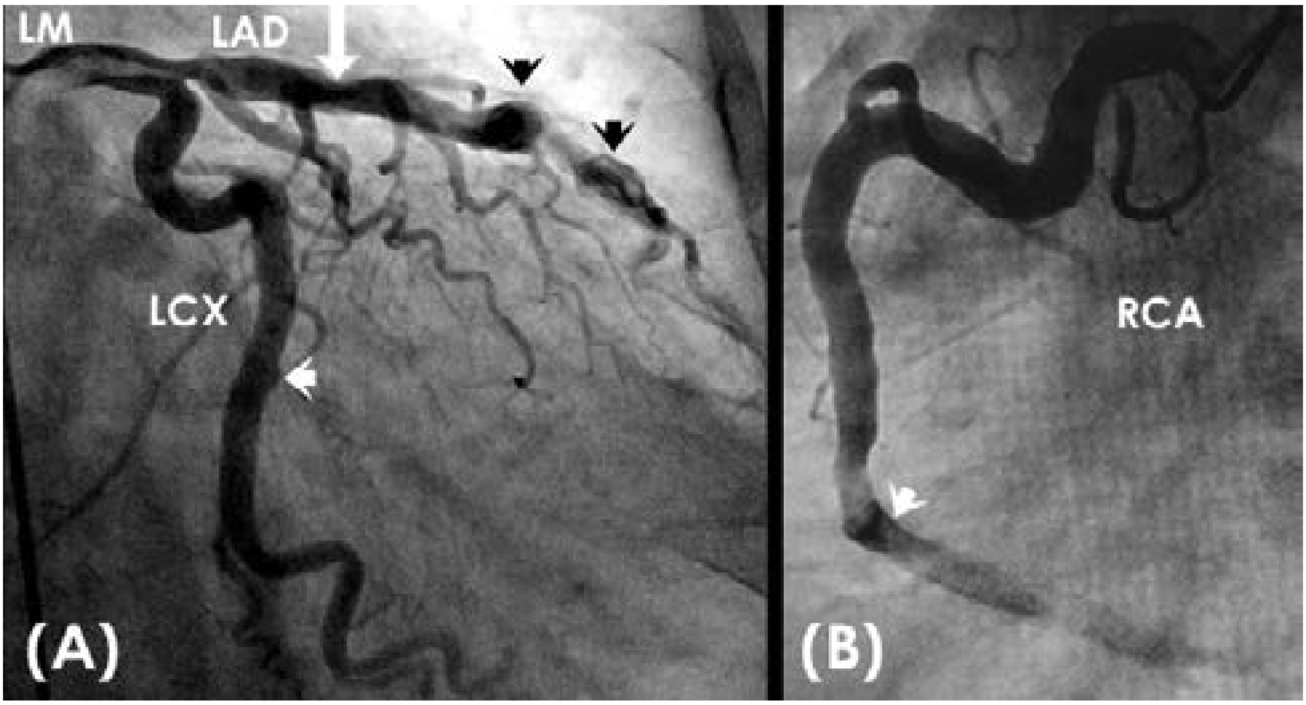

Fig. 2.- Coronary Angiograms and Aneurysmal Arteries. **(A)** In this CAG of the left coronary artery, there was diffuse no-critical lesion in the left main (LM) left anterior descending (LAD) and the left circumflex arteries (arrow heads). The LAD had a mild to moderate ostial lesion (white arrow) and has been stable for the last 5 years. The fractional flow reserve was negative. **(B)** CAG of the right coronary artery (RCA) showed diffuse mild lesions.

suitable for laminar flow to be developed distally and so offer protection from new plaque formation and rupture of current plaques (Nguyen et al., 2021a; 2021b; Billinger et al., 2001).

Speed of the Coronary Flow. In the hemodynamics of coronary flow, fast speed was correlated with cavitation phenomenon so more lesion could develop during fast speed in diastole. Beta blockers slowed the speed in general as seen (Fig. 5). By slowing the speed, less turbulence occurs and so less chance for cavitation and lesion formation (Nguyen et al., 2021a; 2021b).

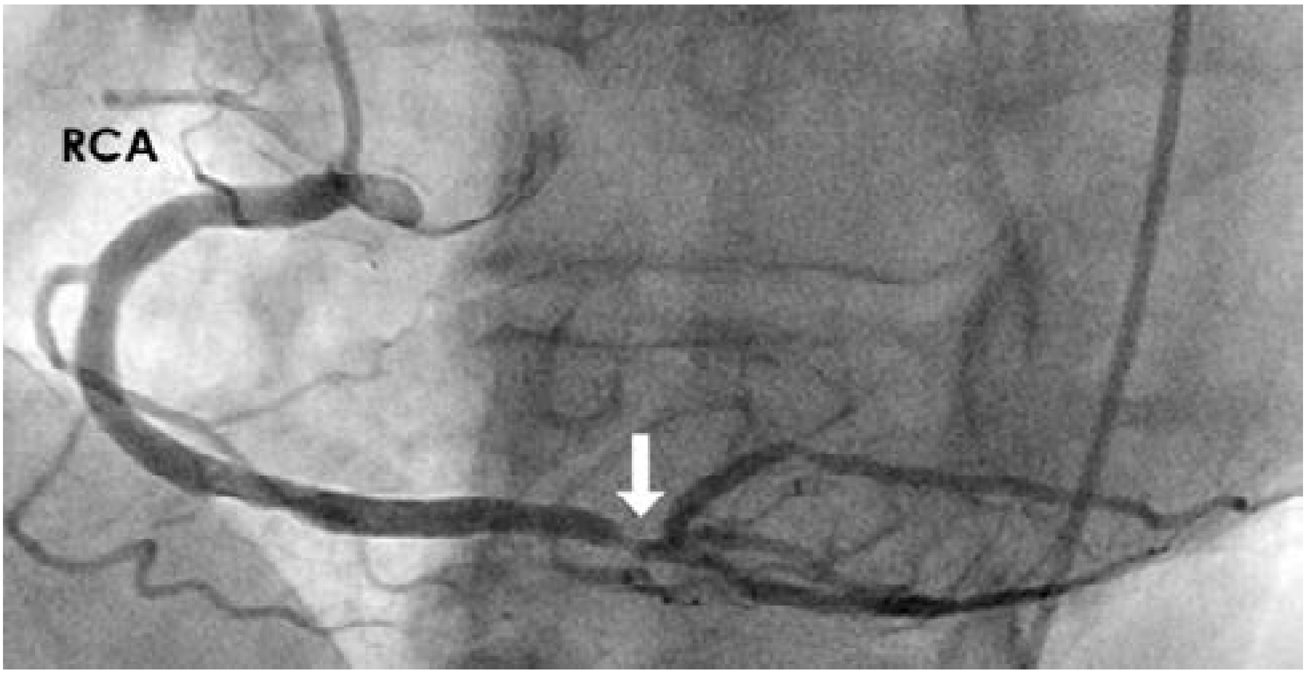

Fig. 3.- Right Coronary Angiogram. This is the CAG of the right coronary artery (RCA) of an elderly patient who came for stenting of the proximal left anterior descending artery. A significant lesion was observed in the distal RCA. The patient refused further stenting of the distal posterior descending artery and was treated successfully with statin, beta blockers and aspirin.

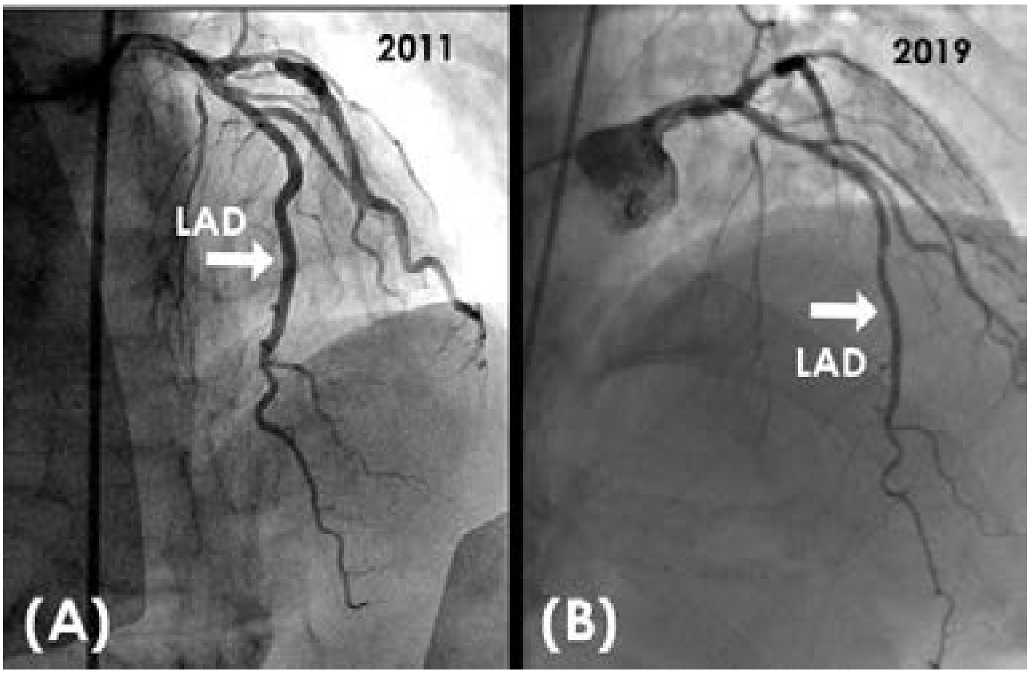

Fig. 4.- Left Coronary Angiograms before and after Beta Blockers. **(A)** In 2011 after undergoing stenting; with the 6 French guide of diameter = 2.03 mm, so the diameter of the mid-segment of the left anterior descending (LAD) artery was >2.5 mm (arrow). At discharge, beta blockers were prescribed **(B)** In 2019 the left CAG showed the size of the mid-LAD while patient was on beta blockers. The diameter of the 5 French diagnostic catheter was equal = 1.67 mm, so the diameter of the mid-to-distal segment of the LAD was a little below 2 mm (arrow). Beta blockers caused distal vasoconstriction and provided an environment for development of laminar flows which caused no new coronary lesion. This is the beneficial mechanism of beta blockers (i.e., restorative anatomy).

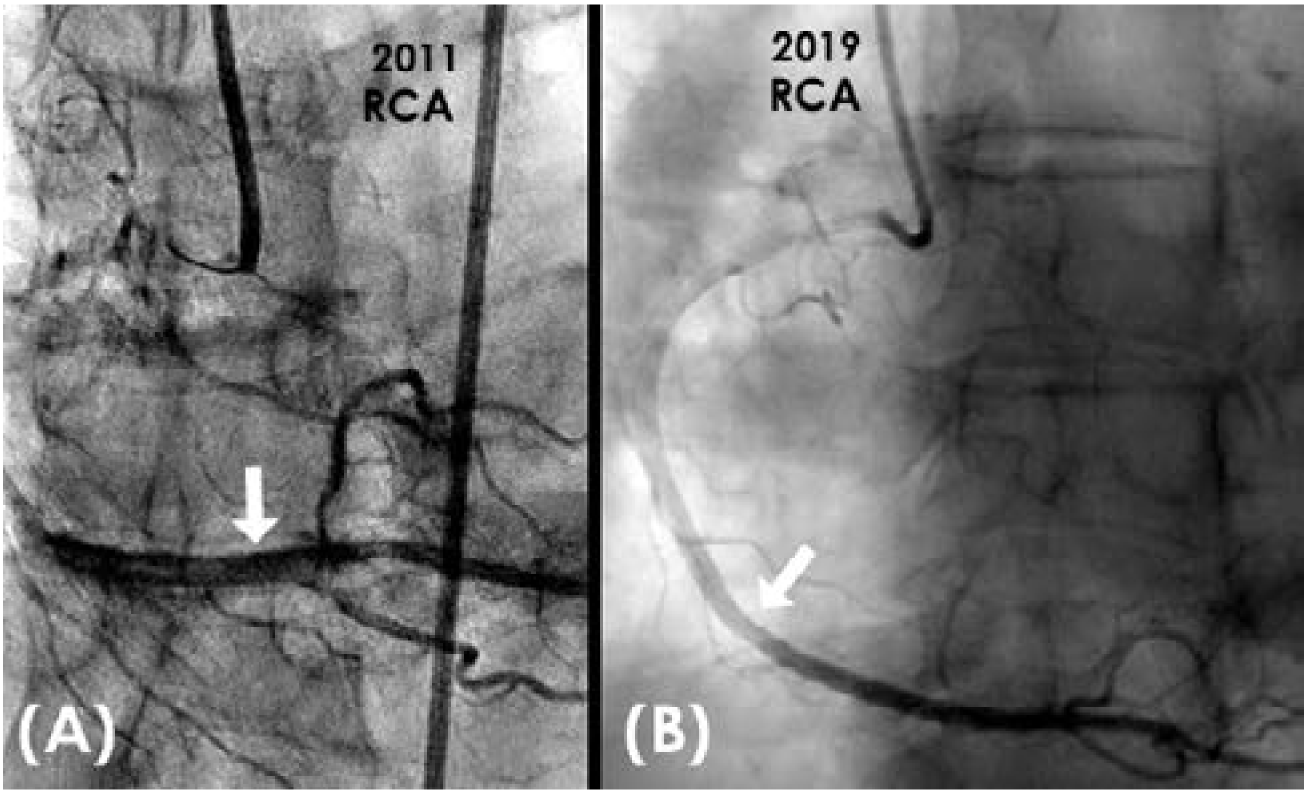

Fig. 5.- Right Coronary Angiography, Beta Blockers and Flow. **(A)** In 2011 after stenting, after 10 images or 0.6second, the blood arrived to the distal segment of the right coronary artery (RCA) (arrow). At that time, the patient was not on beta blockers. **(B)** in 2019 with the patient on beta blockers, the blood arrived after 0.6 second at the beginning of the distal segment (arrow). The blood moved more slowly and had less turbulence. This is the secondary protective effect of beta blockers.

ADVANCED ANATOMICAL INTERVENTION

Restoration of the Natural Anatomy by Stenting

In coronary arteries, at the end of diastole and beginning of systole, there was a strong collision between the antegrade and retrograde flow, seen on CAGs as mixing of blood in white and contrast in black. In many cases, there was a sharp horizontal demarcation line suggestive of the high intensity of collision. This location was called the collision line and was where the majority of lesions were found (Fig. 6). This event could happen to every person even before birth; however in patients (i.e., years after birth) with high LDL cholesterol level, the injured area had enough material available to build up a plaque. The anatomy of the artery provided a favorable environment at a specific location - the collision line - for plaque development.

In the management of CAD, how does the interventional cardiologist (i.e., interventional anatomist) restore the natural anatomy of a coronary segment? The answer is the placement of a small wire mesh tube, or stent. The role of a stent is to crush the lesion and prop the artery open, thus restoring the anatomy of the original lumen in its radial axis. What happened to the flow after stenting of the mid RCA in patient show in Fig. 6? CAG documented restoration of the arterial lumen and laminar flow with a minimal boundary layer (Fig. 7). Thus, restoration of the natural anatomy removed the environment favorable for collision and cavitation.

In summary, stenting restored the anatomy and changed the flow pattern by: (1) moving the collision line distally, (2) creating less turbulent flow, (3) favoring less flow reversal, (4) producing more laminar flow. All of these 4 factors provide a less favorable environment for turbulence and jet waves and prevent formation of new plaques and the rupture of current plaques. The above effects were reinforced further with beta blockers and statin. This is the protective mechanism created by restoring the original *anatomy* by stenting, antiplatelet and anti-inflammatory medications.

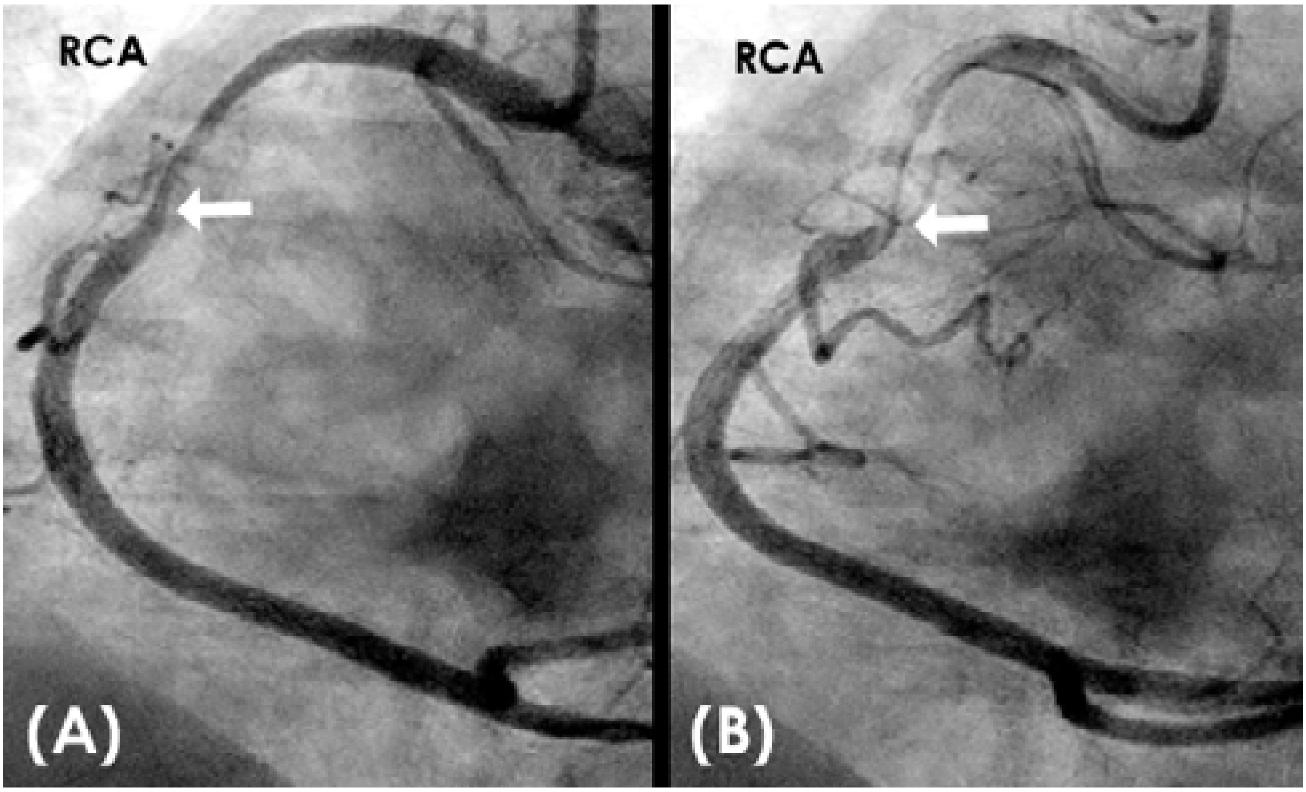

Fig. 6.- Right Coronary Angiogram and Collision Line. **(A)** There was a severe lesion (white arrow) in the mid-right coronary artery (RCA). Why did the lesion happen here, and not more proximally or more distally? **(B)** The reason was because the antegrade flow arrived at the mid RCA at the end of diastole and beginning of systole. There both antegrade and retrograde flows collided, causing shock wave and triggering the cavitation phenomenon. This location was called the collision line (arrow).

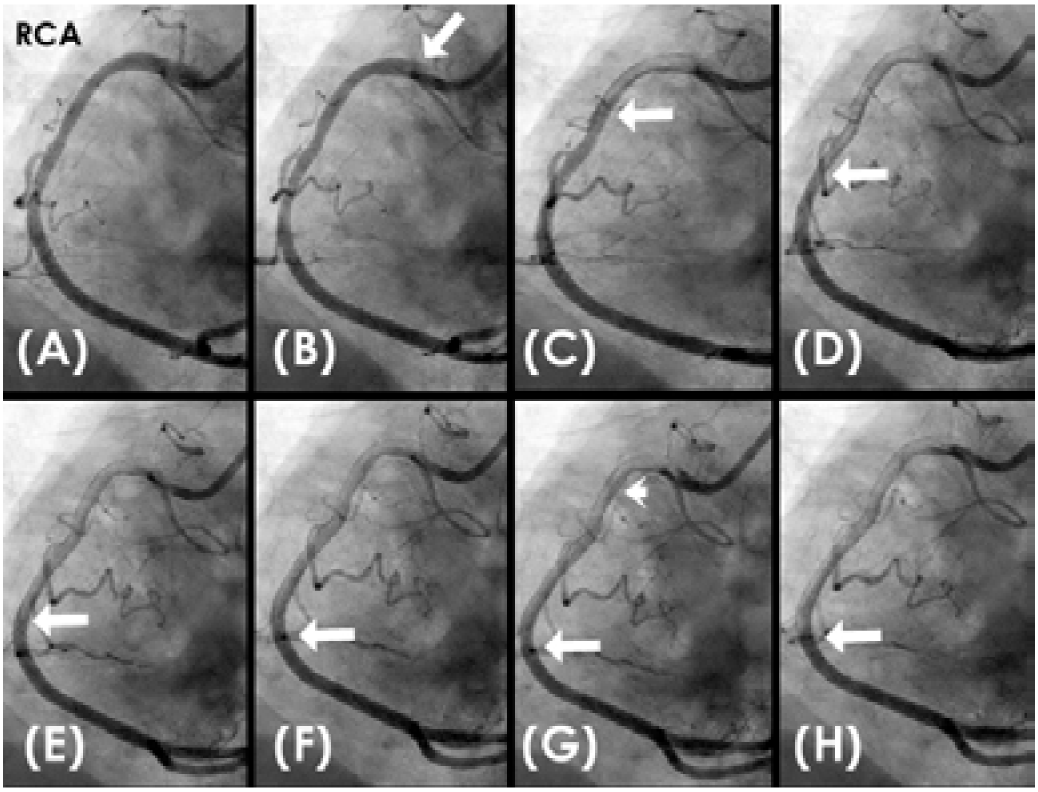

Fig. 7.- Right Coronary Angiogram after Stent Procedure. These images are continuously sequenced. **(A)** The right coronary artery (RCA) was completely filled with contrast (black) after stenting. **(B)** The blood (white) moved in at the ostial proximal segment of the RCA (arrow). **(C)** The blood now covered the proximal part of the mid-segment. The flow was laminar with a minimal boundary layer (arrow). **(D)** The blood (white) passed the collision line and reached the distal part of the mid-segment (arrow). **(E)** The blood in laminar flow almost reached the junction between the mid and the distal segment (arrow). **(F)** The blood could only advance minimally. This is the beginning of systole and the location of the collision line (arrow). **(G)** The blood (white) stayed in one place and there was some reversal of the flow (i.e., with more black contrast in the inner curve; arrowhead). **(H)** The blood now reached the junction of the mid and distal segment of the RCA with a sharp demarcation line. After stenting, the location where the antegrade and retrograde flow collided, was moved further distally (arrow).

ADVANCED INTERVENTIONS

Does Restoration of the Anatomy Restore Function?

In the care of patients with CAD, restoration of the natural ideal anatomy of the patient is the goal of interventional anatomy or cardiology. If the original anatomy is tortuous, because the metallic stent is somewhat straight and difficult to be bent, PCI may not perfectly restore the original curve (Fig. 8). This raises an interesting question for the cardiac patient. Does this new anatomy correct the ischemic problem and prevent future angina? In the case of a middle-aged patient (Fig. 8), the question of the correction of the lesion was that it changed the original anatomy. Was this correction acceptable and beneficial to patients? Based on the characteristics of flow dynamics and the extended time post-stenting (Fig. 8D), the answer is yes.

Does Intervention to Restore the Anatomy Correct the Functional Problem? The Detrimental Effect of Stenting.

In the spring of 2011, a young woman was seen because of recurrent angina. Her risk factor was smoking. CAG showed severe lesion in the mid left circumflex artery (LCX) and mild lesion in the right coronary artery (RCA) (Fig. 9). Her left main was special with a distal trifurcation to the left

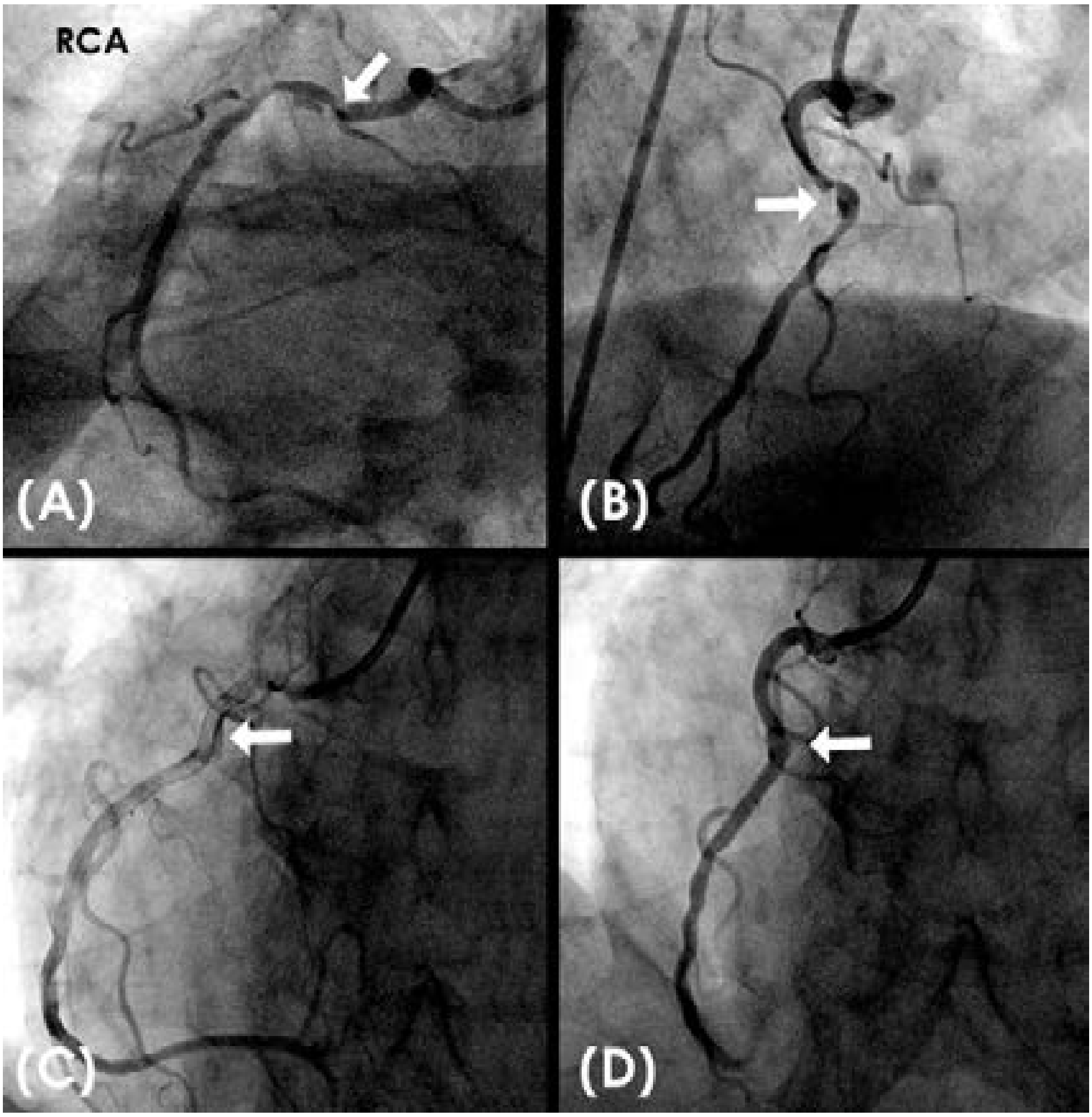

Fig. 8.- Right Coronary Angiogram before and after Stenting. **(A)** This is the right CAG (left anterior oblique caudal view) of a middle-aged man. There was a severe lesion in the proximal right coronary artery (RCA) (arrow). The segment was very tortuous. **(B)** The RCA in the right anterior oblique view. **(C)** After stenting, the curve of the angles was not as stiff. Blood (white) entered the RCA in laminar fashion (arrow). **(D)** This CAG is from the same patient 10 years after stenting. The patient did well; without recurrent chest pain.

anterior descending artery (LAD), a large ramus intermedius and the LCX (Fig. 9A, arrow). She successfully underwent stenting of the mid LCX. In 2020, the patient came back because of recurrent chest pain. She underwent a new CAG which showed severe disease in the ramus intermedius (Fig. 9C). Why did this occur if stenting restored the anatomy? The reason for this observation has not yet been well explained.

Extent of the Recirculation Flow

In the hemodynamics of coronary flow, after a bifurcation, specifically at the distal end of the left main (LM) artery, where the LM divided into the left anterior descending (LAD) and left circumflex arteries (LCX), blood tends to course through the larger branch with fewer curves.

Because the LAD was frequently the primary branch, less blood was available for the LCX. When the blood moved through the ostium of the LCX, the layers at the centerline would continue go forwards while the layers at the borders would for recirculation flow. This condition created turbulence and mixing between layers and formed a favorable environment for cavitation and plaque formation. Because beta blockers (BB) slowed the speed of the coronary flow, did BB decrease the incidence and the extent of recirculation flow? When evaluating the CAG in Fig. 10, the answer is yes.

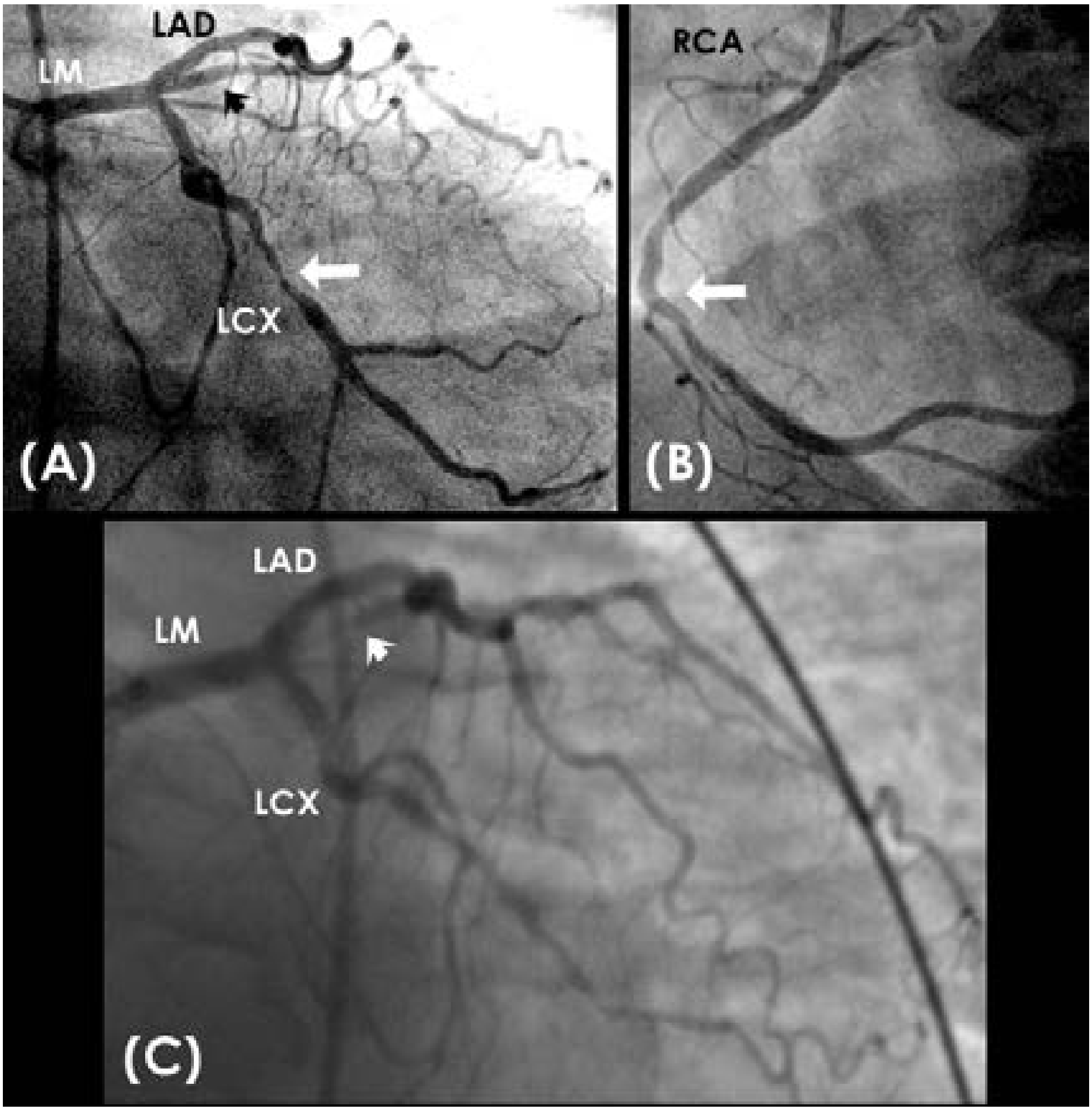

Fig. 9.- Coronary Angiograms. **(A)** The CAG of the left system in 2011 - left main (LM) left circumflex artery (LCX), left anterior descending artery and the ramus intermedius (t black arrow head) - before stenting of the LCX (arrow). **(B)** The CAG of the same patient of the right coronary artery (RCA) with 2 lesions (arrow). **(C)** CAG of the left system in March 2020. Besides the in-stent restenosis in the distal LCX, there was another important abnormality in the angiogram. The ramus intermedius had severe proximal disease (arrow head).

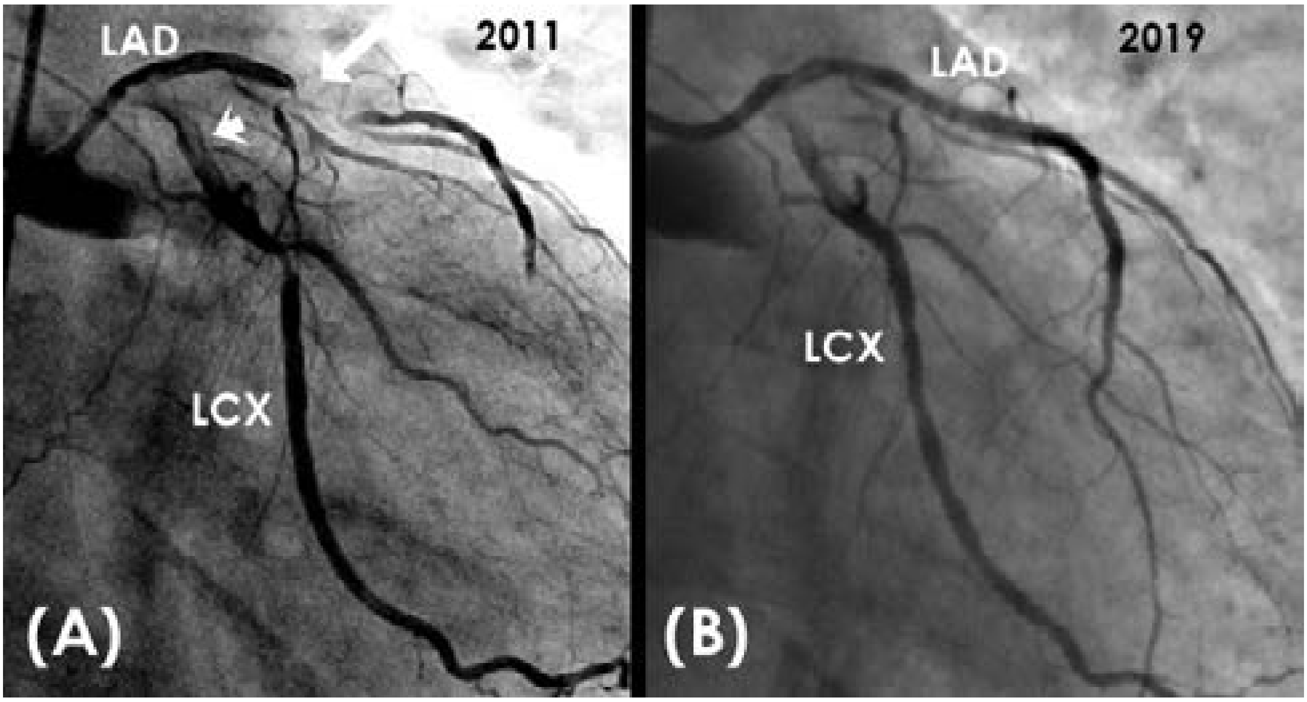

Fig. 10.- Restoration of Anatomy and Recirculation of Flow. **(A)** In 2011, a patient underwent stenting of the left anterior descending artery (LAD) (arrow). The flow to the left circumflex artery (LCX) showed the usual thick separation layer at the outer curve of the LCX, opposite to the carina (arrow head). Since the CAG of 2011, patient was treated with aspirin, statin and beta blockers. **(B)** In 2019, because of recurrent chest pain, the patient underwent stenting of the mid LCX. The stent in the LAD was patent. The separation layer in the proximal LCX was thinner and shorter, because the flow from the left main to the LCX was more organized. This is the benefit of beta blockers and anti-inflammatory drugs. In this case, the correct anatomy helps to keep patients healthy.

CONCLUSIONS

The application of hydraulic principles of fluid dynamics to blood flow in the coronary arterial system shows that the normal anatomy and anatomical variation of the arteries affect blood flow and that changes in the anatomy can result in the development of coronary lesions. The anatomy can be used to predict where lesions will form. Restoration of the natural anatomy of the coronary arteries results in blood flow that is more laminar, and less turbulent, and thus less likely to produce the cavitation phenomenon. This model extends beyond the coronary system to the peripheral arterial system.

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REFERENCES

ANBUMANI TL, DEEPTHI C, THAMARAI SELVI A, ANTHONY AMMAL S (2016) An anatomical study of the coronary arteries and their variations. *Int J Anat Res*, 4(1): 2114-2118.

BALLESTEROS LE, RAMIREZ ML, QUINTERO ID (2011) Right coronary artery anatomy: anatomical and morphometric analysis. Rev *Bras Cir Cardiovasc*, 26(2): 230-236.

BHIMALLI S, DIXI D, SIDDIBHAVI M, SHIROL VS (2011) A study of variations in coronary arterial system in cadaveric human hearts. *World J Sci Technol*, 1(5): 31-35.

BILLINGER M, SEILER C, FLEISCH M, EBERLI FR, MEIER B, HESS OM (2001) Do beta-adrenergic blocking agents increase coronary flow reserve. *J Am Coll Cardiol*, 38(7): 1866-1871.

BODEN WE, O'ROURKE RA, TEO KK, HARTIGAN PM, MARON DJ, KOSTUK WJ, KNUDTSON M, DADA M, CASPERSON P, HARRIS CL, CHAITMAN BR, SHAW L, GOSSELIN G, NAWAZ S, TITLE LM, GAU G, BLAUSTEIN AS, BOOTH DC, BATES ER, SPERTUS JA, BERMAN DS, MANCINI GB, WEINTRAUB WS, COURAGE Trial Research Group (2007) Optimal medical therapy with or without PCI for stable coronary disease. *N Engl J Med*, 356(15): 1503-1516.

DE LUCA G, DE BOER MJ, OTTERVANGER JP, VAN 'T HOF AW, HOORNTJE JC, GOSSELINK AT, DAMBRINK JH, SURYAPRANATA H (2005) Impact of beta-blocker therapy at discharge on long-term mortality after primary angioplasty for ST-segment elevation myocardial infarction. *Am J Cardiol*, 96(6): 806-809.

FAZLIOGULLARI Z, KARABULUT AK, ULVER DUGAN N, UYSAL II (2010) Coronary artery variations and median artery in Turkish cadaver hearts. *Singapore Med J*, 51(10): 775-780.

GACIONG Z, SIŃSKI M, LEWANDOWSKI (2013) Blood pressure control and primary prevention of stroke: summary of the recent clinical trial data and meta-analyses. *Curr Hypertens Rep*, 15(6): 559-574.

HÖRNSTEN C, WEIDUNG B, LITTBRAND H, CARLBERG B, NORDSTRÖM P, LÖVHEIM H, GUSTAFSON Y (2016) High blood pressure as a risk factor for incident stroke among very old people: a population-based cohort study. *J Hypertens*, 34(10): 2059-2065.

KALPANA R (2003) A study on principal branches of coronary arteries in humans. *J Anat Soc India*, 52(2): 137-140.

MOORE KL, DALLEY AF, AGUR AMR (2018) Clinically Oriented Anatomy, 8th edition. Wolters Kluwer, Alphen an den Rijn, Netherlands.

NGUYEN TN, Duy Chung, Luan Ngo, Loc Vu, Duy Nguyen, Hung N. Pham, Nhi Luong, Thao NP Vu, Beula Ben, Thinh Cao, Ernest Talarico, Gianluca Rigatelli (2021a) Methodist Hospital, Merrillville, IN, USA, Tan Tao University, Long An, Viet Nam Reversal of viscous effect in patients with ACS by statin and betablockers by regressed thickness and length of the boundary layers. Accepted for presentation at the *American College of Cardiology Scientific Meeting*, Atlanta, GA. Abstract ID. 12-A-19051-ACC.

NGUYEN TN, Luan Ngo, Duy Chung, Loc Vu, Thinh Cao, Nha Chau, Quan NM Le, Hung Pham, Thao NP Vu, Dzung Ho, Gianluca Rigatelli (2021b) Methodist Hospital, Merrillville, IN, USA, Tan Tao University, Long An, Viet Nam Protective mechanisms of betablockers in the prevention of acute myocardial infarction are by distal vasoconstriction and lower speed in proximal segment: A study by dynamic angiography and artificial intelligence program. Accepted for presentation at the *American College of Cardiology Scientific Meeting*, Atlanta, GA. Abstract ID. 12-A-19102-ACC.

NGUYEN VH, TALARICO JR EF (2018) A morphometric anatomical study of the division of the left main coronary artery and myocardial bridges. *Eur J Anat*, 22(4): 355-365.

NGUYEN VH, TALARICO JR EF (2019) A morphometric anatomical study of the right coronary artery in Vietnamese. *Eur J Anat*, 23(5): 341-353.

ORTALE JR, KEIRELLA LCB, CAMPINAS LS (2004) The posterior ventricular branches of the coronary arteries in the human heart. *Arqivos Brasileiros de Cardiologia*, 82(5): 468-472.

ORTALE JR, FILHO JM, PACCOLA AMF, LEAL JGPG, SCARANARI CA (2005) Anatomy of the lateral, diagonal and anterosuperior arterial branches of the left ventricle of the human heart. *BJCVS/RBCCV*, 20(2): 149-158.

SU D, WANG K, QIN S, PANG Y (2014) Safety and efficacy of warfarin plus aspirin combination therapy for giant coronary artery aneurysm secondary to Kawasaki disease: a meta-analysis. *Cardiology*,129(1): 55-64.

SECTION 2

ANATOMY EDUCATON IN THE NEW ERA OF ANATOMY AND DURING AND AFTER THE COVID-19 PANDEMIC.

Anatomical dissection and Medical Education: a systematic review of literature

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SUMMARY

Today, the place of anatomical dissection (AD), the former "gold standard" of anatomy teaching is largely debated in medical education due to various factors (i.e. new and attractive pedagogical tools, changes in academic medical curricula, shortage of bodies). The aim of this study was to assess the current place of AD in both undergraduate students' curriculum and more generally in medical education, and to evaluate both the students' perception and the effectiveness of AD compared to other teaching techniques, by means of a review of literature.

A systematic research was conducted using the electronic databases of PubMed and various publishers with combinations of the relevant MeSH terms. A manual research was added.

Considerable variation in the place of AD in undergraduate students' curriculum was identified according to the studies. The use of AD was also reported in various postgraduate training programs and numerous anatomical research projects.

Students' perceptions regarding AD were largely positive in the vast majority of the surveys. Objective evaluations were rarer but globally positive. A striking finding was the concept of the "silent mentor" or "first teacher" suggesting the strong impact of AD as the first step of medical practice and ethics.

Despite an indubitable regression in most of undergraduate students' curricula, AD still stands out as an unparalleled pedagogical tool in medical education in the light of literature. By combination of AD with various other educational methods, its place should be adapted according to the specific conditions of each institution and purpose.

Key words: Anatomy – Dissection – Body – Cadaver – Medical Education – Teaching – Learning – Undergraduate Medical Education – Postgraduate Education – Ethics

ABBREVIATIONS

AD: anatomical dissection

3D: three dimensional

CT: computed tomography

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INTRODUCTION

For centuries, anatomical dissection (AD) has been considered the gold standard of anatomy education in most countries (Ghosh, 2015). Initially practiced in the first half of the 3rd century BC, AD was the dominant means of learning anatomy in ancient Greece, and after a total disappearance in the Middle ages, revived in the early 14th century Italy in spite of various taboos, and spread progressively to many other countries, standing as an indispensable tool for a sound knowledge of the human body anatomy (Fig. 1). In particular, AD allowed to correct many previous errors based on animal dissections and blind faith on ancient authoritative books.

Today, this place is largely debated (Marom, 2020) for three main reasons: dramatic changes in most academic medical curricula (Kim et al., 2019), emergence of numerous new and attractive teaching techniques (Iwanaga et al., 2021), shortage of bodies (Chen et al., 2018), or specific (religious, ethical, legal, emotional) issues with them (Gürses et al., 2018).

As a result, many questions arise. For some of them, parts of answers may be found by means of a review of the literature. Among them, four questions seemed essential:

-1. What is the current place of AD in undergraduate students' curriculum today?

-2. What about an objective evaluation of the effectiveness of AD when compared to other teaching techniques?

-3. What about the students' perceptions of AD?

-4. In the light of literature, is AD limited to anatomical teaching in the field of medical education?

In order to attempt to answer these questions, a systematic review of literature was carried out over the last five years.

Fig 1.- Andreas Vesalius demonstrating cadaveric dissection before his students in Padua. Image in public domain. *"Vesalius and the anatomy of man"*, by Robert Thom.

MATERIALS AND METHODS

Search strategy

A systematic search was conducted using the electronic databases of PubMed, ScienceDirect and various publishers.

The search was performed to include publications from January 2016 up to December 2020 with various combinations of the following key words: "Anatomy", "Dissection", "Body", "Cadaver", "Education", "Undergraduate Medical Education", "Postgraduate Medical Education", "Teaching", "Learning", "Ethics".

The results of a manual search of assumed pertinent articles obtained from the reference list of the selected publications were added to the electronic search, yielding further references. Reports in the grey literature were not pursued.

Selection of studies

Articles were reviewed for relevance, carefully examined, and references of pertinent papers were hand-traced in the limit of up to 100.

RESULTS

1. Place of AD in undergraduate students' curriculum today

Although anatomical sciences retain an important place in medical education in several countries (Drake et al., 2014; Salinas-Alvarez et al., 2020), the general decrease of the time devoted to anatomy teaching in general and AD in particular is reported by numerous authors all around the world (Estai and Bunt, 2016; Eppler et al., 2018; Houser and Kondrashov, 2018; Kim et al., 2019; Zhang et al., 2019; Abdellatif, 2020; Oktem et al., 2020; Rockarts et al., 2020). In addition, in some countries, shortage of cadavers or difficulties in body procurement have been emphasized by the authors (Chen et al., 2018; Gürses et al., 2018). These difficulties in body procurement may be due to religious, educational, legal, ethical, or socio-economic factors (Oktem et al., 2020). Moreover, the increasing number of medical students may also sometimes result in crowding in the dissection room, adding a supplementary barrier for AD (Kim et al., 2019).

In fact, the most striking finding is the considerable variation regarding the organization of AD (including the time allocation, content delivery and assessment method), often reflecting the various strategies, including novel dissection approaches, that have been adopted to overcome these impediments (Pais et al., 2017; Hlavac et al., 2018; Hu et al., 2018; Bellier et al., 2019; Kim et al., 2019; Cotofana et al., 2020; Cotofana and Lachman, 2020; Hunter et al., 2020; Sotgiu et al., 2020). In numerous horizontal or vertical integrated curricula, AD was included according to various modalities (Hlavac et al., 2018; Houser and Kondrashov; 2018; Hunter et al., 2020; Eppler et al., 2018; Estai and Bunt, 2016; Abdellatif, 2020).

2. Effectiveness of AD on anatomic knowledge retention versus other teaching methods

Several studies showed that practicing dissection helps students to achieve higher results than learning using only models and prosections (Abdellatif, 2020), or models, prosected human material, and medical imaging (Huynh et al., 2021).

However, an objective evaluation of the effectiveness of dissection on anatomic knowledge retention was far to be systematically available for each paper on the one hand, and on the other hand, the results of some studies were contradictory: a meta-analysis conducted on studies published between January 1965 and December 2015 and itself published in 2018 showed no difference between AD and alternative instructional modalities (Wilson et al., 2018a).

Comparison of students' performance after prosection versus dissection gave also different results (Williams et al., 2019, Lackey-Cornelison et al., 2020).

Besides, according to some studies, other important factors should be taken into account, such as the repetition activity (in any form), and the prior anatomy and /or clinical experience.

According to Koolos (Kooloos et al., 2020), the repetition of anatomical information is the main factor on knowledge retention, both immediately following the activity and in the long term, whereas the type of repetition activity itself has no effect on both of them. According to Lackey-Cornelison (Lackey-Cornelison et al., 2020) the prior anatomy experience is also an important factor. In addition, according to Schultz (Schulz, 2017), the importance of clinical experience must also be taken into account.

3. **Students' perceptions**

Despite the important heterogeneity of the curricula, and a various amount of anxiety (Chang et al., 2018; Romo Barrientos et al., 2019), outcomes of AD in various multimodal courses, were almost constantly considered positive by the students (Estai and Bunt, 2016; Pais et al., 2017; Eppler et al., 2018; Flack and Nicholson, 2018; Houser and Kondrashov, 2018; Kim et al., 2019; Sotgiu et al., 2020). "AD was conveyed as an appropriate and valuable education tool useful for learning and teaching anatomical knowledge "(Flack and Nicholson, 2018); a vast majority of students considered "that dissection practices were more useful than theoretical models" (Romo- Barrientos et al., 2019).

"A Silent mentor"

Beyond the anatomical knowledge, an unparalleled dimension of AD that was revealed by the analysis of these papers is its huge impact in the field of ethical behavior and humanistic attitudes. "Not only a specimen", "the silent mentor ", "cadaver as a first teacher" are the most striking expressions used by several studies that emphasized the major role of AD in the field, including teaching of professionalism, respect and human dignity (Talarico, 2013; Ghosh, 2017; Hasselblatt et al., 2018; Goss et al., 2019; Souza et al., 2020). The importance of anatomy, and more specifically of AD, in this respect has been investigated by several studies and must be kept in mind, as well as the role of memorial funeral ceremonies, other memorial services, and the impact of donor dissection on priming students' focus on medical ethics (Jones and King, 2017; Chang et al., 2018; Stephens et al., 2019; Ghosh, 2020; Holland et al., 2021; Smith et al., 2020). Sharing personal information about the donor and interacting with his/her family has also been highlighted as an important change in paradigm of teaching in the anatomy laboratory, offering to the students improvement of their skills and attitudes with regard to their future profession and their future patients (Talarico, 2013).

4. **In the light of literature, is AD limited to anatomy teaching for undergraduate students?**

Postgraduate courses

Unsurprisingly, it turned out that AD has also been evaluated in postgraduate courses. In addition, AD were frequently carried out to improve the anatomical knowledge on very various topics.

Of course, the value of AD for surgical training has been highlighted by several studies (Estai and Bunt, 2016; Krähenbühl et al., 2017; Hu et al., 2018; Selcuk et al., 2019).

As a specific example, in the field of eye and orbital anatomy and surgery, the benefit of a dissection-based anatomy course has been evaluated in both undergraduate and postgraduate participants, showing the value of clinical practice (Schulz, 2017).

Besides surgical purposes, improvement of anatomical knowledge may also be required for various postgraduate physicians, such as rheumatologists practicing musculoskeletal ultrasonography. The effectiveness of combined human cadaveric dissection and musculoskeletal sonoanatomy has been investigated, regarding the rotator cuff region, knee tendons and muscles not adjacent to joints (Manghani et al., 2020).

Improvement of anatomical knowledge

In the light of numerous publications, it turned out that the AD may still improve the anatomical knowledge in very various fields. The table 1 provides some examples of topics (between others) on which we are learning new things thanks to AD.

Most of these anatomical studies were specifically designed for an anatomical topic, sometimes with a very specialized surgical purpose (Henry et al., 2017; Mojallal and Cotofana, 2017; Negm et al., 2018; Cotofana et al., 2019; Schwam et al., 2020; Shofoluwe et al., 2021).

In some studies, the data of AD were combined with imaging techniques, such as computed tomography (CT) scan (Cases et al., 2017; Tardo et al., 2017; Cotofana and Lachman, 2019), CT scan and magnetic resonance imaging (Schenck et al., 2018), or sonography (Czyrny et al., 2019).

Less frequently, the publications were the result of routine dissections (Eid et al., 2018; Lake et al., 2018; Darvishi and Moayeri, 2019).

Integrating pathology during anatomy dissection

In addition to anatomy education, it has also been suggested to combine pathology education during anatomical dissections since a wide variety of pathology lesions have been demonstrated in bodies used for

Table 1. Examples of recent improvement of anatomical knowledge thanks to AD.

	Topic	Reference
Neuroanatomy		
	sledge runner fasciculus	(Koutsarnakis et al., 2019)
	medial temporal lobe	(Patra et al., 2018)
Head and neck		
	branches of the facial artery	(Bhattacharya et al., 2020)
	course of the facial nerve	(Kalaiarasi et al., 2018)
	scalenovertebral triangle	(Singal et al., 2020a)
	variability of oval window	(Singal et al., 2020b)
Limbs		
	susbcapular vessels	(Lhuaire et al., 2019)
	axillary arch	(Lhuaire et al., 2020)
	pulley system of the thumb	(Gnanasekaran et al., 2018)
	superficial palmar arch	(Gnanasekaran and Veeramani, 2019)
	middle cluneal nerve entrapment	(Konno et al., 2017)
	musculocutaneous nerve and coracoid process	(Singh et al., 2020)
	layered anatomy of the dorsum of the foot	(Custozzo et al., 2020)
Chest		
	right coronary artery	(Nguyen and Talarico, 2019)
	left coronary artery and myocardial bridges	(Nguyen and Talarico, 2019)
	sternalis muscle	(Sonne, 2020)
	attachments of the breast to the chest wall	(Gaskin et al., 2020)
	relationship of the lateral costotransverse ligament and the dorsal root ganglion	(D'Antoni et al., 2018)
Abdomen		
	vermiform appendix	(Nayak and Soumya, 2019)
	left gastroepiploic artery	(Kumar et al., 2019)
	rare variations of the hepatic biliary system	(Garg et al., 2019)
	portal vein	(Nayak, 2019)
	mesenteric arteries	(Manyama et al., 2019)

medical dissection (Geldenhuys et al., 2016). In several countries, it has been proposed to combine imaging and pathology education by systematic postmortem imaging during academic anatomical dissection (Noriki et al., 2019).

DISCUSSION

Today, a myriad of teaching tools are available in the field of anatomical education in addition to the two traditional keystones, i.e. in-person lectures based on drawings and cadaveric dissection (Iwanaga et al., 2021). Among them, prosection (i.e. inspection of prosected specimens) (Talarico, 2010; Williams et al., 2019) and plastination (Chytas et al., 2019) are the closest to AD. In parallel, various 3D models (Bannon et al., 2018; Bartikian et al., 2019; Chytas et al., 2020) have been developed. Living anatomy and medical imaging (Grignon, 2012; Grignon et al., 2012; Grignon et al., 2016) offer the great advantage to be close to the practice of future physicians. Computed-based learning methods are due to the general dramatic improvements in information technology, the attractiveness and popularity of which has been highlighted (Iwanaga et al., 2021). They include virtual reality and augmented reality (Bork et al., 2019; Romand et al., 2020), virtual dissection (Boscolo-Berto et al., 2020), various e-applications for three- dimensional anatomy education (Zilverschoon et al., 2019), such as 3D stereoscopy (Bernard et al., 2020), or stereoscopic 3-dimensional visualisation (Jacquesson et al., 2020). Active learning techniques are learner-centered methods including flipped classrooms, problem-based, team- based, and case-based learning (Bell et al., 2019). Social media learning has also been cited and evaluated (Barry et al., 2016).

At the same time, exponential expansion of medical knowledge, increasing numbers of medical students, recurrent changes in medical curricula and national guidelines has generally reduced the time devoted to anatomy education in most countries throughout the world, favoring the choice of more attractive and “modern” teaching tools.

However, numerous combinations of traditional and technological pedagogical methods have been reported and evaluated, often showing a significant improvement of medical students learning outcomes (Boscolo-Berto et al., 2020). These combinations are recommended by several authors (Estai and Bunt, 2016; Carter et al., 2017; Eppler et al., 2018; Houser and Kondrashov, 2018; Wilson et al., 2018b). In parallel, the particular benefit of connections between routine dissection and medical imaging techniques allowing to create two-dimensional axial images and then interactive 3D models from anatomical dissections has also been reported and emphasized (Moore et al., 2017).

CONCLUSIONS

Despite an indubitable regression in most of undergraduate students’ curricula, AD still stands as an unparalleled pedagogical tool in medical education in the light of literature. Not limited to anatomical education of undergraduate students, AD offers them the opportunity of a first humanistic approach, and may also be of great interest for postgraduate students or seasoned physicians. By combination of AD with various other educational methods, its place should be adapted according to the specific conditions of each institution and each purpose.

REFERENCES

ABDELLATIF H (2020) Time spent in practicing dissection correlated with improvement in anatomical knowledge of students: experimental study in an integrated learning program. *Cureus*, 12(4).

BANNON R, PARIHAR S, SKARPARIS Y, VARSOU O, CEZAYIRLI E (2018) 3D printing the pterygopalatine fossa: a negative space model of a complex structure. *Surg Radiol Anat*, 40(2): 185-191.

BARRY DS, MARZOUK F, CHULAK-OGLU K, BENNETT D, TIERNEY P, O’KEEFFE GW (2016) Anatomy education for the YouTube generation. *Anat Sci Educ*, 9(1): 90-96.

BARTIKIAN M, FERREIRA A, GONÇALVES-FERREIRA A, NETO LL (2019) 3D printing anatomical models of head bones. *Surg Radiol Anat*, 41(10): 1205-1209.

BELL FE, 3RD, NEUFFER FH, HADDAD TR, EPPS JC, KOZIK ME, WARREN BC (2019) Active learning of the floor of mouth anatomy with ultrasound. *Anat Sci Educ*, 12(3): 310-316.

BELLIER A, CAVALIE G, MASSON P, PALOMBI O, CHAFFANJON P (2019) Feedback on the usefulness of an illustrated guidebook in an anatomical dissection course. *Surg Radiol Anat*, 41(10): 1173-1179.

BERNARD F, RICHARD P, KAHN A, FOURNIER HD (2020) Does 3D stereoscopy support anatomical education? *Surg Radiol Anat*, 42(7): 843-852.

BHATTACHARYA A, SHARMA R, ARMSTRONG C, SOLIS L (2020) Case report of unique anastomosis between facial and inferior alveolar arteries. *Surg Radiol Anat*, 42(5): 603-606.

BORK F, STRATMANN L, ENSSLE S, ECK U, NAVAB N, WASCHKE J, KUGELMANN D (2019) The benefits of an augmented reality magic mirror system for integrated radiology teaching in gross anatomy. *Anat Sci Educ*, 12(6): 585-598.

BOSCOLO-BERTO R, TORTORELLA C, PORZIONATO A, STECCO C, PICARDI EEE, MACCHI V, DE CARO R (2020) The additional role of virtual to traditional dissection in teaching anatomy: a randomised controlled trial. *Surg Radiol Anat*, doi: 10.1007/s00276-020-02551-2.

CARTER JL, PATEL A, HOCUM G, BENNINGER B (2017) Thyroid gland visualization with 3D/4D ultrasound: integrated hands-on imaging in anatomical dissection laboratory. *Surg Radiol Anat*, 39(5): 567-572.

CASES C, GARCÍA-ZOGHBY L, MANZORRO P, VALDERRAMA-CANALES FJ, MUÑOZ M, VIDAL M, SIMÓN C, SANUDO JR, MCHANWELL S, ARRAZOLA J (2017) Anatomical variations of the renal arteries: Cadaveric and radiologic study, review of the literature, and proposal of a new classification of clinical interest. *Ann Anat*, 211: 61-68.

CHANG HJ, KIM HJ, RHYU IJ, LEE YM, UHM CS (2018) Emotional experiences of medical students during cadaver dissection and the role of memorial ceremonies: a qualitative study. *BMC Med Educ*, 18(1): 255.

CHEN D, ZHANG Q, DENG J, CAI Y, HUANG J, LI F, XIONG K (2018) A shortage of cadavers: The predicament of regional anatomy education in mainland China. *Anat Sci Educ*, 11(4): 397-402.

CHYTAS D, PIAGKOU M, JOHNSON EO, TSAKOTOS G, MAZARAKIS A, BABIS GC, NIKOLAOU VS, KASETA MK, NATSIS K (2019) Outcomes of the use of plastination in anatomy education: current evidence. *Surg Radiol Anat*, 41(10): 1181-1186.

CHYTAS D, JOHNSON EO, PIAGKOU M, TSAKOTOS G, BABIS GC, NIKOLAOU VS, MARKATOS K, NATSIS K (2020) Three-dimensional printing in anatomy teaching: current evidence. *Surg Radiol Anat*, 42(7): 835-841.

COTOFANA S, GAVRIL DL, FRANK K, SCHENCK TL, PAWLINA W, LACHMAN N (2020) Revisit, reform, and redesign: a novel dissection approach for demonstrating anatomy of the orbit for continuing professional development education. *Anat Sci Educ*, 29(10). doi: 10.1002/ase.2006.

COTOFANA S, GOTKIN RH, FRANK K, KOBAN KC, TARGOSINSKI S, SYKES JM, SCHLAGER M, SCHLATTAU A, SCHENCK TL (2019) The functional anatomy of the deep facial fat compartments: a detailed imaging-based investigation. *Plast Reconstr Surg*, 143(1): 53-63.

COTOFANA S, LACHMAN N (2019) Arteries of the face and their relevance for minimally invasive facial procedures: an anatomical review. *Plast Reconstr Surg*, 143(2): 416-426.

COTOFANA S, LACHMAN N (2020) The superficial face dissection as an example for integrating clinical approaches, authentic learning, and changing perspectives in anatomy dissection. *Anat Sci Educ*, 13(1): 117-121.

CUSTOZZO A, FRANK K, SCHENCK TL, GOTKIN RH, SMITH MP, GREEN JB, SYKES J, TAMURA B, LACHMAN N, COTOFANA S (2020) Anatomy of the dorsum of the foot and its relevance for nonsurgical cosmetic procedures. *Plast Reconstr Surg*, 146(1): 64-72.

CZYRNY Z, KORDASIEWICZ B, KICIŃSKI M, BRZOZOWSKA M (2019) Macroscopic and ultrasonographic anatomy of the rotator cuff layers. *J Ultrason*, 19(77): 120-124.

D'ANTONI AV, COLLIN PG, GRAHAM RA, KENNEDY HM, NDJATOU T, PEREZ P, TUBBS RS, LOUKAS M, KOZLOWSKI PB, MTUI EP (2018) Surgical relevance of the lateral costotransverse ligament in relation to the dorsal root ganglion. *Anat Sci Int*, 93(1): 108-113.

DARVISHI M, MOAYERI A (2019) Anatomical variations of the musculocutaneous and median nerves: a case report. *Folia Med (Plovdiv)*, 61(2): 327-331.

DRAKE RL, MCBRIDE JM, PAWLINA W (2014) An update on the status of anatomical sciences education in United States medical schools. *Anat Sci Educ*, 7(4): 321-325.

EID S, IWANAGA J, OSKOUIAN RJ, LOUKAS M, TUBBS RS (2018) Bifid xiphoid process: case report and review. *Cureus*, 10(8): e3153.

EPPLER E, SEROWY S, LINK K, FILGUEIRA L (2018) Experience from an optional dissection course in a clinically-orientated concept to complement system-based anatomy in a reformed curriculum. *Anat Sci Educ*, 11(1): 32-43.

ESTAI M, BUNT S (2016) Best teaching practices in anatomy education: A critical review. *Ann Anat*, 208: 151-157.

FLACK N, NICHOLSON HD (2018) What do medical students learn from dissection? *Anat Sci Educ*, 11(4): 325-335.

GARG S, KUMAR H, SAHNI D, YADAV TD, AGGARWAL A, GUPTA T (2019) Rare anatomic variations of the right hepatic biliary system. *Surg Radiol Anat*, 41(9): 1087-1092.

GASKIN KM, PEOPLES GE, MCGHEE DE (2020) The attachments of the breast to the chest wall: a dissection study. *Plast Reconstr Surg*, 146(1): 11e-22e.

GELDENHUYS EM, BURGER EH, VAN HELDEN PD, MOLE CG, KOTZÉ SH (2016) Optimizing the use of cadavers by integrating pathology during anatomy dissection. *Anat Sci Educ*, 9(6): 575-582.

GHOSH SK (2015) Human cadaveric dissection: a historical account from ancient Greece to the modern era. *Anat Cell Biol*, 48(3): 153-169.

GHOSH SK (2017) Paying respect to human cadavers: We owe this to the first teacher in anatomy. *Ann Anat*, 211: 129-134.

GHOSH SK (2020) The practice of ethics in the context of human dissection: Setting standards for future physicians. *Ann Anat*, 232: 151577.

GNANASEKARAN D, VEERAMANI R (2019) Newer insights in the anatomy of superficial palmar arch. *Surg Radiol Anat*, 41(7): 791-799.

GNANASEKARAN D, VEERAMANI R, KARUPPUSAMY A (2018) Topographic anatomical landmarks for pulley system of the thumb. *Surg Radiol Anat*, 40(9): 1007-1012.

GOSS AL, VISWANATHAN VB, DELISSER HM (2019) Not just a specimen: a qualitative study of emotion, morality, and professionalism in one medical school gross anatomy laboratory. *Anat Sci Educ*, 12(4): 349-359.

GRIGNON B (2012) Anatomy and medical imaging: a symbiotic relationship. *Surg Radiol Anat*, 34(8): 673-674.

GRIGNON B, MAINARD L, DELION M, HODEZ C, OLDRINI G (2012) Recent advances in medical imaging: anatomical and clinical applications. *Surg Radiol Anat*, 34(8): 675-686.

GRIGNON B, OLDRINI G, WALTER F (2016) Teaching medical anatomy: what is the role of imaging today? *Surg Radiol Anat*, 38(2): 253-260.

GÜRSES İ A, COŞKUN O, ÖZTÜRK A (2018) Current status of cadaver sources in Turkey and a wake-up call for Turkish anatomists. *Anat Sci Educ*, 11(2): 155-165.

HASSELBLATT F, MESSERER DAC, KEIS O, BÖCKERS TM, BÖCKERS A (2018) Anonymous body or first patient? A status report and needs assessment regarding the personalization of donors in dissection courses in German, Austrian, and Swiss Medical Schools. *Anat Sci Educ*, 11(3): 282-293.

HENRY BM, SANNA B, VIKSE J, GRAVES MJ, SPULBER A, WITKOWSKI C, TOMASZEWSKA IM, TUBBS RS, TOMASZEWSKI KA (2017) Zuckerkandl's tubercle and its relationship to the recurrent laryngeal nerve: A cadaveric dissection and meta-analysis. *Auris Nasus Larynx*, 44(6): 639-647.

HLAVAC RJ, KLAUS R, BETTS K, SMITH SM, STABIO ME (2018) Novel dissection of the central nervous system to bridge gross anatomy and neuroscience for an integrated medical curriculum. *Anat Sci Educ*, 11(2): 185-195.

HOLLAND JC, NÍ DHÓNAILL R, CLARKE M, JOYCE P (2021) Physician associate students' experience of anatomy dissection. *Anat Sci Educ*, 14(1): 52-61.

HOUSER JJ, KONDRASHOV P (2018) Gross anatomy education today: the integration of traditional and innovative methodologies. *Mo Med*, 115(1): 61-65.

HU M, WATTCHOW D, DE FONTGALLAND D (2018) From ancient to avant-garde: a review of traditional and modern multimodal approaches to surgical anatomy education. *ANZ J Surg*, 88(3): 146-151.

HUNTER LD, MOSLEY CF, QUINN MM, CRAY JJ, JR., BAKER AS, BURGOON JM, KALMAR E, MCHUGH KM (2020) A novel approach to gross dissection of the human pelvis and perineum. *Anat Sci Educ*, 13(5): 618-627.

HUYNH N, BURGESS A, WING L, MELLIS C (2021) Anatomy by whole body dissection as an elective: student outcomes. *J Surg Educ*, 78(2): 492-501.

IWANAGA J, LOUKAS M, DUMONT AS, TUBBS RS (2021) A review of anatomy education during and after the COVID-19 pandemic: Revisiting traditional and modern methods to achieve future innovation. *Clin Anat*, 34(1): 108-114.

JACQUESSON T, SIMON E, DAULEAC C, MARGUERON L, ROBINSON P, MERTENS P (2020) Stereoscopic three-dimensional visualization: interest for neuroanatomy teaching in medical school. *Surg Radiol Anat*, 42(6): 719-727.

JONES DG, KING MR (2017) Maintaining the anonymity of cadavers in medical education: Historic relic or educational and ethical necessity? *Anat Sci Educ*, 10(1): 87-97.

KALAIARASI R, KIRAN AS, VIJAYAKUMAR C, VENKATARAMANAN R, MANUSRUT M, PRABHU R (2018) Anatomical features of intratemporal course of facial nerve and its variations. *Cureus*, 10(8): e3085.

KIM DH, SHIN DH, HWANG YI (2019) Effects of alternate dissection on anatomy learning. *Anat Cell Biol*, 52(1): 69-75.

KONNO T, AOTA Y, SAITO T, QU N, HAYASHI S, KAWATA S, ITOH M (2017) Anatomical study of middle cluneal nerve entrapment. *J Pain Res*, 10: 1431-1435.

KOOLOOS JGM, BERGMAN EM, SCHEFFERS M, SCHEPENS-FRANKE AN, VORSTENBOSCH M (2020) The effect of passive and active education methods applied in repetition activities on the retention of anatomical knowledge. *Anat Sci Educ*, 13(4): 458-466.

KOUTSARNAKIS C, KALYVAS AV, SKANDALAKIS GP, KARAVASILIS E, CHRISTIDI F, KOMAITIS S, VELONAKIS G, LIAKOS F, EMELIFEONWU J, GIAVRI Z, KALAMATIANOS T, KELEKIS N, STRANJALIS G (2019) Sledge runner fasciculus: anatomic architecture and tractographic morphology. *Brain Struct Funct*, 224(3): 1051-1066.

KRÄHENBÜHL SM, ČVANČARA P, STIEGLITZ T, BONVIN R, MICHETTI M, FLAHAUT M, DURAND S, DEGHAYLI D, APPLEGATE LA, RAFFOUL W (2017) Return of the cadaver: Key role of anatomic dissection for plastic surgery resident training. *Medicine*, 96(29): e7528.

KUMAR N, AITHAL AP, GURU A (2019) Unusual duplication and vulnerable intrapancreatic course of the left gastroepiploic artery: a rare anatomical variation. *Surg Radiol Anat*, 41(3): 351-353.

LACKEY-CORNELISON WL, BAULER LD, SMITH J (2020) A comparison of the effectiveness of dissection and prosection on short-term anatomic knowledge retention in a reciprocal peer- teaching program. *Adv Physiol Educ*, 44(2): 239-246.

LAKE S, IWANAGA J, OSKOUIAN RJ, LOUKAS M, TUBBS RS (2018) A case report of an enlarged suboccipital nerve with cutaneous branch. *Cureus*, 10(7): e2933.

LHUAIRE M, HIVELIN M, DERDER M, HUNSINGER V, DELMAS V, ABRAHAMS P, SOMMACALE D, KIANMANESH R, FONTAINE C, LANTIERI L (2019) Anatomical variations of the subscapular pedicle and its terminal branches: an anatomical study and a reappraisal in the light of current surgical approaches. *Surg Radiol Anat*, 41(4): 385-392.

LHUAIRE M, WEHBE K, GARRIDO I, HUNSINGER V, DERDER M, BALAYA V, DELMAS V, ABRAHAMS P, SOMMACALE D, KIANMANESH R, FONTAINE C, LANTIERI L (2020) Anatomy of the axillary arch: from its incidence in human to an embryologic and a phylogenetic explanation of its origins. *Surg Radiol Anat*, doi: 10.1007/s00276-020-02605-5.

MANGHANI M, CHEUNG PP, MOGALI SR, PRAKASH A, CHEW LC (2020) An evaluation of the effectiveness of teaching anatomy to rheumatologists through combined musculoskeletal sonoanatomy and human cadaveric dissection. *Rheumatol Adv Pract*, 4(1): rkaa010.

MANYAMA M, MALYANGO A, RAOOF A, MLIGILICHE NL, MSUYA C, NASSIR N, MTUI E (2019) A variant source of arterial supply to the ascending, transverse and descending colon. *Surg Radiol Anat*, 41(11): 1383-1386.

MAROM A (2020) The birth, death, and renaissance (?) of dissection: a critique of anatomy teaching with-or without-the human body. *Acad Med*, 95(7): 999-1005.

MOJALLAL A, COTOFANA S (2017) Anatomy of lower eyelid and eyelid-cheek junction. *Ann Chir Plast Esthet*, 62(5): 365-374.

MOORE CW, WILSON TD, RICE CL (2017) Digital preservation of anatomical variation: 3D- modeling of embalmed and plastinated cadaveric specimens using uCT and MRI. *Ann Anat*, 209: 69-75.

NAYAK SB (2019) Variant termination of first and second jejunal veins into a "pancreatic portal vein". *Surg Radiol Anat*, 41(3): 347-349.

NAYAK SB, SOUMYA KV (2019) "Anterior appendix": a boon for clinicians and radiologists. *Surg Radiol Anat*, 41(11): 1387-1389.

NEGM HM, SINGH H, DHANDAPANI S, COHEN S, ANAND VK, SCHWARTZ TH (2018) Landmarks to identify petrous apex through endonasal approach without transgression of sinus. *J Neurol Surg B Skull Base*, 79(2): 156-160.

NGUYEN VH, TALARICO EF (2019) A morphometric anatomical study of the right coronary artery in Vietnamese. *Eur J Anat*, 23: 341-353.

NORIKI S, IINO S, KINOSHITA K, FUKAZAWA Y, INAI K, SAKAI T, KIMURA H (2019) Pathological analysis of cadavers for educational dissection by using postmortem imaging. *Pathol Int*, 69(10): 580-600.

OKTEM H, PELIN C, KURKCUOGLU A, YILDIRIM RV, YAZICI GUVERCIN AC (2020) Attitudes of Turkish university employees and their relatives towards whole body and organ donation. *Ann Anat*, 229: 151426.

PAIS D, CASAL D, MASCARENHAS-LEMOS L, BARATA P, MOXHAM BJ, GOYRI-O'NEILL J (2017) Outcomes and satisfaction of two optional cadaveric dissection courses: A 3-year prospective study. *Anat Sci Educ*, 10(2): 127-136.

PATRA DP, TEWARI MK, SAHNI D, MATHURIYA SN (2018) Microsurgical anatomy of medial temporal lobe in north-west indian population: cadaveric brain dissection. *Asian J Neurosurg*, 13(3): 674-680.

ROCKARTS J, BREWER-DELUCE D, SHALI A, MOHIALDIN V, WAINMAN B (2020) National survey on Canadian undergraduate medical programs: the decline of the anatomical sciences in Canadian medical education. *Anat Sci Educ*, 13(3): 381-389.

ROMAND M, DUGAS D, GAUDET-BLAVIGNAC C, ROCHAT J, LOVIS C (2020) Mixed and augmented reality tools in the medical anatomy curriculum. *Stud Health Technol Inform*, 270: 322-326.

ROMO-BARRIENTOS C, CRIADO-ÁLVAREZ JJ, GIL-RUIZ MT, GONZÁLEZ-GONZÁLEZ J, RODRÍGUEZ-HERNÁNDEZ M, CORREGIDOR-SÁNCHEZ AI, UBEDA-BAÑON I, FLORES-CUADRADO A, MOHEDANO-MORIANO A, POLONIO-LÓPEZ B (2019) Anatomical prosection practices in the Occupational Therapy degree. Student anxiety levels and academic effectiveness. *Ann Anat*, 221: 135-140.

ROMO BARRIENTOS C, JOSÉ CRIADO-ÁLVAREZ J, GONZÁLEZ-GONZÁLEZ J, UBEDA-BAÑON I, SAIZ-SANCHEZ D, FLORES-CUADRADO A, LUIS MARTÍN-CONTY J, VIÑUELA A, MARTINEZ-MARCOS A, MOHEDANO-MORIANO A (2019) Anxiety among medical students when faced with the practice of anatomical dissection. *Anat Sci Educ*, 12(3): 300-309.

SALINAS-ALVAREZ Y, QUIROGA-GARZA A, MARTINEZ-GARZA JH, JACOBO-BACA G, ZARATE-GARZA PP, RODRÍGUEZ-ALANÍS KV, GUZMAN-LOPEZ S, ELIZONDO-OMAÑA RE (2020) Mexican educators survey on anatomical sciences education and a review of world tendencies. *Anat Sci Educ*, 9(10). doi: 10.1002/ase.2017.

SCHENCK TL, KOBAN KC, SCHLATTAU A, FRANK K, SCLAFANI AP, GIUNTA RE, ROTH MZ, GAGGL A, GOTKIN RH, COTOFANA S (2018) Updated anatomy of the buccal space and its implications for plastic, reconstructive and aesthetic procedures. *J Plast Reconstr Aesthet Surg*, 71(2): 162-170.

SCHULZ C (2017) The value of clinical practice in cadaveric dissection: lessons learned from a course in eye and orbital anatomy. *J Surg Educ*, 74(2): 333-340.

SCHWAM ZG, KAUL VZ, COSETTI MK, WANNA GB (2020) The utility of intraoperative navigation of the temporal bone for otolaryngology resident training. *Laryngoscope*, 130(5): E368-E371.

SELCUK İ, TATAR I, HURI E (2019) Cadaveric anatomy and dissection in surgical training. *Turk J Obstet Gynecol*, 16(1): 72-75.

SHOFOLUWE A, FOWLER B, MARQUES L, STEWART GW, BADANA ANS (2021) The relationship of the Phantom® Lapidus Intramedullary Nail System to neurologic and tendinous structures in the foot: An anatomic study. *Foot Ankle Surg*, 27(2): 231-234.

SINGAL A, GUPTA T, SAHNI D, AGGARWAL A (2020a) Anatomy of scalenovertebral triangle: A vade mecum for clinicians. *Morphologie*, 104(346): 174-181.

SINGAL A, SAHNI D, GUPTA T, AGGARWAL A, GUPTA AK (2020b) Anatomic variability of oval window as pertaining to stapes surgery. *Surg Radiol Anat*, 42(3): 329-335.

SINGH H, YANG JS, WILEY T, JUDSON C, ARCIERO RA, MAZZOCCA AD, VOSS A (2020) Relationship of the musculocutaneous nerve and its twigs to the coracoid process: an operative exposure. *Orthop J Sports Med*, 8(10): 2325967120954417.

SMITH CF, ALDERTON DL, CLIFFORD KM, WELLS G (2020) A good death - can the concept be applied to anatomy? *Anat Sci Educ*, 13(5): 657-663.

SONNE JWH (2020) Prevalence of the sternalis muscle in a sample of routinely dissected human cadavers. *Surg Radiol Anat*, 42(1): 87-90.

SOTGIU MA, MAZZARELLO V, BANDIERA P, MADEDDU R, MONTELLA A, MOXHAM B (2020) Neuroanatomy, the Achille’s heel of medical students. A systematic analysis of educational strategies for the teaching of neuroanatomy. *Anat Sci Educ*, 13(1): 107-116.

SOUZA AD, KOTIAN SR, PANDEY AK, RAO P, KALTHUR SG (2020) Cadaver as a first teacher: A module to learn the ethics and values of cadaveric dissection. *J Taibah Univ Med Sci*, 15(2): 94-101.

STEPHENS GC, REES CE, LAZARUS MD (2019) How does donor dissection influence medical students’ perceptions of ethics? A cross-sectional and longitudinal qualitative study. *Anat Sci Educ*, 12(4): 332-348.

TALARICO EF JR (2010) A human dissection training program at Indiana University School of Medicine-Northwest. *Anat Sci Educ*, 3(2): 77-82.

TALARICO EF JR (2013) A change in paradigm: giving back identity to donors in the anatomy laboratory. *Clin Anat*, 26(2): 161-172.

TARDO DT, BRIGGS C, AHERN G, PITMAN A, SINHA S (2017) Anatomical variations of the renal arterial vasculature: An Australian perspective. *J Med Imaging Radiat Oncol*, 61(5): 643-649.

WILLIAMS SR, THOMPSON KL, NOTEBAERT AJ, SINNING AR (2019) Prosection or Dissection: which is best for teaching the anatomy of the hand and foot? *Anat Sci Educ*, 12(2): 173-180.

WILSON AB, MILLER CH, KLEIN BA, TAYLOR MA, GOODWIN M, BOYLE EK, BROWN K, HOPPE C, LAZARUS M (2018a) A meta-analysis of anatomy laboratory pedagogies. *Clin Anat*, 31(1): 122-133.

WILSON JS, ALVAREZ J, DAVIS BC, DUERINCKX AJ (2018b) Cost-effective teaching of radiology with preclinical anatomy. *Anat Sci Educ*, 11(2): 196-206.

ZHANG X, YANG J, CHEN N, ZHANG S, XU Y, TAN L (2019) Modeling and simulation of an anatomy teaching system. *Vis Comput Ind Biomed Art*, 2(1): 8.

ZILVERSCHOON M, KOTTE EMG, VAN ESCH B, TEN CATE O, CUSTERS EJ, BLEYS R (2019) Comparing the critical features of e-applications for three-dimensional anatomy education. *Ann Anat*, 222: 28-39.

Designer Dissections: Tailor-made for your career in Anatomy and Medicine

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SUMMARY

Exposure to a cadaver dissection highlights the crucial humanistic values required to become a successful physician, including learning the qualities of respect, empathy, and compassion. This encounter has a usefulness for knowledge learned in basic sciences and medicine. Due to the Covid-19 pandemic, the transition from the cadaver-based laboratory to software-based applications has been expedited. By pioneering a movement called "*Designer Dissections,*" this concept paper presents a personalized, medical education experience in a specific anatomical region and in an area of specialty-interest. Allopathic and Osteopathic Medical students, physicians, and professors will develop this project to promote Interprofessional Education. This project provides a *novel* approach for anatomical teaching and the production and use of additional material for anatomical sciences education and medical education. Further, this paper addresses a gap in knowledge and its possible long-term effects on patient care due to a lack of anatomical knowledge and skills secondary to the absence of cadaver dissection experiences. This design is an early invitation for first-year medical students to get involved in basic and clinical research, develop positive mentor-mentee relationships, and strengthen their knowledge in their specialty of interest, and the approach can be applied to electives in the clinical-training year, as well as professional, continuing medical education.

Key words: *Designer dissections* – Cadaver dissection – Medical Education – Specialty training – Anatomy – Anatomical Education

ABBREVIATIONS

Collaborative Institutional Training Initiative (CITI)

Commission on Osteopathic College Accreditation (COCA)

Corona Virus Disease 2019 (COVID-19)

Environment, Health and Safety (EHS)

Liaison Committee on Medical Education (LCME)

Nova Southeastern University (NSU)

Personal Protective Equipment (PPE)

Institutional Review Board (IRB)

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INTRODUCTION

For the past 700 years, each generation of physicians has had the privilege of learning the human body's intricacies via a hands-on approach from the prior generation using human cadaver dissections as a vital learning tool. Dissections have been a critical aspect of medical education since the 3rd Century B.C. in Greece (Ghosh, 2015). In the United States, human gross anatomy and neuroscience are taught in the pre-clinical years, typically during the first semester of medical school. This knowledge has served as a critical foundation for medical students' learning of the human body that is later grown and strengthened with physiology, pathology, and pharmacology.

Within two decades after universities began to dedicate less time to cadaver dissection, or to omit it entirely, the gaps in anatomical knowledge among medical students became evident (Memon et al., 2018). General Practitioners graduating during this era were significantly lacking the knowledge and skills necessary for simple medical procedures (Memon et al., 2018). This gap led to many universities reinstating human cadaver dissection into their anatomy programs in the pre-clinical years. Some institutions that have returned to cadaver laboratory include New York University, University of Hawaii, University of Washington, University of California at San Francisco, and University of California-Davis (Rizzolo et al., 2006). Further, because of these concerns, additional surgical training programs, optional dissection opportunities, cadaver dissection laboratories, elective dissection courses, and student-led anatomy clubs have become increasingly available for many incoming medical students and trainees with diminished dissection experience (Holland et al., 2011; Rizzolo et al., 2006).

Cadaver dissections have been used for research purposes in both medical school and residency programs, not only investigating basic anatomy but also clinical anatomy, anatomical variations, and clinical applications. As students become familiar with the anatomy through formal laboratories, they also learn about anatomical variations and pathologies. This also applies to "anatomy refresher" courses/workshops taken by residents and practicing physicians. This connection consolidates didactic knowledge, skills in human anatomy and dissection, and clinical application (Chang et al., 2018; Anyanwu et al., 2010; Bogomolova et al., 2020). In addition, research has become a crucial part of a medical student's career. The Liaison Committee on Medical Education (LCME) has encouraged redesign of medical education curricula to promote research opportunities for all students, made available by the faculty. In fact, in the LCME accreditation standards, the word "research" is mentioned fourteen times, in the context of opportunities, development, participation and enhancement (LCME, 2018). The Commission on Osteopathic College Accreditation (COCA) also supports research opportunities for students (COCA, 2019). In the COCA revised accreditation standards, the COCA states that a college of Osteopathic Medicine must demonstrate a commitment to research to assist students in research and peer review through publications, grant application, and inclusion of its students in research throughout all four years of the Osteopathic Medical education (COCA, 2019).

The process of discovery and examination of pathological findings from cadaver dissection has resulted in many different innovative publications. Examples of cutting-edge research in anatomical sciences include research on vascular flow (Sarkar et al., 2018), computed tomography (Krahenbuhl et al., 2019), muscular strength (Rudy et al., 2017), vasculature (Nguyen and Talarico, 2018), cancer (Talarico et al., 2018), and Iniencephaly (Talarico and Hiemstra, 2013), and there are numerous other examples. Different research experiences give students opportunities to seek knowledge for their own benefit at their own pace. Most importantly, these studies showcase how even short-term exposure to basic science research results in meaningful benefits in the form of knowledge gained and publishable findings.

The anatomy laboratory is one of the few educational settings where first-year medical students can complete their assigned work without the ability to neglect their emotions or develop a detached attitude to the material at hand (Ghosh, 2015; Robbins et al., 2009). Scholarly studies have suggested that cadaver dissection experiences could significantly affect medical students' attitudes towards death and caring (Charlton et al., 1994; Goss et al., 2019; Ghosh, 2017; Chiou et al., 2017; Arraez-Aybar et al., 2010). Developing this emotional intelligence early in a medical career is one of the most essential and translatable lessons in becoming a competent physician.

Despite the importance of cadaver dissection, the time devoted to it in the health professions curriculum has diminished. Some schools have opted to remove it altogether (Rizzolo et al., 2002). Due to the Covid-19 pandemic, the transition from the cadaver-based laboratory to software-based applications has been expedited. This shift has mostly been due to the adoption of integrated medical curricula worldwide, the high cost, and the required time restrictions, and now safety and social distancing concerns (Kumar et al., 2017).

A survey of the literature shows numerous authors opposing this software-based transition and warning the medical education community of the long-term consequences that a resultant shortage of anatomical knowledge may have on patient outcomes (Ghosh, 2015; Rizzolo et al., 2002; Yammine et al., 2014; Bergman et al., 2014). This gives rise to an insightful question posed by anatomists and clinicians: How can anatomy educators correct for this knowledge gap created by the lack of cadaveric experience once the pandemic is over? Can an instrument be developed to correct this, and can this same instrument be useful in the future of anatomy education? This is a critical period in anatomical sciences education – a time for anatomy to reinvent itself and create a *new type of cadaver dissection experience*. The purpose of this paper is to produce a teaching instrument that can be used in the future via a new approach for anatomical education that will also yield additional educational materials (and resources) for anatomical sciences education.

The *Designer Dissections* approach in Anatomy Education

The *Designer Dissections* is a personalized, medical education experience in a specific anatomical region related to an area of specialty interest for implementation at Nova Southeastern University (NSU). This post-Covid-19 model will promote interprofessional education between Allopathic and Osteopathic Medical students, physicians, and professors. In addition, this model concept aims to address a gap in knowledge and its possible long-term effects on patient care due to a lack of anatomical knowledge and skills secondary to the absence of cadaver dissection experiences. Products (i.e., dissection videos; prosections, tutorials, instructions, etc.) of this novel method can be used for educational purposes by faculty, physicians, and students.

The requirements, roles, and objectives for the project personnel are shown in Table 1. In this model, the participant, an Allopathic Medical student, will get dissection training from an anatomy tutor, an Osteopathic Medical student, who was previously trained in the cadaver laboratory. All participants are required to complete (or renew) Collaborative Institutional Training Initiative (CITI) and Environment, Health and Safety Management (EHS) courses/modules to permit entry and work in the human gross anatomy laboratory. With the guidance of the tutors, the participant can plan and complete their regional *Designer Dissections*. For example, the mentor, or faculty member, such as a hand surgeon, will be grouped with participants interested in orthopedic surgery of the hand. The mentor and student will select a project – for this example: dissection of the left hand, and dissection of the right hand with surgical tendon/muscle trans-disposition of the palmaris longus muscle. The mentor will work with participants and tutors via virtual meetings to guide research, dissection, and create abstracts, oral and poster presentations. Part of this *Designer Dissections* work product might include recorded presentations of the completed prosection and/or of the surgical procedure. These recordings can then be used as teaching resources for anatomy faculty, and learning tools for students.

MATERIALS AND METHODS

This is a concept paper for a novel approach to teaching and learning of human gross anatomy. Below, the method is described, and the authors invite feedback and discussion.

Student Group

The students will include first-year Allopathic Medical students who have had no cadaver dissection experience in medical school and anatomy tutors exposed to cadaver dissection within the past year. The anatomy tutors are first-year Osteopathic Medical students. In 2019, these students were partnered with another anatomy tutor and dissected anatomical donors from head-to-toe. In 2020 at NSU, during the Covid-19 pandemic, these students served as teaching assistants for Virtual Gross Anatomy, where they assisted and tutored their classmates using an online application. The first-year Allopathic Medical students have had no cadaver experience. At NSU, medical students must also be involved with research during the summer semester before starting their second year in medical school.

Table 1. Requirements, roles and objectives for the *Designer dissections*.

Personnel	Requirements	Role	Objectives
Faculty	Experience with anatomy dissections and feel comfortable presenting a case study on a specific anatomical area: Musculoskeletal, Thorax, Abdomen, Head & Neck, and Pelvis. Minimal time commitment (see methods). Do not need a dissection kit. This commitment will count towards faculty requirements: (a) NSU Faculty Scholarship with abstract publications, (b) NSU Faculty Service as a mentor	Mentor	Create long-lasting relationships with Osteopathic and Allopathic Medical students. Enhance leadership skills in small group settings. Fulfill school requirements concerning student-professor participation and advising.
Allopathic Medical Students	Taken fundamentals of anatomy and passed without any concern. Engage in necessary time commitment (methods). Have a dissection kit. Have PPE. Complete EHS modules. Complete CITI training in anticipation of submitting an IRB proposal and subsequent research abstract.	Participant	Develop dissecting skills in an area of choice in a human cadaver. Discover different anatomical pathologies during cadaver dissection. Use pathologies discovered to highlight clinical case-based research. MD/DO student collaboration to submit a clinical case-based research abstract for an oral or poster presentation.
Osteopathic Medical Students	Taken at least one anatomy dissection course along with anatomy lectures and passed with an A/honors. Experience with anatomy dissection and feel comfortable teaching at least one of these areas: Musculoskeletal, Thorax, Abdomen, Head & Neck, and Pelvis. Engage in significant time commitments. Have a dissection kit. Have PPE. Complete EHS modules Complete CITI training in anticipation of submitting an IRB proposal and subsequent research abstract.	Tutor	Enhance leadership skills in small group settings. Enhance dissection skills in an area of choice on a human cadaver. Discover different anatomical pathologies during cadaver dissection. Collaborate with MD/DO students to submit a clinical case-based research abstract for an oral or poster presentation. Develop a teaching model that can be used in the future.

Faculty Group

The anatomy and clinical faculty participants will include this opportunity toward their university community service, faculty mentorship hours, and additional faculty scholarship. The faculty will be able to choose the specific specialty group they prefer to mentor. The time requirement will be up to the faculty-student group but will not exceed more than two hours per week.

Cadaveric Materials

Depending on the number of Allopathic Medical students who commit to the experience, this design will require a specific number of cadavers. For example, in the case where one group chooses the female reproductive system and one group chooses the male reproductive system then two cadavers (i.e., one female and one male) are required. In this instance, two cadavers may only be needed allowing for other dissection (i.e., hand, foot, chest, etc.) by other groups. The total number of anatomical dissections would depend on the specific region such as the musculoskeletal system, the thoracic cavity, the abdomen, the reproductive system, and the head and neck musculature. Each cadaver costs approximately $3,300. Additional funds will be necessary for routine cadaver maintenance by the Anatomy staff. After dissections are completed, the cadavers can be used as prosections for the incoming first-year medical students and other health professions programs. These dissections would take place in the Health Professions Division, Gross Anatomy dissection laboratory at NSU, Fort Lauderdale Campus.

Pre-requisites

NSU Institutional Review Board approval will be obtained to survey students. The information provided by the survey will: (1) allow student learners to be paired with student tutors and faculty that share similar interests; (2) provide a general count as to the number of students interested in participating in personalized cadaver dissections and anticipated research, and (3) determine the regional anatomy to be explored and serve as the basis for a poster presentation (and/or the creation of learning resource materials). The benefits of conducting the survey are summarized in Table 2. After the survey data is analyzed, this team will match student learners with student tutors and appropriate faculty content experts. These surveys are available for review using the provided links:

Survey 1 For Participants: Click Here

Survey 2 For Anatomy Tutors: Click Here

Table 2. Survey benefits of *Designer Dissections* projects.

Survey Information	**Benefits**	
	Students	***Faculty***
Specialty Choice	Allows learners to be paired with anatomy tutors and faculty that share similar interests. This match will let the dissection team be more personal and tailored for each student.	Allows mentors to be paired with students that share similar interests.
Cadaver Laboratory Interest	Provide general count of students who want to participate in personalized cadaver dissections: The *Designer Dissections* is not a course requirement for the students to complete; it is a supplemental resource available to them. The dissections will serve as prosections (or recordings) and anatomy teaching tools for medical and other health professions students.	This survey will reduce the number of cadavers needed, which would decrease financial costs to the institution. The dissections will serve as prosections (or recordings) for teaching materials/resources.
Research Interest and Time Commitment.	Determine the regional anatomy to be explored. Serve as the basis for a poster or oral presentation. The specific area would also determine the time commitment required and interested student learner, student tutor, and faculty.	Determine the regional anatomy to be explored. Serve as the basis for a poster or oral presentation. Determine Time Commitment

Training

First-year Allopathic Medical students who indicate an interest in personalized dissections will complete Google forms indicating their specialty of interest shown in Prototype 1. The anatomy tutors will complete a similar form indicating their specialty of interest shown in Prototype 2. Both groups will complete a pre and post-test to assess their knowledge of anatomy. Additionally, per regulations by the Anatomical Board of Florida, all students will complete EHS Modules to ensure they are certified to be in a cadaver laboratory. To be included in anticipated scholarly presentations, students and faculty, will complete CITI training modules. The first-year Allopathic and Osteopathic Medical students will be grouped based on their specialty interest. Each Allopathic Medical student will go into the cadaver laboratory with their corresponding first-year Osteopathic Medical student and dissect the specific area of interest (i.e., those interested in OB/GYN will dissect the pelvis). This project aims for the Allopathic Medical students to feel confident in examining their specific anatomical area of interest and feel encouraged with their specialty choice.

Expected Outcomes

The outcomes of *Designer Dissections* can be found in Table 3. There are nine major outcomes from *Designer Dissections* for both students and faculty: (1) mentorship development, (2) research exposure, (3) sustainability and consolidation of basic science knowledge, (4) horizontal and vertical integration, (5) development of a novel teaching model, (6) early exposure to specialty of interest, (7) development of leadership and communication skills, (8) insight into software application, and (9) innovative transition for cadaver dissection to a post-Covid-19 world.

DISCUSSION

Research

Clinical research helps medical students become better clinicians, and good clinical work makes physicians better researchers (Kichloo, 2020). *Designer Dissections* will allow the student to explore human cadaveric anatomies and their anatomical variations. This first cadaveric interaction will enable participants to see unique postmortem pathologies and consolidate their classroom knowledge. Further, survey outcomes will provide valuable results for anatomy education research.

Another value of human cadaveric research is the advances in diagnoses it can provide. A 2018 study in vascular surgery indicated how a pressurized cadaver flow model successfully replicated multiple aspects of advanced endovascular procedures with tactile feedback (Wang et al., 2019). A different study also illustrated how the placement of cortical bone trajectory screws in the middle-upper thoracic spine was safe and convenient, with navigation assistance (Sarkar et al., 2018), providing a variety of healthcare professionals a reliable practice simulation. Other findings involved the discovery of less complicated patient position on preoperative 3D planning for surgical resection on soft tissue sarcoma in the lower limb (Kaiser et al., 2020), developing patient-specific temporomandibular joint prosthetics (Kraeima et al., 2018), and quantifying and qualifying radiation dosage effects in abdominal C.T. scans (Khawaja et al., 2017). These discoveries are just a few examples of how necessary clinical procedures benefit from human cadaveric research – *a necessity that continues in the dynamic and modern era of human anatomy education.*

Moreover, a 2017 study emphasizes the long-term effect of early research exposure (Berger et al., 2017). This study concluded that students who undertook specialty-related research and developed mentor relationships in their first and second pre-clinical years were significantly more likely to keep the same interest later in training (Berger et al., 2017).

Interdisciplinary Development/Collaboration

The Joint Commission is a nonprofit that is in charge of accrediting more than 22,000 US health care organizations and programs in the United States. This organization cites inter-professional communication failures as the leading cause of medical errors, delays in treatment, and wrong-site surgeries (2005). Patient health and outcomes can be dramatically affected by team collaboration or lack thereof. Research has shown that collaboration in health care improves patient outcomes by decreasing morbidity and mortality rates (Bosh et al., 2015). Interdisciplinary communication and teamwork benefits healthcare workers by increasing job satisfaction and improving the workload (Bosch et al., 2015). Why is this not something that is instilled early on in medical education? *Designer Dissections* addresses this issue in several ways. Typically, first and second-year medical students only interact with their classmates. This design

Table 3. Outcomes of *Designer Dissections*.

COMPONENT	OUTCOMES	
	Students	**Faculty**
Mentorship	One-on-one time with a clinical specialist. Early mentorship in medical school has significant long-term effects on students' attitudes toward their medical careers. Learning through constructive feedback and career counseling.	Creation of positive, long-lasting mentor-mentee relationships in developing caring and humanistic physicians. Increase interactions between specialists and students.
Research	Support and complement their summer research experience with cadaver dissection. Poster presentation for the NSUMD annual conference Research, Innovation, and Service in Education (RISE). Assist with abstract submission and poster presentation.	Co-author an abstract. Co-author in a poster presentation.
Sustainability/ Consolidate Basic Science Knowledge	Consolidate basic anatomical knowledge. Teach their incoming medical students the following year.	Consolidate basic anatomical knowledge.
Horizontal and Vertical Integration	Osteopathic, Allopathic Medical Students, & Medical Sonography students working side by side for the rest of their careers in medicine, according to the Accreditation Council for Graduate Medical Education (ACGME). First year medicals students working with second/third year medical students.	Specialist working alongside future doctors. Specialist working alongside future sonographers.
Novel Teaching	Surgical procedures coupled with anatomical dissection protocol. Self-teach videos plan to be implemented. Pre-recordings of prior dissections (i.e. hand) provide visual and audio experience prior to lab with the video.	Guidance on surgical procedures explored with cadaver dissection. Clinical case presentation based on cadaver dissection pathological findings. Introduce foundation for diagnosis, management, and future patient care.
Early Exposure to Specialty of Interest	Early exposure to an array of specialty choices via cadaveric dissection. Encourage or dissuade student from specialty of interest. Keep morale high during medical school via specialty of interest. Selecting the most suitable specialty is vital to overall physician wellness and reduces physician burnout.	Influence student's medical career planning Impact medical student mental health. Reduce physician burnout.
Leadership and Communication Skills	Teamwork to understand anatomy and pathology of the entire human cadaver. Communicate with physicians, students, and administrators.	Guide students to understand anatomy and pathology of the entire body. Communicate with students, other physicians, administrators.
Software Transition	Well-designed application gives students a solid foundation and understanding of regional anatomy. Anatomical variations cannot be predicted. Software can supplement dissection.	Training future physicians should combine both old and new methods. For example, sonography and ultrasound would be effective supplemental tools for students to use to further their medical education in imaging.
Transition to a Post-Covid-19 World	Preservation of cadaver laboratory while aiding in a personalized medical education. Preserve an environment of respect to recognize attitudes towards death, pain, and empathy.	Preservation of cadaver laboratory while aiding in a personalized medical education. Influence medical education post-pandemic.

seeks to unify the diverse training within the D.O. and M.D. programs. For instance, it is an opportunity for M.D. students to learn about the unique Osteopathic Manipulative Medicine (OMM) training that D.O. students receive. This partnership is especially relevant with the new merger of D.O. and M.D. residency programs, through which all medical students will now be working side by side for the rest of their careers in medicine (ACGME).

Software Transition

Some of the programs are well-designed and give students a solid foundation and understanding of regional anatomy. These programs should not serve as the sole source of learning anatomy but rather a supplemental resource. However, the applications do not accurately reflect the anatomical variations that exist in the human body. If students learned solely using computers, then a medical student's first time sinking a scalpel into a human body would be during their surgery rotation on a live patient. The future of medical education should not turn away from vital cadaver dissections but rather frame their curricula around them. Factors such as time and finances should not outweigh the integrity of hands-on training and medical knowledge. Training future physicians to become competent healthcare professionals should combine both old and new methods to benefit patients and the entire medical community.

Many surgeons and anatomists alike have raised their concerns about the impact this transition will have on future surgeons' competency and, ultimately, patient safety. An article by Dr. Harold Ellis highlighted the drastic spikes in medico-legal claims in the U.K., and attributed them to the insufficient anatomical knowledge created by institutions dedicating less time to cadaver-based training (Ellis et al., 2006). Regenbogen et al. (2007) analyzed 444 malpractice claims and found that 52% of them resulted from technical errors. It highlighted the importance of additional training for inexperienced surgeons to correct these mishaps. Holland et al. (2012) examined the reduction in time spent performing procedures by surgical trainees and expressed concern over the greater scrutiny of outcomes and the importance of maximizing patient benefit. Medical schools worldwide should consider all these instances before making potentially irrevocable decisions that may significantly affect their students.

CONCLUSIONS

Covid-19 has been the catalyst of evolving personalized education. The divergence of medical school curricula away from human cadaver dissection has already had and will continue to have broad-ranging impacts on today's physicians' proficiency. *Designer Dissections* proposes a personalized cadaver dissection experience capable of filling the void that has become apparent for many medical students who have not had the right of passage - the human cadaver dissection. This concept will also allow students to expand upon their research experience and broaden their interprofessional collaboration skills. *Designer Dissections* intends to change the way anatomical education is performed and presented in terms of finances, sustainability, leadership, mentorship, and overall benefit for students. In a Covid-19 world, it is essential to remember human connections in education and learning should not be solely done virtually.

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REFERENCES

ANYANWU G, UGOCHUKWU A (2010) Impact of the use of cadaver on student's ability to pass anatomy examination. *Anatomy*, 4(1): 27-34.

ARRAEZ-AYBAR L, CASTANO-COLLADO G, CASADO-MORALES M (2008) Dissection as a modulator of emotional attitudes and reactions of future health professionals. *Med Educ*, 42(6): 563-571.

BERGER A, GIACALONE J, BARLOW P, KAPADIA M, KEITH J (2017) Choosing surgery as a career: early results of a longitudinal study of medical students. *Surgery*, 161(6): 1683-1689.

BERGMAN E, VERHEIJEN I, SCHERPBIER A, VAN DEL VLEUTEN C, DE BRUIN A (2014) Influences on anatomical knowledge: The complete arguments. *Clin Anat*, 27(3): 296-303.

BOGOMOLOVA K, HIERCK B, VAN DER HAGE J, HOYIUS S (2020) Anatomy dissection course improves the initially lower levels of visual spatial abilities of medical undergraduates. *Anat Sci Educ*, 13: 333-342.

BOSH B, MANSELL H (2015) Interprofessional collaboration in health care: Lessons to be learned from competitive sports. *Canad Pharmac J,* 148(4): 176-179.

CHANG H, KIM H, RHYU I, LEE Y, UHM C (2018) Emotional experiences of medical students during cadaver dissection and the role of memorial ceremonies: a qualitative study. *BMC Medical Education*, 18(1): 255.

CHARLTON R, DOVEY S, JONE D, BLUNT A (1994) Effects of cadaver dissection on the attitudes of medical students. *Med Educ*, 28: 290-295.

CHIOU R, TSAI P, HAN D (2017). Effects of a “silent mentor” initiation ceremony and dissection on medical students’ humanity and learning. *BMC Res Notes*, 10(1): 483. https://doi.org/10.1186/s13104-017-2809-0

COMMISION ON OSTEOPATHIC COLLEGE ACCREDITATION (2019) Accreditation of College of Osteopathic Medicine: COM New & Developing Accreditation Standards. *2019 COCA Standards*, 1-81.

ELLIS H (2006) Medico-legal litigation and its links with surgical anatomy. *Surgery*, 20(8): i-ii.

GHOSH S (2015) Human cadaveric dissection: a historical account from ancient Greece to the modern era. *Anat Cell Biol*, 48(3): 153-169.

GHOSH S (2017). Paying respect to human cadavers: We owe this to the first teacher in anatomy. *Ann Anat,* 211: 129-134.

GOSS A, VISWANATHAN V, DELISSER H (2019) Not Just a specimen: a qualitative study of emotion, morality, and professionalism in one Medical School Gross Anatomy Laboratory. *Anat Sci Educ*, 12(4): 349-359.

GUO K, LUO T, ZHOU L, XU D, ZHONG G, WANG H, XU J, CHU G (2020) Cultivation of humanistic values in medical education through anatomy pedagogy and gratitude ceremony for body donors. *BMC Medical Education*, 20(1): 440.

HOLLAND J, WAUGH L, HORGAN A, PALERI V, DEEHAN D (2011) Cadaveric hands-on training for surgical specialties: is this back to the future for surgical skills development? *J Surg Educ,* 68(2): 110-116.

JOINT COMMISION ON ACCREDITATION OF HEALTHCARE ORGANIZATIONS (2005) The Joint Commission guide to improving staff communication. Oakbrook Terrace, Illinois.

KAISER D, HOCH A, KRIECHLING P, GRAF D, WAIBEL F, GERBER C, MULLER D (2020) The influence of different patient positions on the preoperative 3D planning for surgical resection of soft tissue sarcoma in the lower limb-a cadaver pilot study. *Surg Oncol*, 35: 478-483.

KHAWAJA R, SINGH S, PADOLE A, OTRAKJI A, LIRA D, ZHANG D, LIU B, PRIMAK A, XU G, KALRA M (2017) Point organ radiation dose in abdominal CT: Effect of patient off-centering in an experimental human cadaver study. *Radiation Protect Dosimetry*, 175(4): 440-449.

KICHLOO A (2020) Early mentoring for research and academic careers. *J Invest Med High Impact Case Reports*, 8: 1-2.

KRAEIMA J, MEREMA B, WITJES M, SPIJKERVET F (2018) Development of a patient-specific temporomandibular joint prosthesis according to the Groningen principle through a cadaver test series. *J Cranio-Maxillo-Facial Surg*, 46(5): 779-784.

KRAHENBUHL N, BURSSENS A, DAVIDSON N, ALLEN C, HENNINGER H, SALTZMAN C, BARG A (2019) Can weight bearing computed tomography scans be used to diagnose subtalar joint instability? A cadaver study. *J Orthop Res,* 37: 2457-2465.

KUMAR N, RAHMAN E (2017) Effectiveness of teaching facial anatomy through cadaver dissection on aesthetic physicians’ knowledge. *Adv Medical Educ Pract*, 8: 475-480.

LIAISON COMMITTEE ON MEDICAL EDUCATION SECRETARIAT (2018) Functions and Structure of a Medical School: Standards for Accreditation of Medical Education Programs Leading to the MD Degree. *Association of American Medical Colleges and American Medical Association.*

MEMON I (2018) Cadaver dissection is obsolete in medical training! A misinterpreted notion. *Medical Principles Practice,* 27(3): 201-210.

NGUYEN V, TALARICO E (2018) A morphometric anatomical study on the division of the left main coronary artery and myocardial bridges. *Eur J Anat,* 22(4): 355-365.

NIMMONS D, GINY S, ROSENTHAL J (2019) Medical student mentoring programs: current insights. *Adv Med Educ Pract*, 10: 113-123.

REGENBOGEN S, GREENGERG C, STUDDERT D, LIPSITZ S, ZINNER M, GAWANDE A (2007) Patterns of technical error among surgical malpractice claims: an analysis of strategies to prevent injury to surgical patients. *Ann Surg,* 246(5): 705-711.

RIZZOLO L (2002) Human dissection: an approach to interweaving the traditional and humanistic goals of medical education. *Anat Rec,* 269(6): 242-248.

RIZZOLO L, STEWARD W (2006) Should we continue teaching anatomy by dissection when ...?. *Anat Rec,* 289(6): 215-218.

ROBBINS B, TOMAKA A, INNUS C, PATTERSON J, STYN G (2009) Lessons from the dead: The experiences of undergraduates working with cadavers. *OMEGA - J Death Dying,* 58(3): 177-192.

RUDY, MUSTAMSIR E, PHATAMA K (2017) Tensile strength comparison between peroneus longus and hamstring tendons: A biomechanical study. *Int J Surg*, 9: 41-44.

SALAMEH F, O’REILLY B, BALTA J (2020) The cadaver is not dead. *Anat Sci Int*, 95(4): 571-572.

SARKAR A, KALSI R, AYERS J, DRUCKER C, KAUSHAL V, SUTTON W, CRAWFORD R (2018) Continuous flow perfused cadaver model for endovascular training, research, and development. *Ann Vasc Surg*, 48: 174-181.

TALARICO E, HIEMSTRA T (2013) A case of iniencephaly in a 36-week-old human female fetus. *Eur J Anat,* 17(4): 209-219.

TALARICO E, MAS J, JONES J (2018) A comprehensive anatomical characterization and radiographic study of stage III testicular cancer in a 31-year-old male patient. *Eur J Anat,* 22(3): 241-256.

WANG K, ZHANG Z, CHEN J, WU A, WANG X, SHENG S (2019) Design and application of individualized, 3-dimensional-printed navigation template for placing cortical bone trajectory screws in middle-upper thoracic spine: cadaver research study. *World Neurosurg*, 125: 348-352.

YAMMINE L (2014) The current status of anatomy knowledge: where are we now? Where do we need to go and how do we get there? *Teach Learn Med,* 26(2): 184-188.

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Practical pregraduate teaching in Human Anatomy: A review

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SUMMARY

There is a general agreement in all fields of sciences that practical pre-graduate education in human anatomy is absolutely necessary. It constitutes an inseparable partner with theoretical learning on the path to knowledge. As such is it critical to (1) establish the set of specific objectives for each practical session (PS), and (2) define more precisely the outcomes (i.e., knowledge, skills and attitudes) that are expected by students. The principle for efficiency of practical sessions (PSs) is that they should take place immediately after didactic sessions of the corresponding topic(s). In this way, students could best reinforce their learning. Considering that the morphology of the human body can be learned by means other than direct observation/dissection of anatomical donors, media, models and imaging have also gained popularity as "anatomy learning tools" in recent years. Imaging is a perfect complement for teaching in the dissecting room, but always in correlation with the reality of body-donor sections, prosections and dissections of the same region. Anatomical models and computer programs express the reality of the human body, however, anatomical variations and many other qualities (i.e., surgical skills, ethics, pathology, professionalism) can only be appreciated via hands-on use of an anatomical donor to science. Therefore, the anatomical donor remains the *Gold Standard* for anatomy teaching, especially topographical Anatomy.

Key words: Anatomy – Education – Human Anatomy – Practical session – Dissection – Body-donor

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ABBREVIATIONS

Practical Session(s) (PS/PSs)

INTRODUCTION

As in all fields of sciences, practical teaching in Human Gross Anatomy is absolutely necessary, and there is a general agreement in this concept since it constitutes an inseparable partner with theoretical learning on the path to knowledge (Konschake and Brenner, 2014). The practical class is the direct confrontation of facts with reality; in this way Cajal's quotation is recalled, "Much teach books, but much more teaches nature, reason and source of all the books."(Ramón y Cajal, 1940).

Human Anatomy has, in recent decades, been considered by some authors as a hangover from the renaissance, even leading to the disappearance of the Departments of Human Anatomy in some universities (Drake et al., 2009; Dyer and Thorndike, 2000; Ramsey-Stewart, 2014; Zumwalt et al., 2007). Yet, it appears to be a general agreement that the discipline of Human Anatomy is one of the fundamental pillars of medical training (Alyafi et al., 2012; Cappabianca and Magro, 2009; Garment et al., 2007; McLachlan and Patten, 2006; Mompeó and Pérez, 2003; Moon et al., 2010; Ramsey-Stewart, 2014). Nonetheless, there is still a latent debate on the "crisis" of the role of Human Anatomy and the importance of dissection of the human body in medical education (Benninger et al., 2014; Di Dio, 1999; Korf et al., 2008; Older, 2004; Ramsey-Stewart, 2014; Sugand et al., 2010; Winkelmann, 2007). This controversy is revived from time-to-time, coinciding with the design of new training syllabi and new technologies. Moreover, anatomy teaches the scientific method essential in any professional of health sciences (Bunge, 2012). Still further, skilled team-dissection in the anatomy laboratory promotes the learning of communication and problem-solving skills, teamwork, and understanding of pathological and ethical (or end-of-life) issues – all of which are essential to healthcare professionals. Lastly, with the decrease in time devoted to anatomy and modernization of medical education curricula, peer-teaching during PSs has become another tool in the anatomy laboratory, and students are requesting more time with PSs (Drake et al., 2009; Elizondo-Omaña et al., 2010; Moxham and Plaisant, 2007; Talarico, 2010).

In the present work, the focus is on the practical teaching of human gross anatomy by a review of the essential components that create a successful practical teaching session. The main aim of practical teaching in anatomy is to help the comprehension of concepts and anatomical details encountered during didactic (i.e., theoretical) sessions. The student can acquire new information and reinforce learning new and prior concepts. Students not only gain knowledge of identifying structures, but also acquire skills in handling instruments, tactile and observational skills, and in scientific methodology and the ability to analyse results (Cox and Ewan, 1988; Newble and Cannon, 2001). The success of the process relies not only on student initiative and ability, but also on the interaction of anatomy and clinical faculty with student learners and the organization of the session. The advantages and disadvantages of practical teaching in traditional dissection and using the peer-learning approach in Table 1 (Cox and Ewan, 1988; Miller, 1961).

OBJECTIVES

Before starting the practical protocol, it is necessary to: (1) establish a specific set of learning objectives for each session, and (2) define the learning outcomes (i.e., the knowledge, skills and attitudes, etc.) that students are expected to achieve at the end of each PS. Session level objectives should be matched to overall course objectives, as well as institutional objectives. Learning outcomes are specific statements of what students will be able to do when they successfully complete a learning experience (whether it's a project, course or program). They are always written in a student-centered, measurable fashion that is concise, meaningful, and achievable.

How are learning outcomes different from learning objectives (i.e., learning goals)?

These terms are often used interchangeably, and they are all related to the teaching and learning that is expected to take place in the classroom or laboratory. However, the difference between goals or objectives and outcomes lies in the emphasis on who will be performing the activities. Learning goals and objectives generally describe what an instructor, program, or institution aims to do, whereas a learning outcome describes in observable and measurable terms what a student is able to do as a result of completing a learning experience (i.e., the PS). To summarize, a learning outcome (also known as a terminal or performance objective) is a statement in specific and measurable terms that describes whet the learner will be able to do as a result of engaging in a learning activity, or PS, whereas learning objectives (i.e., goals or enabling objectives) address a component of the learning outcome and help track the learner's progress towards that objective (Fig. 1 and Table 2).

PSs must be conveniently planned to achieve the defined objectives. Therefore, objectives never should be too complex or difficult for students to accomplish.

Table 1. Advantages and Disadvantages of Practical Teaching Session.

Traditional Practical Session		**Peer-Teaching Practical Session**	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Provides the student an opportunity for direct experience for correlating the theory with the reality of human body.	They have an important cost in infrastructure, equipment and staff.	Provides the student an opportunity for direct experience for correlating the theory with the reality of human body.	They have an important cost in infrastructure, equipment and staff.
Provides an opportunity for learning and practice different skills and develop some important clinical attitudes.	They have no sense if the student is not adequately prepared.	Increases sense of accountability to the team. Increases motivation (a "need to know" attitude). Requires preparation and verbalization (enhancement of organizational and communication skills).	
Students could work at their own rhythm.	They have no sense if the students adopt a passive attitude, just as merely observers.	Offers education to students on their own cognitive level (less distance between peer teachers than professors).	
Provides an opportunity to the personal relationship between teacher and student.		Fosters a more comfortable and safe educational environment; reduces barriers to asking questions.	
Permits the student to evaluate their emotions in the process of learning.		Supports development of independent learning by learning how to self-reflect; "one way to learn to reflect and teach is by being a teacher for others" (Ten Cate & Durning 2007).	
Creates a strong anatomy learning community.		Creates a strong anatomy learning community.	
		Fosters a sense of empowerment ("I know more and am experiencing more"), which increases student confidence and contributions to the group.	
		Interval of peer instruction and communication can be likened to future patient care "pass off" between clinicians leaving/coming on service –effective communication of anatomic information is vitally important for continuity of learning by all members of the team.	

The establishment of the specific objectives have to be done not individually for each teacher of the Department, but they should be established by consensus between all members for being more effective. In this way, objectives will have more consistency and accuracy by matching different experiences (COMMITTEE, 1996). The collaboration of students can be particularly useful to get a list of affordable and achievable objectives, and to promote active participation and accountability of students in their own learning (Steele et al., 1987).

The specific objectives should consider the taxonomic fields of knowledge, skills and attitudes (Seaman, 2011). They could be formulating as: to identify, to interpret, to understand, to resolve. With respect to PS in anatomy, it is important to consider relevant anatomical details from the clinical point of view, however, anatomy educators should be cautious as to not include details that are not relevant (Sañudo et al., 2004). In general, a useful guideline to keep in mind when developing the specific objectives of the Human Anatomy course is to consider the main statements approved in the 2nd Pan American Association of Anatomy Congress (Caracas, Venezuela, 25-31 July, 1969) in relation with "general problems of teaching Morphology" (Sañudo et al., 2004).

Morphology teaching should be based on an active method, scientific, and directed study, in which the student's individual work has vital importance. It should project the dynamic knowledge of a living patient relative to findings during the course of dissection; thus, allowing the student to understand the functional, pathological, psychological, social aspects of human disease. Both didactic (i.e., theory) sessions and PSs must have the unified purpose of preparing students for self-directed learning and self-training.

Ideally, this method of addressing objectives should be integrated not only into teaching human gross anatomy, but also into all of the related anatomy disciplines (i.e., medical imaging, ultrastructure, embryology, and histology). Further, in developing any program, teaching of these related disciplines are key to integrated learning and clinical application, that should be incorporated as soon as possible in the program. Because of the importance of

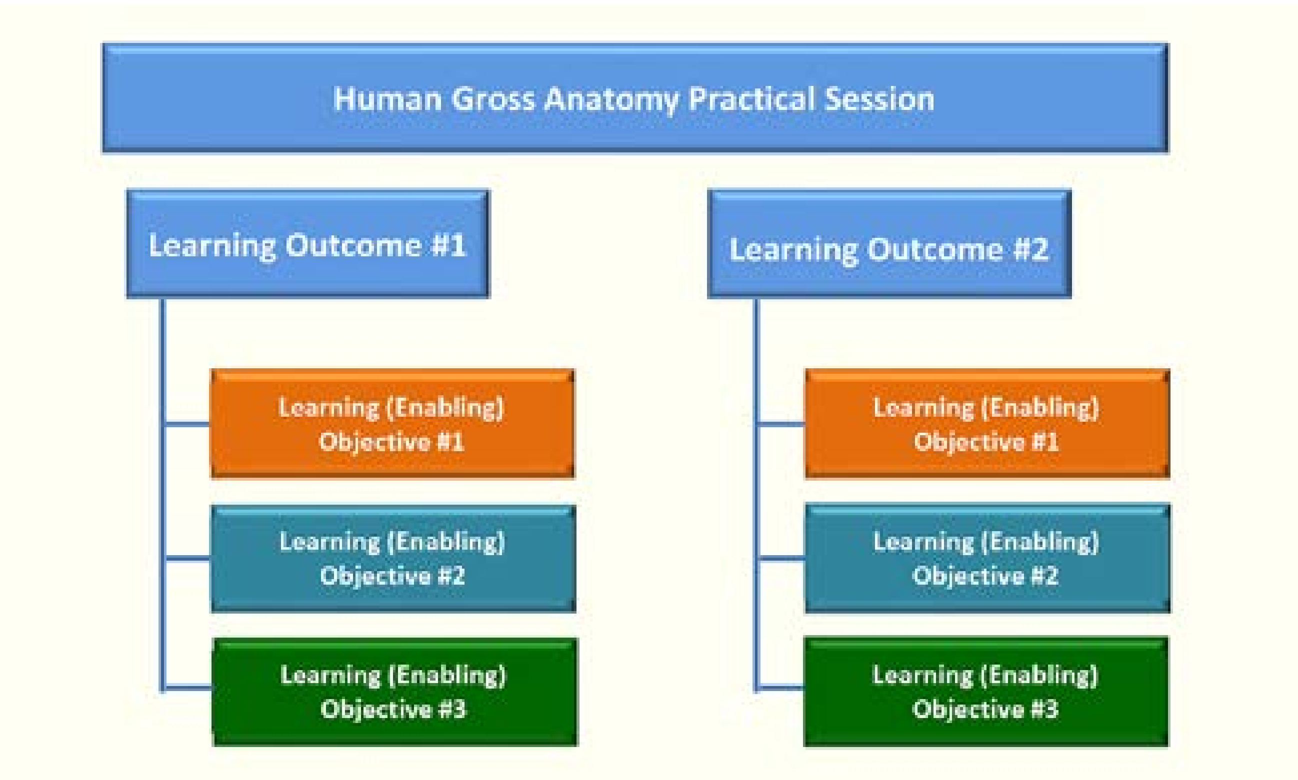

Fig. 1.- Objectives and learning outcomes in anatomy practical sessions. Learning outcomes are specific statements of what students will be able to do when they successfully complete a learning experience. Learning objectives (i.e., goals or enabling objectives) address a component of the learning outcome and help track the learner's progress towards that objective.

early morphological knowledge of man in health sciences, it is advisable to seek coordination with other basic and clinical disciplines. Thus, it is suggested to adopt the Terminologia Anatomica, not only for the anatomists but also for the rest of member of the health Faculties (Dirckx, 1998).

Table 2. Elements of effective Learning Outcomes.

ELEMENT	DESCRIPTION
Student-Centered	Outcomes are phrased from the perspective of the student and are written in language that can be easily understood by them.
Measurable	Outcomes emphasize higher-order thinking and are consistent with university, college, department, and program learning outcomes or objectives.
Concise	Outcomes are written in short, succinct sentences.
Meaningful	Outcomes emphasize higher-order thinking and are consistent with university, college, department, and program learning outcomes.
Achievable	The total number of outcomes is reasonable for this population of students and is achievable within the time available.
Out-come-Based	Outcomes should specify the skills and knowledge students must demonstrate to prove mastery instead of focusing on the assignment format, such as a quiz or essay. Well-worded outcomes should remain flexible enough to accommodate a variety of formats for a corresponding assessment.

ORGANIZATION

The PSs of Human Anatomy in different countries are composed of different elements of gross anatomy, histology and developmental biology. Herein, attention is focused on aspects related to the organization (or development) of PSs in gross anatomy.

One principle for efficiency of PSs is that they should take place immediately after lecturing of the corresponding topic. In this way students could reinforce their learning. If this is impossible, they should be done as close to the lectures as allowed.

During PSs we expect that students, at minimum, receive some knowledge, skills and attitudes in relation with objectives proposed (Seaman, 2011). This includes:

1. The verification of anatomical details should be not accomplished only by observing, but on interpreting details and anatomical relationships in the spirit of observation. Some teachers recommend drawing specimens presented: bones, topographical sections, prosections, etc. (de Pablo and Díaz, 2008).
2. The acquisition of skills not only arise from the practice of dissection but also reflective and critical thinking of findings. Therefore, it is important to promote discussion between group members about the specific objectives proposed for the session.
3. Learning of clinical reasoning skills, which is important for the development of a systematic and efficient approach to clinical cases that will serve medical trainees in all subsequent educational endeavours and in their careers in medicine (Elizondo-Omaña et al., 2010; Talarico, 2010, 2013; Talarico Jr, 2010).
4. The acquisition of attitudes should be based first on the acceptance of rules previously established for respecting the anatomical body-donor (Talarico, 2010, 2013) and the dissecting room: wear coat with identification, wear gloves, no drinks or meals are allowed, etc. That rules are for sanity and security and should be hang in the entrance of the dissecting room.

Experience by these authors suggests that not all students of the group read guidelines. Therefore, the recommendation is that before starting the session a brief explanation be given to students that contextualizes the PS relative to lectures aims justifying the specific objectives improve student progress.

PSs should be done in small groups, under the direct supervision of a teacher (Talarico, 2010, 2013). It is important that students be responsible and become self-aware and self-directed learners. Therefore, educator should limit help, but should ask provoking questions, assist students in critical thinking and encourage student progress and learning. In some countries secondary to the student/teacher ratio in the PS, retired surgeons, young practitioners (i.e., in the United Kingdom), near peer instructors volunteer to act in the role of teachers for the PS (Durán et al., 2012; Reyes-Hernández et al., 2015).

Pabst et al. (1986) suggested that, in addition to movies/films focused on individual topographic regions for dissection, those films that included clinical case content are also appropriate in the teaching of Human Anatomy. These films including clinical cases, introduce and explain clinical terms and enable students to understand the relevance of anatomy to their medical studies (Pabst et al., 1986). In addition, students realize the differences in anatomy between embalmed vs. fresh cadaveric materials (Pabst et al., 1986). Aside from movies/films, it is recommended that an area of the dissection laboratory be adapted for the study of clinical imaging (i.e., X-ray, CT, MRI, and ultrasound) relative to the region of the cadaver being dissected. This area should be fitted with computers, high-resolution monitors, etc. Further, the reduction in the cost for ultrasonography devices, make it possible to extend their use to student volunteers (and the cadaver) via portable, hand-held devices. Therefore, objectives, clinical correlations and exercises should be incorporated into PSs that not only involve the exploration of surface and internal anatomy, but also otoscopy, ophthalmoscopy, laryngoscopy, ultrasound (and other imaging modalities), as well as articulation movements, balance, gait and stance. When the use of radiological material is involved, it should focus on the identification and description of anatomical structures when related to dissection, in contrast to when using clinical cases, then the radiology should focus on relating anatomy to what happens within the patient so that students can improve their clinical reasoning skills (Durán et al., 2012).

A critical aspect to each PS is that faculty must never fail to improvise and correlate the use of all materials used within the session. Faculty and graduate teaching assistants/fellows must fully comprehend the objectives, procedures of dissection, and the complementary material (i.e., radiological material, prosections, clinical cases, etc.) being used during the PS. If instructors are not familiar with them, then students will be frustrated and discouraged, and will lose interest and faith in both instructors and the course. The latter should make it difficult to recover the trust of the student in the staff.

It is important to address that when PSs are based on the use of anatomical donors that an introductory session, possibly named "practice zero" (or something similar) should be incorporated (Talarico, 2010,2013). In this PS, faculty can elaborate on:

1. anatomical donors.
2. the anatomical donation process.
3. care, respect, professionalism and human dignity with regard to anatomical donors.
4. issues of life and death.
5. anatomical variations versus the "ideal anatomy" that is represented in many atlases and textbooks.
6. skilled use of surgical instruments, etc.

This "zero session" permits to contextualise the dissecting room in the life of the students as future professional of health sciences. Finally, to promote this and the interest and responsibility of students, it is recommended that knowledge, skills and attitudes be assessed at the end or during developing of the PSs. This can be done by:

1. individual or small group presentations
2. steeplechase (or laboratory practical)
3. peer-teaching hand-off
4. multiple choice questions

DIGITALIZATION AND MEDIA IN THE DISSECTING ROOM

Every professional educator understands that students remember approximately 20% of what they hear, 30% of what they see and 50% of what they hear and see (Howe, 1977). Therefore, the use of appropriate audio-visual media will enhance the level of understanding of a topic at the same time promote long-term retention of information.

In medical education the use of audio-visual media has a long history (Ramey, 1964):

Although useful, they should not replace cadaveric dissection. Cadaver dissection remains the *Gold Standard* in anatomy teaching. However, PSs might be recorded, stored (i.e., in a digital library) and therefore, accessed for student use at request (on their own time and at their own pace). Recorded PSs can be used as a supplement during dissection to help students to solve doubts that are frequently presented during the dissection practice (Omaña and Vilchez, 2006).

Moreover, the use of videotapes facilitates the extension of this type of information to a greater number of students (Cox and Ewan, 1988). In addition, recordings are useful for teaching specifically dynamic activities such as procedures of dissection or joint movements. An additional tool is live recording with direct transmission to dissection rooms/theatres of more sophisticated dissection procedures as demonstrated by professionals (i.e., correct opening of the orbit from above).

There are many different media products: videotapes, computer programs, CD-ROM, DVD, etc. These products have the advantage of lower cost. However, the major disadvantages is the inability to interact directly with them; the exception being some computer programs (Brenton et al., 2007). Yet, the incorporation of computer video projector dissecting rooms, associated with the development of multimedia programs suitable and easy to use, has facilitated a vast array of products (Carmichael and Pawlina, 2000). These programs allowed genuine multimedia presentations that incorporate diagrams and tables, images, movies and sound (Newble and Cannon, 2001). Currently, the most widely used program is Microsoft PowerPoint *(Microsoft Corporation*, Redmond, WA, USA). This program also allows text, images and sound can occur with a diverse variety of effects, among which is included the use of animation (Carmichael and Pawlina, 2000). However, faculty must exercise caution because such effects, if abused, can cause interference with the primary objective of the presentation which is to convey in the most realistic possible information. Still further, the projection of videos are not generally adequate to accomplish during the PSs because they need a darker room that results in the interruption of the normal course of the class (Katz et al., 1978; Randall, 1987). However, if the films are clear and well done, they can be an excellent complement to PS. It is the recommendation herein, that it is more convenient to project them at the beginning or at the end of the session, always ensuring that their content enrich student learning.

COMPUTER AIDED INSTRUCTION

There are many computer-based anatomical programs like: ADAM (Animated Dissection of Anatomy for Medicine), MacMan, Digital Anatomist, The Visible Human Data Set, Anatomage, etc. These programs are usually categorized into self-assessment packages, tutored exercises, simulated models and clinical problems. From the point of view of the authors, computers can be particularly effective to facilitate self-assessment. However, the programs dedicated to simulation or to illustrate dynamic processes and their application clinical scenarios are also useful (Katz et al., 1978; Randall, 1987). Simulated clinical problems cover all aspects of patient management that a future physician may encounter; thus, students can face “real-life” situations, examine the results of their decisions, and reflect and review for improvement. Although more inherent to teaching courses in clinical years, multidisciplinary collaboration in drafting the integration of such modalities into medical education curricula facilitates students’ understanding of the relationships, value and importance (Bidwell et al., 1985).

A disadvantage is that many programs are more specific and available only in the institutions that they were created. Therefore, objectives and learning outcomes of the “institutional package” my not coincide your own PS requirements. And, if faculty desire to develop or adapt the “institutional package” to their own specific requirements, then the cooperation of specialists in programming and systems design may be needed, and the costs prohibitive. A final disadvantage is that although qualitative studies on these computerized programs exist, an extensive literature survey shows no studies that quantitate and validate improvements in student outcomes.

THE HUMAN BODY AND THE DISSECTING ROOM

Considering that the morphology of the human body can be learned by means other than direct observation of anatomical donors, media, models and radiology have been gaining popularity in recent. Therefore, at present there are many departments of Human Anatomy that do not use the anatomical donors for teaching anatomy (NA Moore, 1998). Today, many dissecting rooms are no longer like a field of numerous tables with anatomical donors, but are rooms with computers, anatomical models, internet points, TV screens and DVD or CDs, etc. (Cahill and Leonard, 1999). These anatomical models could be of a great quality but in any case, they lack the expression of the reality of the human body (i.e., age, death, disease, texture of structures and organs, anatomical variations and many other qualities) that can only be viewed, felt and appreciated by hands-on dissection of the body. Therefore, it is opined that the anatomical donor is the best model and the *Gold Standard*.

Radiological images (i.e., X-Rays, CT, MRI, ultrasound, etc.) do not need the plastic format and the source of light for being analysed (Schramek et al., 2013; Swamy and Searle, 2012). In modern times, they can be observed by means of a computer and a screen or video projector. Images of the different modalities as mentioned above, represent one alive instant of a particular patient frozen in time. But does this mean that the anatomical donor is no longer necessary for learning anatomy? One can argue that students can learn anatomy solely with the use of clinical images. However, in the best educational practice, radiological images are a perfect complement for teaching in the dissecting room but in correlation with the reality of body-donor sections, prosections and dissections of the same region. Collectively, this facilitates a student's better understanding of anatomy, 2D radiological images, and disease.

The human anatomical donor represents for most students, the first experience of the contact of the five senses with a real 3D model, not with plastic or digital human models – but a true human body (KL Moore, 1989). Therefore, it is not a surprise that for some authors, dissection could be considered as a feast for the human senses (Aziz et al., 2002).

Moreover, the value of the body-donor is more, it adds realism and hence it encourages students to reflect and discuss concepts such as morbidity, mortality, variations of the human body, ethics and end-of-life issues (Bergman, 1988; Brennan et al., 1991; Konschake and Brenner, 2014; Lippert and Pabst, 1985; Marc Rodríguez-Niedenführ et al., 2002; M Rodríguez-Niedenführ et al., 2001; Sañudo et al., 2003; Talarico, 2010,2013; Tubbs et al., 2016). In addition, another value of anatomical donors is that the hands-on discovering structures and organs and anatomical relationships is essential to the skills necessary for future medical training. No digital programs, models or radiological images can provide the above-mentioned aspects to student. The human body-donor, therefore, can never be replaced.

If the anatomical donor is so important for learning anatomy, how is possible that now cadavers are used in fewer departments? The progressive abandonment of the practice of dissection in the Departments of Human Anatomy are justify for many reasons (Ellis, 2001):

1. The arrival of medical education experts who advocate a model based on the resolution of problems, where the anatomy happens to have a secondary role in medical training.
2. The pressure of researchers to gain new space for its laboratories with the offense involved large spaces containing the dissecting rooms.
3. The "high cost" involved in maintenance personnel, equipment, chemicals and infrastructures of the dissecting room for administration.

Finally, it is important to mention that learning Human Anatomy based on the use of the anatomical donors to science facilitates the student to question aspects such as biological variations and pathological changes - *aspects of great importance in the practice of medicine* (Ellis, 2001; Granger, 2004; Konschake and Brenner, 2014). Therefore, the anatomical donor introduces students to the medical world by means of death. Like in the

Renaissance (University of Padova, Italy), when in the frontispiece of the main gate of the dissecting room were the phrase “Hic locus est ubi mors gaudet succurrere vitae” (“This is the place where death delights in helping life”). Another beautiful example of such fundamental truth appears at one of the entrances of the Department of Anatomy, Histology and Embryology of the Medical University of Innsbruck (MUI): “Mors auxilium vitae” (“The dead serve the living”).

Recently, different documents (Book or Journal’s Supplement) have appeared that examine the dissecting room in a wide sense (i.e., from the donation to preservation and dissection) with the aim of facilitate the study of the Anatomy with the minimum of risk in terms of security and hygiene. Herein, the team of the present work cites an excellent book and supplement for people that would like to learn more about the process for studying with human bodies (Chan and Pawlina, 2015).

REFERENCES

ALYAFI MM, ALAMODI AA, JUURLINK BH, GANGULY P (2012) How the dissection laboratory facilitates integration of learning: presence of abdominal aortic aneurysm with a large intracardiac thrombus: a rare cadaver finding. *Int J Angiol,* 21(2): 77-80.

AZIZ MA, MCKENZIE JC, WILSON JS, COWIE RJ, AYENI SA, DUNN BK (2002) The human cadaver in the age of biomedical informatics. *Anat Rec,* 269(1): 20-32.

BENNINGER B, MATSLER N, DELAMARTER T (2014) Classic versus millennial medical lab anatomy. *Clin Anat,* 27(7): 988-993.

BERGMAN RA (1988) *Compendium of human anatomic variation: text, atlas, and world literature*: Urban & Schwarzenberg.

BIDWELL CM, COLLINS-NAKAI RL, TAYLOR WC, JENSEN WA (1985) Multidisciplinary team production of computer-based simulations to teach pediatrics. *J Med Educ,* 60(5): 397-403.

BRENNAN TA, LEAPE LL, LAIRD NM, HEBERT L, LOCALIO AR, LAWTHERS AG, HIATT HH (1991) Incidence of adverse events and negligence in hospitalized patients: results of the Harvard Medical Practice Study I. *New Eng J Med,* 324(6): 370-376.

BRENTON H, HERNANDEZ J, BELLO F, STRUTTON P, PURKAYASTHA S, FIRTH T, DARZI A (2007) Using multimedia and Web3D to enhance anatomy teaching. *Computers & Education,* 49(1): 32-53.

BUNGE M (2012) *Scientific research II: The search for truth.* Springer Science & Business Media.

CAHILL DR, LEONARD RJ (1999) Missteps and masquerade in American medical academe: clinical anatomists call for action. *Clin Anat,* 12(3): 220-222.

CAPPABIANCA P, MAGRO F (2009) The lesson of anatomy. *Surg Neurol,* 71(5): 597-598; discussion 598-599.

CARMICHAEL SW, PAWLINA W (2000) Animated PowerPoint as a tool to teach anatomy. *Anat Rec,* 261(2): 83-88.

CHAN LK, PAWLINA W (2015) Teaching Anatomy. A Practical Guide. Switzerland: Springer International Publishing.

COMMITTEE EA (1996) A clinical anatomy curriculum for the medical student of the 21st century: gross anatomy. *Clin Anat,* 9(2): 71-99.

COX KR, EWAN CE (1988) *The medical teacher.* Churchill Livingstone.

DE PABLO PC, DÍAZ JF (2008) *Recursos didácticos en ciencias naturales.* Real Sociedad Española de Historia Natural.

DI DIO LJ (1999) The importance of anatomy. *Ann Anat,* 181(5): 455-465.

DIRCKX JH (1998) Federative Committee on Anatomical Terminology (FCAT). Terminologia Anatomica. International Anatomical Terminology. *Terminology. International Journal of Theoretical and Applied Issues in Specialized Communication, 5*(2): 279-283.

DRAKE RL, MCBRIDE JM, LACHMAN N, PAWLINA W (2009) Medical education in the anatomical sciences: the winds of change continue to blow. *Anat Sci Educ,* 2(6): 253-259.

DURÁN CE, BAHENA EN, RODRÍGUEZ MDE, BACA GJ, URESTI AS, ELIZONDO-OMAÑA RE, LÓPEZ SG (2012) Near-peer teaching in an anatomy course with a low faculty-to-student ratio. *Anat Sci Educ,* 5(3): 171-176.

DYER GS, THORNDIKE ME (2000) Quidne mortui vivos docent? The evolving purpose of human dissection in medical education. *Acad Med,* 75(10): 969-979.

ELIZONDO-OMAÑA RE, MORALES-GÓMEZ JA, MORQUECHO-ESPINOZA O, HINOJOSA-AMAYA JM, VILLARREAL-SILVA EE, GARCÍA-RODRÍGUEZ MDLA, GUZMÁN-LÓPEZ S (2010) Teaching skills to promote clinical reasoning in early basic science courses. *Anat Sci Educ,* 3(5): 267-271.

ELLIS, H (2001) Teaching in the dissecting room. *Clin Anat,* 14(2): 149.

GARMENT A, LEDERER S, ROGERS N, BOULT L (2007) Let the dead teach the living: the rise of body bequeathal in 20th-century America. *Acad Med,* 82(10): 1000-1005.

GRANGER NA (2004) Dissection laboratory is vital to medical gross anatomy education. *Anat Rec Part B: The New Anatomist,* 281(1): 6-8.

HOWE MJ (1977) *Adult learning: Psychological research and applications.* J. Wiley.

KATZ S, HOLLINGSWORTH RG, BLACKBURN JG, CARTER HT (1978) Computer simulation in the physiology student laboratory. *Physiologist,* 21(6): 41-44.

KONSCHAKE M, BRENNER E (2014) “Mors auxilium vitae”--causes of death of body donors in an Austrian anatomical department. *Ann Anat,* 196(6): 387-393.

KORF HW, WICHT H, SNIPES RL, TIMMERMANS JP, PAULSEN F, RUNE G, BAUMGART-VOGT E (2008) The dissection course - necessary and indispensable for teaching anatomy to medical students. *Ann Anat,* 190(1): 16-22.

LIPPERT H, PABST R (1985) *Arterial variations in man: classification and frequency.* Springer.

MCLACHLAN JC, PATTEN D (2006) Anatomy teaching: ghosts of the past, present and future. *Med Educ,* 40(3): 243-253.

MILLER GE (1961) *Teaching and learning in medical school.* Published for the Commonwealth Fund, by Harvard University Press.

MOMPEÓ B, PÉREZ L (2003) Relevancia de la anatomía humana en el ejercicio de la medicina de asistencia primaria y en el estudio de las asignaturas de segundo ciclo de la licenciatura en medicina. *Educación Médica,* 6(1): 47-57.

MOON K, FILIS AK, COHEN AR (2010) The birth and evolution of neuroscience through cadaveric dissection. *Neurosurgery,* 67(3): 799-809; discussion 809-810.

MOORE KL (1989) Meaning of “normal”. *Clin Anat,* 2(4): 235-239.

MOORE NA (1998) To dissect or not to dissect? *Anat Rec,* 253(1): 8-9.

MOXHAM B, PLAISANT O (2007) Perception of medical students towards the clinical relevance of anatomy. *Clin Anat,* 20(5): 560-564.

NEWBLE DI, CANNON RA (2001) *A handbook for medical teachers*: Springer Science & Business Media.

OLDER J (2004) Anatomy: a must for teaching the next generation. *Surgeon,* 2(2): 79-90.

OMAÑA RE, VILCHEZ F (2006) An interactive tool for the human anatomy laboratory. *Int J Morphol,* 24(3): 377-382.

PABST R, WESTERMANN J, LIPPERT H (1986) Integration of clinical problems in teaching gross anatomy: living anatomy, X-ray anatomy, patient presentations, and films depicting clinical problems. *Anat Rec,* 215(1): 92-94.

RAMEY JW (1964) Television: growing pains of a new teaching medium. *J Med Educ,* 39: 1107-1113.

RAMÓN Y CAJAL S (1940) Reglas y consejos sobre investigación científica: Los tónicos de la voluntad.

RAMSEY-STEWART G (2014) Anatomy teaching: confusion continues. Do surgeons have the answer? *ANZ J Surg,* 84(11): 800-801.

RANDALL JE (1987) *Microcomputers and physiological simulation*.

REYES-HERNÁNDEZ CG, CARMONA PULIDO JM, DE LA GARZA CHAPA RI, SERNA VÁZQUEZ RP, ALCALÁ BRIONES RD, PLASENCIA BANDA PM, ELIZONDO OMAÑA RE (2015) Near-peer teaching strategy in a large human anatomy course: Perceptions of near-peer instructors. *Anat Sci Educ,* 8(2): 189-193.

RODRÍGUEZ-NIEDENFÜHR M, VÁZQUEZ T, GOLANÓ P, PARKIN I, SAÑUDO JR (2002) Extensor digitorum brevis manus: anatomical, radiological and clinical relevance: a review. *Clin Anat,* 15(4): 286-292.

RODRÍGUEZ-NIEDENFÜHR M, VÁZQUEZ T, NEARN L, FERREIRA B, PARKIN I, SAÑUDO J (2001) Variations of the arterial pattern in the upper limb revisited: a morphological and statistical study, with a review of the literature. *J Anat,* 199(5): 547-566.

SAÑUDO J, VÁZQUEZ R, PUERTA J (2003) Meaning and clinical interest of the anatomical variations in the 21 st century. *Eur J Anat,* 7(1): 1-3.

SAÑUDO J, VÁZQUEZ R, RIESCO J, FONOLLÁ AJP (2004) The teaching of human Anatomy in Spain at the beginning of the twenty-first century. *Eur J Anat,* 8(3): 155-163.

SCHRAMEK GG, STOEVESANDT D, REISING A, KIELSTEIN JT, HISS M, KIELSTEIN H (2013) Imaging in anatomy: a comparison of imaging techniques in embalmed human cadavers. *BMC Med Educ,* 13: 143.

SEAMAN M (2011) Bloom's Taxonomy. *Curriculum & Teaching Dialogue,* 13.

STEELE R, ABBATT FR, ORGANIZATION WH, ASSOCIATION IFOMS (1987) *Peer learning in health science education: an alternative didactic method*.

SUGAND K, ABRAHAMS P, KHURANA A (2010) The anatomy of anatomy: a review for its modernization. *Anat Sci Educ,* 3(2): 83-93.

SWAMY M, SEARLE RF (2012) Anatomy teaching with portable ultrasound to medical students. *BMC Med Educ,* 12: 99.

TALARICO EF JR (2010) A human dissection training program at Indiana University School of Medicine-Northwest. *Anat Sci Educ,* 3(2): 77-82.

TALARICO EF JR (2013) A change in paradigm: giving back identity to donors in the anatomy laboratory. *Clin Anat,* 26(2): 161-172.

TALARICO JR EF (2010) A human dissection training program at Indiana University School of Medicine-Northwest. *Anat Sci Educ,* 3(2): 77-82.

TUBBS RS, SHOJA MM, LOUKAS M (2016) *Bergman's comprehensive encyclopedia of human anatomic variation*: John Wiley & Sons.

WINKELMANN A (2007) Anatomical dissection as a teaching method in medical school: a review of the evidence. *Med Educ,* 41(1): 15-22.

ZUMWALT AC, MARKS L, HALPERIN EC (2007) Integrating gross anatomy into a clinical oncology curriculum: the oncoanatomy course at Duke University School of Medicine. *Acad Med,* 82(5): 469-474.

Practical postgraduate teaching in Human Anatomy: A review

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SUMMARY

Anatomy is a fundamental subject for both medical and surgical training. Anatomy departments might collaborate with clinicians organizing continuing medical education (CME) and other professional development courses. The courses should have a large practical component (in content and organization) but also should provide the latest scientifically based theoretical knowledge, respecting the learning of anatomy as well as aiming at performing different techniques. Anatomy departments should support these courses by establishing hands-on practical training courses and components.

Key words: Applied anatomy – Clinical anatomy – Education – Surgical anatomy – Teaching – Continuing medical education

ABBREVIATIONS

Continuing Medical Education (CME)

International Federation of Anatomical Associations (IFAA)

Federative International Programme for Anatomical Terminology (FIPAT)

INTRODUCTION

The discussion about continuing medical education (CME) courses and gross anatomy tends to cover historical, academic and epistemological aspects. Therefore, it would seem logical that these courses should also include the opinions of practicing professionals, especially since experiments have shown that, when it comes to setting learning objectives, the latter vary

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according to whether they are suggested by an educator of Anatomy or a professional in clinical practice (Chevrel, 1992).

A review of the literature shows that undergraduates in medicine and graduating residents rate anatomy as a highly relevant and a core essential of training affecting the outcomes of patient care (Pabst, 1993; Pabst and Rothkötter, 1997; Saavedra et al., 2016; Talarico Jr, 2010). Further, in a study done in Spain, Mompeó and Pérez (2003) found that physicians and students (in their final year of formal education) considered gross anatomy as fundamental in physical examination and medical image interpretation. These authors also recognized that these two study groups would have increased the number of practical lessons offered in the curriculum. Interestingly, some findings show that there is a clear bias related to the clinician's speciality; in general, surgeons were more favourably inclined towards anatomy than physicians. Indeed, surgeons chose anatomy as the most important basic science for their daily clinical practice while physicians chose physiology (Arráez-Aybar et al., 2010). Arráez-Aybar et al. (2010) showed that surgeons made a positive evaluation for anatomy, 30-40% higher than other physicians. In this sense, surgeons considered anatomy more relevant in terms of their everyday activity and in relation to physical exploration, interpretation of symptomatology, imaging techniques, or during the therapeutical procedures. In contrast, physicians in non-surgical specialties considered anatomy less important but more relevant in all the items with the exception of the therapeutical procedures that logically are less relevant (Arráez-Aybar et al., 2010). Furthermore, also many other medical disciplines require thorough anatomical knowledge such as rheumatology, radiology and all other disciplines performing ultrasonography and interventional procedures (Bandinelli et al., 2011; Hernández-Díaz et al., 2017; Navarro-Zarza et al., 2014; Villaseñor-Ovies et al., 2016). Knowledge in clinical, applied anatomy might be the baseline of every medical procedure performed. In summary, the clinicians answered that gross anatomy was the basic science considered most relevant in their daily clinical activity, not only for making the diagnosis, but also for therapeutics. This fact reinforces the historical relation between anatomy and other medical disciplines, but it does not mean that physicians do not consider anatomy a very relevant discipline in their daily activity (Arráez-Aybar et al., 2010).

This can be seen in many departments of Anatomy where postgraduate workshops are organized for many societies that mainly include physicians. The trend is recognizable in that many different fields of medicine request workshops, such as anaesthesia, orthopaedics, emergency medicine, neural therapy, pain therapy, implantology and primary care practice. Hence, there is an ongoing need for postgraduate courses in human gross anatomy for clinical professionals, surgeons or clinicians. Even further, the suggestion is that relevance and need for practical training in gross anatomy seems to be a "global" opinion, and yet in an era where revised medical education curricula decrease the time devoted to teaching anatomy. Therefore, the aim of this article was to summarize and highlight anatomical principles that should be considered in postgraduate education and which criteria should lead as a guideline.

ANATOMICAL PRINCIPLES

The present team of investigators suggest that there are three essential principles that should be considered in the postgraduate teaching courses for gross anatomy:

1. avoid malpractice by understanding normal anatomy and anatomical variations.
2. understand applied anatomical research using the cadaver and with the practice of surgical or clinical techniques.
3. learn the international anatomical terminology.

Good Medical Practice. Normal and Anatomical Variations

It has been estimated that the number of avoidable deaths per year in the USA is about 80,000 (Brennan et al., 1991). It is suspected that some of these deaths can be directly attributed to anatomical incompetence (Cahill and Leonard, 1999). This highlights the need for continued training in basic sciences with the aim of avoiding mistakes during daily clinical practice.

Clinicians and surgeons suggest that a sound anatomical knowledge helps to avoid mistakes during daily practice in 34.5% of cases for internal medicine specialists, in 55% of cases for pneumologists, in 80% of cases for ENT surgeons, and in 84.9% of cases for orthopaedic surgeons (Sañudo et al., 2007). Thus, it is not surprising that CME courses are supported, and considered necessary by many surgical and medical organizations around the world.

CME and adjunct workshops must take into account not only the anatomy considered as "normal anatomy" but should also be extended to include knowledge of anatomical variations (Sañudo et al., 2003).

The importance of anatomical variations in clinical practice is clear as knowledge of these could help to avoid confusion with pathological disorders or the missing of normal structures of a given anatomical region. For example, to know that, in 18% of cases there could be two main arteries along the arm and elbow (one of them with a superficial course), could avoid malpractice performing a venous puncture in the elbow region or a forearm flap (Rodríguez-Niedenführ et al., 2001). Additionally, in order to make a diagnosis of a tumor in the dorsum of the wrist by imaging techniques such as MRI, it is necessary to take into consideration that, in 2% of cases, an extensor digitorum brevis manus muscle could exist and be mistaken with a benign tumor (Rodríguez-Niedenführ et al., 2001). Injury of the recurrent motor branch of the median nerve may occur during carpal tunnel release if anatomical variations of the distal medial nerve branching are unknown (Elsaftawy et al., 2013). Iatrogenic injuries are also described in the lower limb as a result of the ignorance of anatomical variations; an aberrant course of the anterior tibial artery along the anterior surface of the popliteal muscle may put this artery at risk during surgical procedures around the knee (Klecker et al., 2008). Variations in the anatomy of the lateral femoral cutaneous nerve are of clinical importance in bone harvesting from the iliac crest for autologous bone grafting; this nerve can be damaged if surgeons do not take into account that it can, sometimes, appear laterally to the anterior superior iliac spine (den Brave et al., 2015). Furthermore, even in minimally invasive surgery, such as ankle arthroscopy, the dorsalis pedis artery can be injured if the anatomical variations of that vessel may ignored when performing the approaches (Parikh et al., 2017).

This problem can also be seen in the field of regional anaesthesia, where variations become more and more important due to the fact that ultrasound guided techniques create anatomical images that need to be correctly interpreted (Feigl and Dreu, 2010; Hansen et al., 2020; Nielsen et al., 2019a, b). In case of denying, or ignoring, these variations this can cause major complications. Such variations need to be published to inform clinicians (Feigl and Pixner, 2011). Therefore, knowledge of anatomical variations must be communicated to physicians, scientists and educators through publications, scientific meetings, seminars, CME and other workshop programs. Nevertheless, the scope and the limit of learning all of these variants have to be discussed; some variants occur only once or twice in the working life of a medical practitioner and if you have not seen them before, you will not immediately recognize them. So, where is the boundary for the learner between a variant he/she should know (i.e., a frequent variant)? The authors opine that this has to be discussed for every training in close consultation between the clinically trained anatomists and the clinical practitioner bearing in mind the goal of each course.

Understand applied anatomical research using the body-donor and with the practice of surgical or clinical techniques

In the 19th century, the Spanish Nobel Prize-winner, Ramon y Cajal, wrote to his friend, Federico Oloriz (Professor of Anatomy in the Complutense University), telling him that descriptive anatomy was a dead science in which it was very difficult to find anything new. Cajal advised that it would be better to move towards other fields that were waiting to be explored such as histology, genetics, physiology (Carlos, 1974). If that opinion was already uttered in the 19th century, it is not difficult to imagine what the opinion of many other anatomists is today. However, most anatomists understand that it is one thing to open up new frontiers in research and quite another “to cultivate the land that has been conquered”. Gross anatomy can still be considered as an active area of research, because with the introduction of new technologies for diagnosis and daily clinical practice, anatomy is constantly being rediscovered. At the very least this is true in the sense that known, as well as unknown, structures can now be easily studied and visualised; something that nobody would have foreseen in the 19th century. This becomes obvious if you take as examples new techniques, such as surgical techniques based on endoscopy, or imaging techniques based on computed tomography or Magnetic Resonance Imaging. Consequently, new fields of anatomy evolved such as surgical anatomy, radiologic anatomy, predictive anatomy, and interventional anatomy (Konschake et al., 2020; Konschake et al., 2016; Macchi et al., 2008; Moroni et al., 2019; Myrcha et al., 2020; Nielsen et al., 2019a, b). Nevertheless, it must be clearly stated that nothing new is discovered with the new methods, anatomy remains the same. Rather, anatomy is being “newly discovered” by numerous anatomists. Bearing in mind that if one would read the old books by Henle, Spalteholz etc., everything has been described a hundred times over, but today people are of the opinion that what cannot be found on the internet or what is not published in English, does not exist. Therefore, in the field of applied anatomy, new techniques are on the rise here such as cinematic rendering (Binder et al., 2019; Elshafei et al., 2019). Digitalization, especially virtual reality (VR), are being advanced. One example is the wearing of 3D VR goggles working with a scalpel and drilling on a virtual corpse. This, so far only done with a petrous bone give the operator the impression and feel of the “real-life” situation. The operator can see blood flowing, and the VR model give the operator the impression that he/she has to press harder to remove more tissue/bone and surgery progresses. Therefore, digitalization might become part of postgraduate and pregraduate education.

The importance of gross anatomy in the 21st Century is encompassed under the title of clinical anatomy. Anatomy is a morphological science that cannot fail to interest the clinician. The practical application of anatomical research to clinical problems is continuous in daily clinical activity. Therefore, it can be strongly agreed that research in anatomy should go hand-in-hand with the collaboration of other clinical departments (i.e., radiology, surgery, gynecology, interventional cardiology, etc.), with this viewpoint, there is a dynamic perspective; not only with the knowledge of a problem or disease but also with the knowledge of the structures underlying the problem (i.e., the anatomy). It is also strongly opined that medical research must involve undergraduate students, medical students and residents, not just teachers or specialists (Hammer et al., 2016; Morelos Avalos et al., 2014). This is also the view taken by the Liaison Committee on Medical Education (i.e., the accreditation institute for medical schools in the USA); that endorses the opportunity for every student to be involved in research via wide-spread medical education curricular reforms in the USA.

It is the experience of the team herein that surgical and radiologic anatomy can work together in researching and planning new surgical approaches. The main steps are:

1. identification of a clinical problem and the underlying anatomy.
2. exploration of the anatomical basis of the technique through body-donors.
3. identification of the key anatomical structures and research using radiological imaging.
4. planning/designing a new surgical approach with patient safety as a priority.
5. analysis of the patient’s anatomy through medical imaging.
6. planning a patient-specific surgical approach.

Each step involves teamwork between Anatomists and Clinicians/surgeons. Further, in this case radiological anatomy acts as a transfer between anatomical research trough dissection and the living patient (Konschake et al., 2020; Konschake et al., 2016; Macchi et al., 2008; Tiengo et al., 2010). In addition, the application of other fields to anatomy, such as principles of fluid dynamics to the coronary arterial system, defines a new era of diagnostic, predictive and interventional anatomy (Ngo et al., 2020; Nguyen et al., 2013; Nguyen et al., 2018a; 2018b; 2018c; 2018d; Zuin et al., 2018).

Although, there is a tendency to believe that meaningful advances in anatomy are unlikely, constant revision is necessary.

Facts demonstrate that descriptive anatomy is an important basic science in medicine:

1. the increase number of papers about anatomy that are published in anatomy, surgical or radiological journals (i.e, *Annals of Anatomy*, *European Journal of Anatomy*), and
2. the good health of at least two international journals devoted to publishing research in clinical anatomy (*Clinical Anatomy* and the *Journal of Surgical and Radiologic Anatomy*). Additionally, it has to be mentioned that a lot of international clinical journals have increased their publications of clinically orientated, basic anatomical works.

ANATOMICAL TERMINOLOGY

Anatomy is the discipline that allocates the majority of words in a medical vocabulary (i.e., approximately 7,500 words). These names, descriptors and terms are applied in medicine worldwide, and are also used among scholars in basic and applied health sciences (Moore, 1989).

The goal of finding an international vocabulary that enables precise communication among health care professionals has a long history that began with the creation of the Basilea Nomina Anatomica in the language of Latin (BNA, 1895) (continuing with the Birminghan review (BR) and Jenenser Nomina Anatomica) then, in 1955, a unified document that was created in Paris known as the Nomina Anatomica. However, due to different problems, it was not until the Lisbon meeting of the International Federation of Anatomical Associations (IFAA) in 1994 that there arose an agreement for a unified document. Finally, in 1998, this was published under the new name Terminologia Anatomica (Terminology, 1998). The Federative International Programme for Anatomical Terminology (FIPAT) represents one of the seven programmatic areas of interest of the IFAA. FIPAT develops, publishes and maintains the set of international standard terminologies of human anatomical sciences. The official terminology is in Latin, but FIPAT also publishes English equivalents and encourages the IFAA Member Societies to publish translations of the IFAA terminologies in other languages.

In summary, the Nomina anatomica or the Terminología Anatomica is a list of names compiled for anatomists worldwide that represents a common language for referring to structures of the whole body. Even so, major problems occur. Clinicians mostly ignore the existing anatomical terminology and create their own language. Additional confusion arises when these clinicians use this self-created terminology when mentoring student doctors and residents during hospital and office rotations. Still further, this becomes more complicated when different fields or even specialists within one field use different interpretations, such as the fasciae of the neck. Another example is given by the use of different terminology to describe the coronary arteries and their branching patterns, as well as the numerous variations in the coronary arterial system.

As pointed out, difficulties in anatomical nomenclature still exists. Therefore, we propose a future creation of an “interactive nomenclature” which can be called up like “Wikipedia” and into which one can make entries as an “outsider”. These entries should and could have been checked by the FIPAT members in regular meetings and the anatomical nomenclature could have been updated regularly, i.e., every six months. Instead, meanwhile, we still do not have a more up-to-date anatomical nomenclature than the one from 1998, which is now 23-years-old.

WHO SHOULD ORGANIZE CME COURSES?

A recent article documented that surgeons believe that anatomical courses are necessary in their CME in 95.45% of cases (orthopaedic surgeons) or 97.7% of cases (ENT surgeons) (Sañudo et al., 2007). They also believe that clinical anatomists should participate in the CME courses in 92.42% (orthopaedic surgeons) or 95.5% (ENT surgeons) (Arráez-Aybar et al., 2010). This give rise to an interesting question: "Who or what agency should organize CME courses and workshops?".

Medical Professional Colleges recommend the introduction of periodic assessments with the aim of improving medical and surgical competence. In other words, they want to promote the CME. For example, the Royal College of Surgeons of England is committed to enable surgeons to achieve and maintain the highest standards of surgical practice and patient care. These institutions appeared in response to the academic world that took a more theoretical and conservative approach.

In many countries the only institution authorized to store human cadavers for surgical training are universities and some professional colleges. Therefore, surgeons that wish to undertake CME courses with cadaveric material must contact anatomy departments of colleges or universities. This requests a very well-organized body donation program which is not available in all countries of Europe. Switzerland provides a donation program which is differently developed in the swiss cantons. Problems in the donation program can be clearly seen in many countries. But there are examples of well working programs in Europe and the US. Departments of Anatomy partially offer one workshop per week. The Institutes organize in collaboration with different societies many workshops per year with many postgraduate participants.

WHAT ARE THE CRITERIA APPROPRIATE FOR DOING CME OR POSTGRADUATE COURSES?

In general, if a clinician went to an anatomy department with the aim of developing a CME course, there are two kinds of reactions that could be faced with. The clinician would either receive a simple offer of the department's facilities with an exclusive commercial interest or would be required to show real interest in getting involved in the project. From the point of view of the authors, courses using body-donor materials should be the result of an adequate balance between two different sensibilities: surgical and anatomical. Therefore, they should not be made only with the aim of performing surgical procedures as, in these cases, most of the teaching potential of the human body-donor is undervalued. Thus, it is strongly recommended, to organize courses that show both a deep view of regional anatomy and also the performance of the most relevant or attractive, surgical techniques currently available.

Financially, as a recommendation, monies produced by the enrolment in CME courses and workshops could go to paid salaries and after that to invest in the Department for improving facilities, infrastructures, and research or travel grants. Some dollars could also be recycled to develop other CME activities.

WHAT ARE THE MAIN PRINCIPLES IN ORGANIZING A COURSE?

At the Institute of Clinical and Functional Anatomy, Medical University of Innsbruck (MUI) teams have been organizing courses from 1985 to date. This experience has led development teams to six points that are essential for the organization of a successful CME course or workshop:

1. To have a "dissection guide" recording every procedure that will be undertaken.
2. To be more practical than theoretical.
3. To stimulate the individual work (one region for each attendant) with a high standard of supervision.
4. To provide adequate, modern facilities and equipment.
5. Provide the best available body-donor material: There are many different embalming methods used in departments of anatomy. (Benkhadra et al., 2011; G Feigl et al., 2007; Groscurth et al., 2001; Kessler et al., 2014)

6. To be methodical in organizing daily activities and sessions:

   Courses begin by distributing a Pre-test to participants to assess the level of their prior knowledge. The questionnaire has 15 items with five possible answers, only one being the correct answer. Questions are based on clinical interest. On completion of the course, a Post-test (consisting of the same Pre-test questions) will be given to the participants. Results from previous courses show that participants failed in more than 60% of cases in the preliminary assessment but passed in more that 80% in the final assessment (Sañudo et al., 2007).

   As a recommendation, sessions should precede by a very short didactic session (no more than 10 to 20 minutes) where the same images and contents that are displayed in the dissecting guide used. In the theoretical session, the objectives for the session are established. Next, the dissecting guide is elaborated according to topographical or regional criteria. In this way, it follows a superficial-to-deep sequence. This means dissecting from the skin to deeper structures, passing through superficial fascia, and trying to search for every relevant structure that is located in a given layer. Following this didactic session, participants might go to the dissection laboratory where they perform their individual work; with the ratio of one participant for one anatomical region. During the practical sessions, the doubts that arise can be checked with the help of the dissecting guide or by seeking advice from supervisors. One important fact has to be taken into consideration: The more changes between lecture and practical work are included in the workshop, the more time is lost and will increase the daily time for a workshop.

At the commencement of each session of a CME course, an assessment should be done to determine whether the objectives of the previous session have been accomplished and therefore whether the participants are ready to proceed with the dissection of the next layer/objectives. The entire CME course is a combination of theoretical lectures and practical activities with intervals for lunch or coffee breaks. At the end of the course, a feedback survey about the quality of the course is distributed to the participants that assist CME course developers in continuing to improve the quality of CME sessions and activities.

Anatomy is a fundamental subject for both medical and surgical training. Anatomy departments might collaborate with clinicians organizing continuing professional developing courses. These courses should be mainly practical in content and organization, respecting the learning of anatomy as well as aiming performing surgical techniques. The universities with its anatomical departments might support these courses by establishing hands-on practical trainings.

CONCLUSIONS

There are five critical points in post-graduate anatomy education:

1) Iatrogenic injuries can occur during all (surgical) procedures. Complete familiarity with the anatomy, including variations of the region, might markedly reduce the risk.

2) Incompetencies due to: A) Lack of anatomical knowledge, B) Unskillfulness, C) Too high risk of medical interventions without training (i.e., learning curve), may lead to disadvantages for the patients.

3) The answer is: studying and practicing on human body-donors (i.e., the Gold Standard) including modern digitalization techniques/devices.

4) Frequent and clinically important anatomical variations should be included in lectures of the medical curricula as already suggested by the Netherlands Associations of Anatomists in 1999.

5) Recommend continuing medical education courses developed together by both clinical anatomists and clinicians with possible support of the universities, companies and scientific associations.

REFERENCES

ARRÁEZ-AYBAR LA, SÁNCHEZ-MONTESINOS I, MIRAPEIX RM, MOMPEO-CORREDERA B, SAÑUDO-TEJERO JR (2010) Relevance of human anatomy in daily clinical practice. *Ann Anat,* 192(6): 341-348.

BANDINELLI F, BIJLSMA JW, RAMIRO MS, PIA E, GOEKOOP-RUITERMAN YP, SIVERA F, CUTOLO M (2011) Rheumatology education in Europe: results of a survey of young rheumatologists. *Clin Exp Rheumatol,* 29(5): 843-845.

BENKHADRA M, BOUCHOT A, GÉRARD J, GENELOT D, TROUILLOUD P, MARTIN L, FEIGL G (2011) Flexibility of Thiel's embalmed cadavers: the explanation is probably in the muscles. *Surg Radiol Anat,* 33(4): 365-368.

BINDER J, KRAUTZ C, ENGEL K, GRÜTZMANN R, FELLNER FA, BURGER PH, SCHOLZ M (2019) Leveraging medical imaging for medical education—a cinematic rendering-featured lecture. *Ann Anat - Anatomischer Anzeiger,* 222: 159-165.

BRENNAN TA, LEAPE LL, LAIRD NM, HEBERT L, LOCALIO AR, LAWTHERS AG, HIATT HH (1991) Incidence of adverse events and negligence in hospitalized patients: results of the Harvard Medical Practice Study I. *New Eng J Med,* 324(6): 370-376.

CAHILL DR, LEONARD RJ (1999) Missteps and masquerade in American medical academe: clinical anatomists call for action. *Clin Anat,* 12(3): 220-222.

CARLOS EG (1974) La crisis de la Anatomía Macroscópica en el obra de Federico Oloriz. *Medicina & historia: Revista de estudios históricos de las ciencias médicas,* (39): 7-26.

CHEVREL JP (1992) Clinical anatomy: the new spirit in anatomy. *Surg Radiol Anat,* 14(2): 93-95.

DEN BRAVE PS, VAS NUNES SE, BRONKHORST MW (2015) Anatomical variations of the lateral femoral cutaneous nerve and iatrogenic injury after autologous bone grafting from the iliac crest. *J Orthop Trauma,* 29(12): 549-553.

ELSAFTAWY A, GWORYS B, JABŁECKI J, SZAJERKA T (2013) "Dangerous" anatomic varieties of recurrent motor branch of median nerve. *Pol Przegl Chir,* 85(8): 419-423.

ELSHAFEI M, BINDER J, BAECKER J, BRUNNER M, UDER M, WEBER GF, KRAUTZ C (2019) Comparison of cinematic rendering and computed tomography for speed and comprehension of surgical anatomy. *JAMA surgery,* 154(8): 738-744.

FEIGL GC, DREU M (2010) Important structures to be known for a safe ultrasound-guided supraclavicular plexus block. *Reg Anesth Pain Med,* 35(3): 317-318.

FEIGL GC, PIXNER T (2011) The cleidoatlanticus muscle: a potential pitfall for the practice of ultrasound guided interscalene brachial plexus block. *Surg Radiol Anat,* 33(9): 823-825.

FEIGL G, ANDERHUBER F, SCHWARZ G, DORN C, FASEL J, LIKAR R (2007) Trainingsmethode für Regionalanästhesisten. *Der Anaesthesist,* 56(5): 437-443.

GROSCURTH P, EGGLI P, KAPFHAMMER J, RAGER G, HORNUNG JP, FASEL J (2001) Gross anatomy in the surgical curriculum in Switzerland: improved cadaver preservation, anatomical models, and course development. *Anat Rec,* 265(6): 254-256.

HAMMER CM, PAULSEN F, BURGER PHM, SCHOLZ M (2016) Integration of the musculature in the course "functional anatomy of the locomotor system"-Preparing medical students for the dissection course. *Ann Anat,* 208: 234-240.

HANSEN C, DAM M, MORIGGL B, BENDTSEN TF, BØRGLUM J (2020) Fascia transversalis plane block for elective cesarean section: simpler but not necessarily better. *Reg Anesth Pain Med*, 45(5): 395-396.

HERNÁNDEZ-DÍAZ C, ALVAREZ-NEMEGYEI J, NAVARRO-ZARZA JE, VILLASEÑOR-OVIES P, KALISH RA, CANOSO JJ, SAAVEDRA M (2017) A survey of anatomical items relevant to the practice of rheumatology: pelvis, lower extremity, and gait. *Clin Rheumatol,* 36(12): 2813-2819.

KESSLER J, MORIGGL B, GRAU T (2014) Ultrasound-guided regional anesthesia: learning with an optimized cadaver model. *Surg Radiol Anat,* 36(4): 383-392.

KLECKER RJ, WINALSKI CS, ALIABADI P, MINAS T (2008) The aberrant anterior tibial artery: magnetic resonance appearance, prevalence, and surgical implications. *Am J Sports Med,* 36(4): 720-727.

KONSCHAKE M, ZWIERZINA ME, PECHRIGGL EJ, MORIGGL B, BRENNER E, HÖRMANN R, PROMMEGGER R (2016) The nonrecurrent laryngeal nerve: A clinical anatomic mapping with regard to intraoperative neuromonitoring. *Surgery,* 160(1): 161-168.

KONSCHAKE M, ZWIERZINA M, MORIGGL B, FÜGGER R, MAYER F, BRUNNER W, FORTELNY R (2020) The inguinal region revisited: the surgical point of view : An anatomical-surgical mapping and sonographic approach regarding postoperative chronic groin pain following open hernia repair. *Hernia,* 24(4): 883-894.

MACCHI V, VIGATO E, PORZIONATO A, TIENGO C, STECCO C, PARENTI A, DE CARO R (2008) The gracilis muscle and its use in clinical reconstruction: an anatomical, embryological, and radiological study. *Clin Anat,* 21(7): 696-704.

MOMPEÓ B, PÉREZ L (2003) Relevancia de la anatomía humana en el ejercicio de la medicina de asistencia primaria y en el estudio de las asignaturas de segundo ciclo de la licenciatura en medicina. *Educación Médica,* 6(1): 47-57.

MOORE KL (1989) Meaning of "normal". *Clin Anat,* 2(4): 235-239.

MORELOS AVALOS R, ELIZONDO OMAÑA RE, GUZMÁN LÓPEZ S (2014) The Anatomy Research Group (GIA) 10 years after its founding: Past, present and future. *Medicina universitaria,* 16(63): 102-103.

MORONI S, ZWIERZINA M, STARKE V, MORIGGL B, MONTESI F, KONSCHAKE M (2019) Clinical-anatomic mapping of the tarsal tunnel with regard to Baxter's neuropathy in recalcitrant heel pain syndrome: part I. *Surg Radiol Anat,* 41(1): 29-41.

MYRCHA P, LEWCZUK A, JAKUCIŃSKI M, KOZAK M, SIEMIENIUK D, RÓŻAŃSKI D, WOŹNIAK W (2020) The anatomy of the circle of Willis is not a strong enough predictive factor for the prognosis of cross-clamping intolerance during carotid endarterectomy. *J Clin Med,* 9(12): 3913.

NAVARRO-ZARZA JE, HERNÁNDEZ-DÍAZ C, SAAVEDRA MA, ALVAREZ-NEMEGYEI J, KALISH RA, CANOSO JJ, VILLASEÑOR-OVIES P (2014) Preworkshop knowledge of musculoskeletal anatomy of rheumatology fellows and rheumatologists of seven North, Central, and South American countries. *Arthritis Care Res,* 66(2): 270-276.

NGO LM, CHUNG D, NGO A, NGUYEN T, RIGATELLI G (2020) Persistent reversed flow and antegrade slow flow of the right coronary artery with anomalous origin from the left sinus are the mechanisms for chest pain and sudden death. *J Am Coll Cardiol,* 75(11S1): 1354-1354.

NGUYEN T, COLOMBO A, HU D, GRINES CL, SAITO S (2013) *Practical handbook of advanced interventional cardiology*: Wiley Online Library.

NGUYEN T, DANG T, NGUYEN TN, ANH CH, LE HUY HOANG P, DARWISH T, TALARICO E (2018a) GW29-e0862 New discovery: Gas bubbles rupture in the coronary arteries is most likely the mechanism breaking the thin cap of plaques causing acute coronary syndrome. *J Am Coll Cardiol*, 72(16 Supplement): C105. doi: 10.1016/j.jacc.2018.08.528

NGUYEN T, TRAN CHAU NB, PHUONG THUY LT, DANG T, NGUYEN TN, DARWISH T, TALARICO E (2018b) GW29-e0850 New discovery: New technique of visualization of laminar, turbulent flow and measurement of velocity and dynamic coronary pressure. *J Am Coll Cardiol*, 72(16 Supplement): C200. doi: 10.1016/j.jacc.2018.08.872

NGUYEN T, ZUNI M, LUAN NT, HUYEN VY NN, TRUONG K, DANG T, TALARICO E (2018c) GW29-e0867 Demonstration of cavitation in the coronary arteries by computational fluid dynamic. *J Am Coll Cardiol*, 72(16 Supplement): C72. doi: 10.1016/j.jacc.2018.08.414

NGUYEN TN, NGUYEN NM, PHAM TM, DO QN, LE V, TRUONG VT, RIGATELLI, G (2018d) Cavitation phenomenon creating bubbles and their explosion in the coronary artery causes damage to the endothelium and starts the atheroslerotic process. *J Am Coll Cardiol*, 71(11 Supplement): A269. https://doi.org/10.1016/S0735-1097(18)30810-6

NIELSEN TD, MORIGGL B, BARCKMAN J, JENSEN JM, KØLSEN-PETERSEN JA, SØBALLE K, BENDTSEN TF (2019a) Cutaneous anaesthesia of hip surgery incisions with iliohypogastric and subcostal nerve blockade: A randomised trial. *Acta Anaesthesiol Scand,* 63(1): 101-110.

NIELSEN TD, MORIGGL B, BARCKMAN J, JENSEN JM, KØLSEN-PETERSEN JA, SØBALLE K, BENDTSEN TF (2019b) Randomized trial of ultrasound-guided superior cluneal nerve block. *Regional Anesthesia Pain Med,* 44(8): 772-780.

PABST R (1993) Gross anatomy: an outdated subject or an essential part of a modern medical curriculum? Results of a questionnaire circulated to final-year medical students. *Anat Rec,* 237(3): 431-433.

PABST R, ROTHKÖTTER HJ (1997) Retrospective evaluation of undergraduate medical education by doctors at the end of their residency time in hospitals: consequences for the anatomical curriculum. *Anat Rec,* 249(4): 431-434.

PARIKH S, DAWE E, LEE C, WHITEHEAD-CLARKE T, SMITH C, BENDALL S (2017) A cadaveric study showing the anatomical variations in the branches of the dorsalis pedis artery at the level of the ankle joint and its clinical implication in ankle arthroscopy. *Ann R Coll Surg Engl*, 99(4): 286-288.

RODRÍGUEZ-NIEDENFÜHR M, VÁZQUEZ T, NEARN L, FERREIRA B, PARKIN I, SAÑUDO J (2001) Variations of the arterial pattern in the upper limb revisited: a morphological and statistical study, with a review of the literature. *J Anat,* 199(5): 547-566.

SAAVEDRA MA, VILLASEÑOR-OVIES P, HARFUSH LA, NAVARRO-ZARZA JE, CANOSO JJ, CRUZ-DOMÍNGUEZ P, KALISH RA (2016) Educational impact of a clinical anatomy workshop on 1st-year orthopedic and rheumatology fellows in Mexico City. *Clin Rheumatol,* 35(5): 1299-1306.

SAÑUDO J, VÁZQUEZ R, PUERTA J (2003) Meaning and clinical interest of the anatomical variations in the 21st Century. *Eur J Anat,* 7(1): 1-3.

SAÑUDO JR, VÁZQUEZ M, MARANILLO E, MIRAPEIX R, MOMPEO B, MARCO F, ARRÁEZ L (2007) The participation of Anatomy Departments in the continuing professional development of surgeons. *Eur J Anat,* 11(Suppl 1): 111-119.

TALARICO JR EF (2010) A human dissection training program at Indiana University School of Medicine-Northwest. *Anat Sci Educ,* 3(2): 77-82.

TERMINOLOGY, FCOA (1998) *Terminologia Anatomica: International Anatomical Terminology.* Georg Thieme Verlag.

TIENGO C, MACCHI V, VIGATO E, PORZIONATO A, STECCO C, AZZENA B, DE CARO R (2010) Reversed gracilis pedicle flap for coverage of a total knee prosthesis. *JBJS,* 92(7): 1640-1646.

VILLASEÑOR-OVIES P, NAVARRO-ZARZA JE, SAAVEDRA M, HERNÁNDEZ-DÍAZ C, CANOSO JJ, BIUNDO JJ, ALVAREZ-NEMEGYEI J (2016) A survey of anatomical items relevant to the practice of rheumatology: upper extremity, head, neck, spine, and general concepts. *Clin Rheumatol,* 35(12): 3025-3030.

ZUIN M, NGUYEN T, DANG T, VU A, LUONG P, DARWISH T, CHE K (2018) TCT-307 Mechanism triggering acute coronary syndrome by rupturing plaque based on the cavitation phenomenon (bubble formation and explosion) at the distal left main bifurcation by computational fluid dynamic study. *J Am Coll Cardiol,* 72(13S): B126-B127.

THE HIVE: a multidisciplinary approach to medical education

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SUMMARY

Technological advances have innovated medical education. However, not all technological tools have been useful, nor have been purposefully applied. The authors present how the HIVE – The Hackspace for Innovation and Visualization in Education at the University of British Columbia, Faculty of Medicine – composed of multidisciplinary teams of students and educators, have solved pedagogical challenges, and works on implementing new technologies and educational tools. Collaboration between undergraduate medical students and the use of classroom feedback have been key elements in the identification of problems and implementation of solutions. The diversity of the HIVE amplifies its effectiveness, providing a wide range of perspectives, and promoting inter-professional and inter-university collaboration. The HIVE encourages student participation and may serve as a model for the purposeful implementation of new technologies.

Key words: Medical education – Multimedia – Teaching of neurosciences/neuroanatomy – Anatomy – Collaboration – HIVE

ABBREVIATIONS

Application (App)

Augmented Reality (AR)

Extended Reality (xR)

Hackspace for Innovation and Visualization in Education (HIVE)

Mixed Reality (MR)

Three Dimensional (3D)

Virtual Reality (VR)

INTRODUCTION

Medical education has rapidly changed due to the dynamic healthcare environment influenced by technologies, the evolving role of physicians, the need for teamwork and collaboration, and a need for diversification of pedagogical approaches (McGaghie et al., 2010; Sugand et al., 2010; Guze, 2015; Salinas-Alvarez et al., 2020). Medical education is a field that must improve the process of delivering well-trained, humane and empathetic physicians, while effectively treating patients and improving society's healthcare (McGaghie et al., 2010; Bleakley and Brennan, 2011; Guerrero-Mendivil et al., 2020; Quiroga-

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Garza et al., 2020a).

Recently, advances in technology have impacted how students, educators, and clinicians learn, teach, and practice medicine (McGaghie et al., 2010; Guze, 2015). Indeed, innovation in medical education has become synonymous with technology (Sugand et al., 2010; Delgaty et al., 2017). Applications, such as "computer-assisted learning, mobile devices, digital games, simulation, virtual reality (VR), and wearable technologies" have influenced how users learn and interact with their environment (Cook et al., 2011; Krebs et al., 2014; Guze, 2015; Delgaty et al., 2017). Increasingly, the impact of xR (extended reality, including AR [Augmented Reality], VR, and MR[Mixed Reality]) is being explored (Pennefather and Krebs, 2019), as the hardware and software for these devices is under rapid development., especially in surgical training and anatomy teaching (Silva et al., 2018; Guerrero-Mendivil et al., 2020; Quiroga-Garza et al., 2020b). 3D printing is another instrument used for improving knowledge and understanding of anatomy (Garcia et al., 2018). Mobile devices are used to enable and mediate educational activities, practicing medicine, and everyday living (Masters et al., 2016). Evidence suggests mobile devices provide potentially powerful educational support on clinical placement, particularly with student transitions, meta-learning, and care contribution (Maudsley et al., 2016). Medical students' interest in using mobile technologies in education has been reported worldwide (Koehler et al., 2012; Mosa et al., 2012; Boruff and Storie, 2014).

The aims of technological advancements in medicine include facilitating basic knowledge acquisition, improving decision making, promoting psychomotor skill coordination (for example, with xR), practicing for rare or critical events, and learning team training (Rengier et al., 2010; Guze, 2015). Evidence shows these help students work faster and makes learning creative (Khamis et al., 2018).

Frenk et al. describe a world of increasing complexity that requires novel approaches to address the challenges emerging from this complexity (Frenk et al., 2010; Cheng et al., 2021; Muñoz-Leija et al., 2020). Collaborative praxis will stimulate the creativity of the team, which when coupled with a diversity of ideas and perspectives can lead to innovative approaches to solving a problem – a practical application of the design thinking process in medical education (Cook et al., 2011; Badwan et al., 2017; Elizondo-Omaña et al., 2019, 2020a).

The authors share their experience of working in a multidisciplinary team in the "Hackspace for Innovation and Visualization in Education (HIVE)." Located in the Life Sciences Centre at the University British of Columbia in Vancouver, Canada, this initiative has allowed multidisciplinary teams to come together, identify educational problems and develop solutions through an interactive innovation pipeline approach.

THE HIVE DESCRIPTION

The HIVE (https://hive.med.ubc.ca/) is a multidisciplinary team that includes students from programs such as engineering, medicine, kinesiology, and computer science. The level of education varies from early undergraduate to post-doc students. Students are encouraged to find a project at the HIVE that suits their educational strengths and personal interests.

Working together, students aim to develop complementary technologies for foundational sciences such as anatomy, neuroanatomy, physiology, and embryology. Students collaborate with faculty mentors and staff with different areas of expertise (teaching, biomedical content, instructional design, biomedical visualization).

Together they identify challenges they encounter in their classroom and ideate pedagogical and technological solutions. Specific outcome objectives that support student learning are an integral part of the development plan to ensure that the technology will serve a concrete curricular need.

Projects are brought to the HIVE by the students themselves and in close collaboration with faculty – the proponents of an idea then become the collaborators and content expert leads on the development team.

One focus is the development of 3D learning solutions using emerging media such as xR. The 3D objects for these applications are acquired through 3D reconstructions from imaging scans (Wilson and Krebs, 2008), 3D surface scanning and photogrammetry (Dixit et al., 2019), as well as 3D modeling. Another focus is the creation of accessible, high-quality web materials, including interactive learning modules (Krebs et al., 2013), videos (Krebs et al., 2014), and 2D animations. All learning resources are shared as open educational resources on www.neuroanatomy.ca (Krebs, 2009) and www.clinicalanatomy.ca. One of the key discussion points in the development process is determining which technology is best suited to address the challenge – it is always the technology that serves the pedagogy, as it should be in medical education, with the aim of aiding and improving learning, not trying to replace the educator.

Project teams focus on anatomical areas that are difficult to understand due to their complex 3D relationships, such as the brain, the pelvis, and the developing embryo (Wilson and Krebs, 2008; Holman et al., 2018). The websites aim to develop an open library of resources to be used by students and educators around the world to complement their learning of the anatomical sciences. These resources include high-quality video tutorials (Krebs et al., 2014; Student et al., 2015), web atlases (Mordhorst et al., 2017), learning modules (Rheaume et al., 2018), interactive slices, and 3D reconstructions.

Projects are diverse and have included:

- **HoloBrain**: A 3D holographic brain segmented from MRI scans and uploaded into custom software into the Microsoft HoloLens. This software allows students to manipulate a 3D brain as if it were physically in the room. Other features include a "dissection" mode that displays deep structures of the brain with relation to one another and an fMRI mode that color and fiber tracts of the brain, allowing an in- depth look into the functional anatomy of the brain. This project was also made cross-compatible with Google Cardboard VR, thus allowing a low-cost engagement of large groups of students in "digital anatomy labs".
- **Learning Modules:** Several click-through interactive online modules have been developed to supplement challenging core topics in the pre-clinical medical school curriculum. These modules include quizzes, detailed illustrations, and simple animations designed to effectively teach traditionally difficult topics within anatomy, neuroanatomy, and embryology.
- **Pocket Pelvis:** The HIVE team created a custom smartphone application that took advantage of the augmented reality (AR) technology. The app is designed to digitally overlay anatomic structures (nerves, muscles) on a 3D-printed model of a pelvis using a standard smartphone camera. This allows users to manipulate a "real" pelvis, adding or removing the overlying structures, to better elucidate the complex relationship of the pelvic anatomy in a more tangible manner than traditional textbooks can offer.

Key to the success of this endeavor has been the participation of a multidisciplinary team composed largely of undergraduate students (Elizondo-Omaña et al., 2019), many of whom have provided advice regarding future curricular improvements given their recent exposure to the curriculum. They identified the problem and provided valuable data to create more efficient solutions to learning. Meanwhile, faculty mentors supervise the various projects, ensuring the content was both correct and easily integrated into the courses. To determine which areas of anatomy to focus on, and how best to address classroom challenges, students regularly conduct quality improvement surveys among their peers. These are then brought to the multidisciplinary team, and an approach is developed (Havyer et al., 2016).

DEVELOPMENT PIPELINE AND QUALITY ASSURANCE

Each project in the HIVE begins with a challenge or problem identified in the classroom – primarily by the students/users (Fig. 1). This "pain point" is then brought to the team for a large and open-ended design thinking session (Frenk et al., 2010). One of the key elements of design thinking is an empathetic connection with the students ("users") who are experiencing the problem. A multidisciplinary team can then suggest multiple approaches to providing solutions to this problem. In the next step, a multidisciplinary and diverse team is assembled to create a "first" prototype. This prototype development goes through iterative development cycles based on the feedback from both students and faculty. This step in the development pipeline aim to "Make the right thing" – a prototype that will meet the needs of the learners and address the problem identified. The next step in the development pipeline is focused on the user interface and the user experience – these are critical next steps so that the use of the technology becomes intuitive and its integration into the classroom a natural extension of the learning experience based on pedagogical principles. This step of the pipeline aims to "Make the thing right" – a more mature technology that is user-friendly and easily accessed. This development step also relies on interactive development cycles in close collaboration with the students who will be using this technology and the content experts who will be deploying the technology in the classroom. It is in this step that universal design principles are fully applied to the development so that the end product will be broadly accessible to students of all abilities.

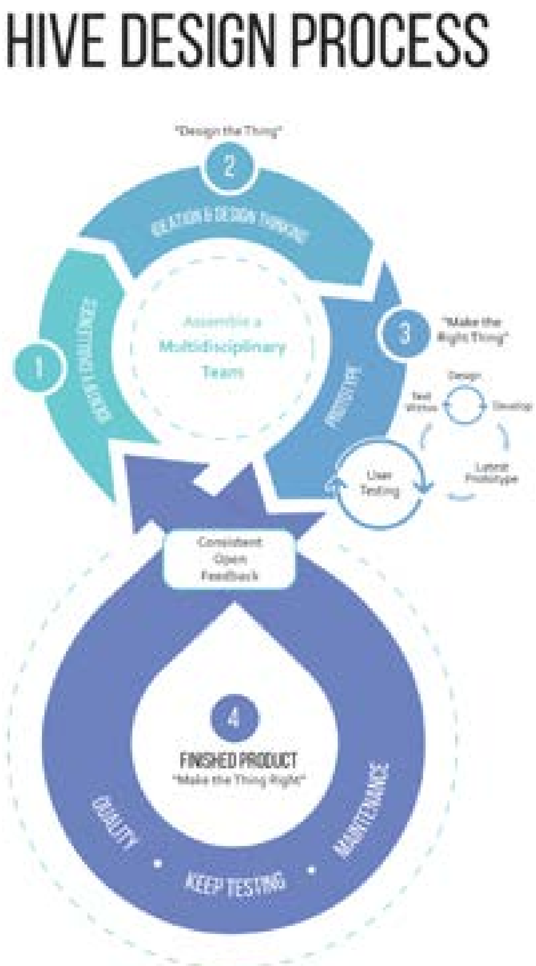

Fig. 1.- Scheme representing the Hive design process.

This agile approach to the development of educational technology allows for iterative cycles of development (Arachchi and Perera, 2018) while also providing apps that can be used in the classroom.

The timelines for these steps can have a lot of variabilities: a viable prototype can be developed within a timeframe of weeks or just a few months, the full development with a focus on a functional user interface and pedagogically sound user experience can take much longer, and never really finishes, as the developed applications continue to the improved.

DISCUSSION

The great advantage of HIVE is its ability to facilitate inter-professional and inter-university collaboration around the world, through programs that allow exchange students to participate in different projects and provide new perspectives and ideas (Havyer et al., 2016). In addition, all output from the HIVE has been made available, as an open educational resource for the enhancement of medical education.

A multidisciplinary team focused on a single objective is critical for the creative approach to solve pedagogical challenges (Chen et al., 2015; Guze, 2015; Badwan et al., 2017; Elizondo-Omaña et al., 2019; Elizondo-Omaña et al., 2020b). The team integrates the affordances of a particular technology with the needs identified to offer a creative, imaginative, and ultimately innovative approach to iteratively produce a solution that is most appropriate to the problem (Cook et al., 2011; Badwan et al., 2017; Delgaty et al., 2017). The difference between an invention and an innovation is the impact the technology has in its application – an innovation can be transformative in the classroom.

The inclusion of undergraduate students, as well as classroom feedback as key elements in the identification of problems and possible solutions in learning of any given subject (Chen et al., 2015). Projects such as the Pocket Pelvis could easily be expanded into healthcare beyond the student level and patient education. For example, a surgeon could utilize this technology to more easily explain their procedures to a patient using these 3D models. In addition, the HoloBrain (with further development) can be used in clinical settings to educate a patient on the complex intricacies of the neural connections. However, evidence of student satisfaction in relationship with technology is reported, but only few studies really explore the improvements of learning, and the results are still unclear (Clunie et al., 2018).

Current trends have moved traditional curriculum into unified, integrated, interdisciplinary teaching modules, breaking down barriers through vertical and horizontal medical education. Implementation of tools and technologies allow a structured acquisition and application of concepts in an integrated curriculum using a wider range of delivery learning methods/models, such as those provided by the HIVE. This allows the implementation of clinicopathological reasoning (Vidic and Weitlauf, 2002; Hassan, 2013; Quintero et al., 2016, Quiroga-Garza et al., 2020a, b).

To promote innovative educational resources for pedagogic challenges, universities should strive to provide students and faculty with spaces (such as the HIVE) to boost collaborative teamwork. An extensive literature survey shows that the present work is the first descriptive article regarding a novel collaborative, teamwork approach to medical education technology such as the HIVE.

A limitation of this article is that there are no published articles about the efficiency and satisfaction of the projects developed at the HIVE. The members contribute many gratifying and satisfactory commentaries regarding their work and refer the same when the projects are applied to their colleagues, however, this is subjective. The same can be said about online material, as gratifying emails have been received, but these have not been anonymously and objectively evaluated. However, the team is now designing objective, quantitative studies that will assess HIVE projects relative to student satisfaction and objective educational outcomes.

CONCLUSION

A multidisciplinary hackspace can serve as a nexus point for ideas and technology that advance innovation in medical education. This designated team needs to have a solid development and innovation pipeline and multidisciplinarity coupled with student engagement at its core. Together, the team can tackle a challenge encountered in the classroom and propose innovative technological solutions. These solutions remain an authentic response to a pedagogical challenge due to strong collaboration with students and multiple iterative development cycles. This ensures that the pedagogy remains at the core with the technology merely serving as an enabler of new approaches.

REFERENCES

ARACHCHI S, PERERA I (2018) Continuous integration and continuous delivery pipeline automation for agile software project management. *MERCon*, 156-161. doi: 10.1109/MERCon.2018.8421965

BADWAN B, BOTHARA R, LATIJNHOUWERS M, SMITHIES A, SANDARS J (2017) The importance of design thinking in medical education. *Med Teach,* 40: 425-426.

BLEAKLEY A, BRENNAN N (2011) Does undergraduate curriculum design make a difference to readiness to practice as a junior doctor?. *Med Teach,* 33: 459-467.

BORUFF JT, STORIE D (2014) Mobile devices in medicine: a survey of how medical students, residents, and faculty use smartphones and other mobile devices to find information. *J Med Libr Assoc,* 102: 22-30.

CHEN HC, VAN DEN BROEK WS, TEN CATE O (2015) The case for use of entrustable professional activities in undergraduate medical education. *Acad Med,* 90: 431-436.

CHENG X, CHAN LK, PAN SQ, CAI H, LI YQ, YANG X (2021) Gross anatomy education in China during the Covid-19 pandemic: a national survey. *Anat Sci Educ,* 14(1): 8-18.

CLUNIE L, MORRIS NP, JOYNES VC, PICKERING JD (2018) How comprehensive are research studies investigating the efficacy of technology-enhanced learning resources in anatomy education? A systematic review. *Anat Sci Educ,* 11: 303-319.

COOK DA, HATALA R, BRYDGES R, ZENDEJAS B, SZOSTEK JH, WANG AT, ERWIN PJ, HAMSTRA SJ (2011) Technology-enhanced simulation for health professions education: a systematic review and meta-analysis. *JAMA,* 306: 978-988.

DELGATY L, FISHER J, THOMSON R (2017) The dark side of technology in medical education. *MedEdPublish,* 6: 19.

DIXIT I, KENNEDY S, PIEMONTESI J, KENNEDY B, KREBS C (2019) Which tool is best: 3D scanning or photogrammetry – it depends on the task. *Adv Exp Med Biol,* 1120: 107-119.

ELIZONDO-OMAÑA R, ZARATE-GARZA P, JACOBO-BACA G, SALINAS-ALVAREZ Y, FERNANDEZ-RODARTE BA, MARTINEZ-GARZA JH, QUIROGA-GARZA A, GUZMAN-LOPEZ S (2019) Collaborative mentoring for effective medical research groups. *MedEdPublish,* 8: 3-65.

ELIZONDO-OMAÑA RE, MUÑOZ-LEIJA MA, QUIROGA-GARZA A, SALINAS-ALVAREZ Y, ZARATE-GARZA PP, MARTINEZ-GARZA JH, GUZMAN-LOPEZ S (2020a) What influences research medical students?. *FASEB J,* 34: S1.

ELIZONDO-OMAÑA RE, QUIROGA-GARZA A, SALINAS-ALVAREZ YE, GUZMAN-LOPEZ S (2020b) Breaking down large anatomy groups. *FASEB J,* 34: S1.

FRENK J, CHEN L, BHUTTA ZA, COHEN J, CRISP N, EVANS T, FINEBERG H, GARCIA P, KE Y, KELLEY P, KISTNASAMY B, MELEIS A, NAYLOR D, PABLOS-MENDEZ A, REDDY S, SCRIMSHAW S, SEPULVEDA J, SERWADDA D, ZURAYK H (2010) Health professionals for a new century: transforming education to strengthen health systems in an interdependent world. *Lancet,* 376: 1923-1958.

GARCIA J, YANG Z, MONGRAIN R, LEASK RL, LACHAPELLE K (2018) 3D printing materials and their use in medical education: a review of current technology and trends for the future. *BMJ Simul Technol Enhanc Learn,* 4: 27-40.

GUERRERO-MENDIVIL FD, MUÑOZ-LEIJA MA, QUIROGA-GARZA A, DE LA FUENTE-VILLARREAL D, JACOBO-BACA G, GUTIERREZ-DE LA O J, ELIZONDO-OMAÑA RE, GUZMAN-LOPEZ S (2020) Training and education model for anatomy near-peer teachers. *Med Univ,* 22: 176-179.

GUZE PA (2015) Using technology to meet the challenges of medical education. *Trans Am Clin Climatol Assoc,* 126: 260.

HASSAN S (2013) Concepts of vertical and horizontal integration as an approach to integrated curriculum. *Educ Med J,* 5: e1-e5.

HAVYER RD, NELSON DR, WINGO MT, COMFERE NI, HALVORSEN AJ, MCDONALD FS, REED DA (2016) Addressing the interprofessional collaboration competencies of the Association of American Medical Colleges: a systematic review of assessment instruments in undergraduate medical education. *Acad Med,* 91: 865-888.

HOLMAN P, BODNAR T, GHOMI M, CHOI R, MOUKHLES H, KREBS C (2018) 3D Neuroanatomy: using the HoloLens for an augmented reality approach in neuroanatomy education. *FASEB J*, 32: S25.3.

KHAMIS N, ALJUMAIAH R, ALHUMAID A, ALRAHEEM H, ALKADI D, KOPPEL C, ABDULGHANI HM (2018) Undergraduate medical students perspectives of skills, uses and preferences of information technology in medical education: A cross-sectional study in a Saudi Medical College. *Med Teach,* 40: S68-S76.

KOEHLER N, YAO K, VUJOVIC O, MCMENAMIN C (2012) Medical students use of and attitudes towards medical applications. *JMTM,* 1: 16-21.

KREBS C (2009) Evaluation of a comprehensive neuroanatomy website in a distributed medical curriculum. *FASEB J,* 23: S1.476.5.

KREBS C, FEJTEK M, HU J, KAZEM M, LAM A, LIANG T, ZHANG T, HAYWARD S, NICOLAOU S (2013) The integration of anatomy and radiology through interactive online modules. *FASEB J,* 27: 960.25.

KREBS C, HOLMAN P, BODNAR T, WEINBERG J, VOGL W (2014) Flipping the neuroanatomy labs: how the production of high quality video and interactive modules changed our approach to teaching (211.3). *FASEB J*, 28: S211.3.

MASTERS K, ELLAWAY RH, TOPPS D, ARCHIBALD D, HOGUE RJ (2016) Mobile technologies in medical education: AMEE Guide no. 105. *Med Teach,* 38: 537-549.

MAUDSLEY G, TAYLOR D, ALLAM O, GARNER J, CALINICI T, LINKMAN K (2019) A Best Evidence Medical Education (BEME) systematic review of: What works best for health professions students using mobile (hand-held) devices for educational support on clinical placements? BEME Guide No. 52. *Med Teach,* 41: 125-140.

MCGAGHIE WC, ISSENBERG SB, PETRUSA ER, SCALESE RJ (2010) A critical review of simulation-based medical education research: 2003-2009. *Med Educ,* 44: 50-63.

MORDHORST A, FEJTEK M, SIDDIQUI A, KREBS C (2017) The development of a globally accessible interactive anatomy web atlas. *FASEB J,* 31: S580.10.

MOSA AS, YOO I, SHEETS L (2012) A systematic review of healthcare applications for smartphones. *BMC Med Inform Decis Mak,* 12: 67.

MUÑOZ-LEIJA MA, ZARATE-GARZA PP, JACOBO-BACA G, QUIROGA-GARZA A, SALINAS-ALVAREZ Y, MARTINEZ-GARZA JH, ELIZONDO-OMAÑA RE, GUZMAN-LOPEZ S (2020) Modifications to the delivery of a gross anatomy course during the COVID-19 pandemic at a Mexican medical school. *Eur J Anat,* 24: 507-512.

PENNEFATHER P, KREBS C (2019) Exploring the role of xR in visualisations for use in Medical Education. *Adv Exp Med Biol,* 1171: 15-23.

QUINTERO GA, VERGEL J, ARREDONDO M, ARIZA MC, GÓMEZ P, PINZON-BARRIOS AM (2016) Integrated medical curriculum: advantages and disadvantages. *J Med Educ Curricular Develop*, S18920.

QUIROGA-GARZA A, ELIZONDO-OMAÑA RE, SALINAS-ALVAREZ YE, GUZMAN-LOPEZ SE (2020a) Effective near-peers in Anatomy. *FASEB J,* 34: S1.

QUIROGA-GARZA A, TERAN-GARZA R, ELIZONDO-OMAÑA RE, GUZMÁN-LÓPEZ S (2020b) The use of clinical reasoning skills in the setting of uncertainty: a case of trial femoral head migration. *Anat Sci Educ,* 13: 102-106.

RENGIER F, MEHNDIRATTA A, VON TENGG-KOBLIGK H, ZECHMANN CM, UNTERHINNINGHOFEN R, KAUCZOR HU, GIESEL FL (2010) 3D printing based on imaging data: review of medical applications. *Int J Comput Assist Radiol Surg,* 5: 335-341.

RHEAUME A, LEONG M, INGLIS T, KREBS C (2018) When traditional teaching leaves your head spinning: a new interactive online learning module on the vestibular system. *FASEB J,* 32: S634.1.

SALINAS-ALVAREZ Y, QUIROGA-GARZA A, MARTINEZ-GARZA JH, JACOBO-BACA G, ZARATE-GARZA PP, RODRÍGUEZ-ALANÍS KV, GUZMAN-LOPEZ S, ELIZONDO-OMAÑA RE (2020) Mexican educators survey on anatomical sciences education and a review of world tendencies. *Anat Sci Educ*, doi: 10.1002/ase.2017.

SILVA JN, SOUTHWORTH M, RAPTIS C, SILVA J (2018) Emerging applications of virtual reality in cardiovascular medicine. *JACC Basic Transl Sci,* 3: 420-430.

STUDENT J, ROTHMAN Z, KREBS C (2015) Flipping the Neuroanatomy labs: a creative approach to producing videos and multimedia for students. *Med Educ,* 49: 87.

SUGAND K, ABRAHAMS P, KHURANA A (2010) The anatomy of anatomy: a review for its modernization. *Anat Sci Educ,* 3: 83-93.

VIDIC B, WEITLAUF HM (2002) Horizontal and vertical integration of academic disciplines in the medical school curriculum. *Clin Anat*, 15: 233-235.

WILSON J, KREBS C (2008) 3D-reconstruction of CNS structures derived from MRI scans: new teaching tools for neuroanatomy. *FASEB J,* 22: S2.3.

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Maintaining cadaveric dissection in the COVID era: new perspectives in anatomy teaching and medical education

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SUMMARY

Cadaveric dissection provides a unique learning experience in anatomy teaching that maps well to the required outcomes for medical graduates as prescribed by the General Medical Council (GMC) in the UK. The COVID-19 pandemic has presented new challenges to the maintenance of this method of teaching which is very much dependent on in-person participation. As a result, dissection ceased in many institutions, with anatomy teaching being conducted online. The conviction that hands-on cadaveric dissection offers considerable benefits beyond the imparting of anatomical knowledge has led to the development of strategies to retain the practical element at the core of anatomy teaching. This paper describes the ways in which this has been achieved in the current academic year within a COVID-secure environment. A blended learning curriculum has provided students with both the opportunity for online interaction as well as in-person dissection classes which have become the highlight of the course for students. This paper describes in detail why cadaveric dissection remains key in anatomical education and demonstrates this by mapping its additional benefits to each of the three sets of GMC Outcomes for Graduates (professional values and behaviors, professional skills and professional knowledge). The means by which these were previously achieved as well as how these goals are still being met in our current program during the pandemic are detailed.

Key words: Cadaveric dissection – Covid-19 – Coronavirus – Anatomy teaching – Medical education – Blended learning

ABBREVIATIONS

COVID = Coronavirus Disease

DR = Dissection Room

GMC = General Medical Council

MCCD = Medical Certificate of Cause of Death

microCT = micro Computed Tomography

VLE = Virtual Learning Environment

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INTRODUCTION

The year 2016 marked the 300th anniversary of the establishment of the Anatomy School in the University of Cambridge (Rolleston, 1932), with College-based dissection beginning even earlier in the 1560s (Jones, 1988). For over four centuries, Cambridge has provided medical students with a comprehensive and realistic appreciation of human anatomy through the irreplaceable experience of full-body dissection.

Recent years have borne witness to vigorous debate concerning the comparative merits of anatomy teaching methods (Jones et al., 1978; Granger, 2004; Korf et al., 2008; Ali et al., 2015; Wilson, 2018). While some authors concluded that no significant difference exists in learning outcomes between dissection- and prosection-based courses, others have noted marginally superior results in summative assessments from those who have dissected (Yeager, 1996; Winkelmann, 2007), especially in final examinations (Johnson, 2002; Granger and Calleson 2007). From the student perspective, Azer and Eizenberg (2007) stated that students considered dissection to be more important than other methods, while Dinsmore et al. (1999) indicated that students favoured prosections as being more efficient for learning, and some courses do not use any cadaveric material in anatomy teaching at all (McLachlan and de Bere, 2004).

Despite this declining trend, cadaveric dissection remains at the core of anatomy teaching, and is a valuable means of delivering the *Outcomes for Graduates* stipulated by the General Medical Council (GMC) (GMC Outcomes for graduates, 2018). While many authors have noted the additional advantages of dissection over other teaching methods (Dyer and Thorndike, 2000; Ellis, 2001; Gregory and Cole, 2002; Pawlina and Lachman 2004; Lempp, 2005; Rehkämper, 2016), this paper explicitly maps its benefits to the desired characteristics in doctors. Thus, students are equipped with the necessary anatomical knowledge as well as an augmented array of professional skills. Prior to the pandemic, student perceptions of the development of these key professional skills were assessed by a survey in 2017.

Figure 1 lists the 16 statements used for the survey and students responded using a 5-point Likert scale. The results of the pre-COVID survey are shown in Table 1, and strongly support the conviction that a dissection-based course provides added value, enabling students to achieve many components of the ***Outcomes for Graduates***.

This paper discusses in detail the ways in which a dissection-based course fulfils the three sets of GMC ***Outcomes for Graduates***: professional values and behaviors, professional skills and professional knowledge. It details how these were achieved pre-COVID and, more importantly, how they remain equally relevant during the pandemic, highlighting the ways in which dissection enhances medical education to produce competent and compassionate clinicians.

DELIVERY OF BLENDED LEARNING DURING A GLOBAL PANDEMIC

In previous years, the core component of the University of Cambridge anatomy course has been hands-on cadaveric dissection, supplemented by lectures, applied anatomy sessions, and a Virtual Learning Environment (VLE) with resources for self-directed learning. Practical classes also comprised teaching with prosections, VH Dissector™ (Touch of Life Technologies, Inc., Aurora, CO USA) software on touchscreens and "live" ultrasound. The COVID pandemic led to widespread suspension of in-person university teaching and body donation programs, with a shift to predominantly online learning (Brassett et al., 2020).

The main challenge posed by the pandemic was to maintain cadaveric dissection while integrating it into a blended learning program. A novel teaching strategy was therefore developed to continue in-person practical dissection classes as the core element of the course. In view of the need to ensure a COVID-secure environment in the dissection room (DR), only 40 students, representing one-eighth of the year group, can attend per session. This necessitated an increased number of weekly practicals, the use of face coverings, visors and fewer cadavers, with only one student dissecting a donor at any one time.

In order to provide each student with a "live" interactive learning experience each week, Zoom™ (Zoom Video Communications, Inc., San Jose, CA USA) sessions were held in parallel with dissection classes. Breakout rooms were hosted by senior colleagues who led students in discussions to apply anatomical knowledge to clinical case scenarios in the relevant region. Short videos were also made at the beginning and end of each dissection session, with the former demonstrating the region to be dissected, and the latter showing anatomical variations or pathological conditions discovered during the class. These were broadcast immediately afterwards within an internal, secure network so that all students can benefit and follow the progress of dissection on their allocated donors. Dedicated "Table group forums" were also set up on the VLE for students to share dissection notes on their specific donors.

Outcomes 1: Professional Values and Behaviors

The first of the three sets of GMC outcomes relates to a range of both generic and specific personal and professional standards of behavior. Doctors have ethical and legal responsibilities relating to patient care, and must demonstrate a breadth of team-working skills in all areas of professional practice. Cadaveric dissection introduces students to the principles of consent and respect that underpin all clinical work, as well as providing an opportunity to reflect on the important concepts of attachment and detachment. These areas are further explored below.

Consent and Respect

Many authors have extolled dissection as a vehicle to address professionalism (Pawlina and Lachman, 2004; Escobar-Poni and Poni, 2006; Talarico, 2012), and to encourage humanistic

Through completion of the anatomy ***dissection*** *course:*	Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly Agree
1. I have an understanding of the importance of patient/donor consent:	1	2	3	4	5
2. I am aware of the laws/acts that regulate the activities in the DR:	1	2	3	4	5
3. I have learnt the importance of personal protective equipment:	1	2	3	4	5
4. I have learnt the importance of the careful handling of sharps:	1	2	3	4	5
5. I have improved my team-working skills:	1	2	3	4	5
6. I have improved my manual dexterity and abilities in handling tissues with instruments:	1	2	3	4	5
7. I feel more able to describe structures/pathology to colleagues using correct medical terms:	1	2	3	4	5
8. Through completing the donor medical record I have begun to appreciate the importance of keeping accurate, legible notes:	1	2	3	4	5
9. I feel confident in explaining the normal structure and function of key parts of the human anatomy:	1	2	3	4	5
10. I have an increased awareness of pathological findings and some medical conditions through findings in my own donor and other tables:	1	2	3	4	5
11. I have learnt to respect patients:	1	2	3	4	5
12. I have developed an awareness of anatomical variation:	1	2	3	4	5
13. I realise the importance of knowledge of anatomical variation in my future medical practice:	1	2	3	4	5
14. I feel more prepared to learn clinical procedures e.g. venepuncture having studied the anatomy of the underlying structures of the relevant areas:	1	2	3	4	5
15. I feel that I have improved my ability to work safely and thus protect my patients in the future:	1	2	3	4	5
16. I have seen, by assisting data collection or observing research in the DR, how the donors and specimens can be used for medical research and the importance of this work:	1	2	3	4	5

Fig. 1.- Student Survey 2017. Students responded to 16 statements (divided into 3 categories of similar themes) using a 5-point Likert scale, ranging from strongly disagree to strongly agree. Consent was obtained for voluntary participation and only complete surveys were included in the study.

Table 1. Results of Student Survey 2017. 242/279 (86.7%) of students completed the survey. A response was positive if the student had selected 4 or 5. Responses were positive in >80% for all questions except Q8, which related to the importance of writing accurate legible notes.

Question Number	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	Mean (±Standard Deviation)	Positive response
1	0.41%	0.41%	3.32%	32.37%	63.49%	4.58 (±0.62)	**95.85%**
2	0.42%	1.67%	7.92%	46.67%	43.33%	4.31 (±0.72)	**90.00%**
3	0.00%	0.41%	9.13%	38.59%	51.87%	4.42 (±0.67)	**90.46%**
4	0.00%	0.41%	7.88%	28.63%	63.07%	4.54 (±0.66)	**91.70%**
5	0.00%	2.90%	10.37%	47.30%	39.42%	4.23 (±0.75)	**86.72%**
6	0.00%	3.73%	13.69%	39.42%	43.15%	4.22 (±0.82)	**82.57%**
7	0.00%	1.26%	6.28%	37.66%	54.81%	4.46 (±0.67)	**92.47%**
8	1.67%	11.67%	30.00%	37.50%	19.17%	3.61 (±0.98)	**56.67%**
9	0.42%	2.08%	8.75%	45.42%	43.33%	4.29 (±0.75)	**88.75%**
10	0.00%	4.58%	15.42%	46.67%	33.33%	4.09 (±0.82)	**80.00%**
11	0.84%	1.26%	9.21%	29.71%	59.00%	4.45 (±0.78)	**88.70%**
12	0.42%	1.26%	3.35%	28.87%	66.11%	4.59 (±0.66)	**94.98%**
13	0.42%	0.42%	6.67%	25.83%	66.67%	4.58 (±0.67)	**92.50%**
14	0.00%	3.35%	12.97%	35.56%	48.12%	4.28 (±0.82)	**83.68%**
15	0.42%	1.68%	15.55%	39.08%	43.28%	4.23 (±0.80)	**82.35%**
16	0.00%	1.26%	11.30%	40.17%	47.28%	4.33 (±0.73)	**87.45%**

attitudes and beliefs (Dyer and Thorndike, 2000; Gregory and Cole 2002; Granger 2004). The GMC specifies that graduates should 'behave according to ethical and legal principles', requiring them to 'respect all patients, respect dignity (understand) the importance of appropriate consent and demonstrate knowledge of laws, and the systems of regulation'**.** In a dissection course, students are entrusted with the bodies of donors and are confronted by issues of death and mortality, which they will experience throughout their medical careers (Ellis, 2001; Aziz et al., 2002). They learn about informed consent in relation to body donation, a principle that will play a significant role in their future interactions with patients. Students acknowledge the generosity of donors, and the sacrifice of relatives who face an extended period between bereavement and committal of the remains of the deceased. This promotes a humane attitude and respect for future patients and relatives (Azer and Eizenberg, 2007), with 89% of students surveyed agreeing with this statement (Q11, Fig. 1). The overwhelming majority of students also agreed that they understood the importance of consent and the laws governing the DR (96% for Q1 and 90% for Q2, Fig. 1).

When the first national lockdown was implemented during the pandemic, the important principles of *consent and respect* were explicitly reinforced through an online interactive enrichment session comprising two lectures. The first, delivered by the Bequeathal Secretary, explained the legal framework by which consent is obtained and, importantly, used anonymized examples of donations to demonstrate the reality of the circumstances under which donors were received. The second presentation described the genesis and role of the Human Tissue Authority, exploring the ways in which compliance with the Human Tissue Act 2004 is achieved and maintained. The ensuing discussions strengthened the significance of consent and dignity as essential professional principles in students' minds.

Attachment and Detachment

At the end of the year, students from each table group collaborate to write a tribute to their donor, with two extracts reproduced in Table 2. After being read by the whole cohort, the tributes are sent to each family. Writing the tributes enables students to reflect on their experiences and express themselves appropriately, as reflective practice is a key component of developing and maintaining professional best practice in clinical medicine. The idea of the donor as their first patient and as a silent teacher is expressed in many tributes, and is the theme of a documentary made by the University of Cambridge about the anatomy course in 2016 (Body of work: the silent teacher helping students learn anatomy 2016). The patient is thus placed at the center of student learning from the very beginning of a dissection-based course.

Table 2. Extracts from student tributes.

"Our donors sparked enthusiasm and demanded respect. They were our first patients and forgave us any mistakes we made, only wanting to teach us more. They made us consider the reverence of human life and through their donation taught us of the trust all patients will give us. They gave us confidence and awareness, all without uttering a word."
"Our donor has enabled us to grasp a firm understanding of anatomy and its clinical relations, which we hope will prove invaluable throughout our medical careers. She has helped us hone many skills, from surgical techniques to working as a team. She has given us the greatest gift anyone could possibly give. In death, she has helped save future lives. Somehow saying thank you is simply not enough."

The dissection experience also teaches students the critical balance between attachment and detachment, as a physician must be emotionally attuned to a patient's feelings without being overwhelmed by them. Withholding a donor's personal information from the students encourages a sense of detachment, although students would often form an emotional bond with their donor throughout the year. During the Committal Service at the end of the year, as students learn the names of their donors for the first time and read biographical details sent by relatives, many are deeply moved as they engage with the lives and personalities of their donors.

As the Committal Service could not be held this year, a pre-recorded service was prepared with staff and student tributes, as well as donor biographical information, family photographs and accompanying music. In previous years, an annual Thanksgiving Service was also held for family and friends of donors, but was postponed this year due to the pandemic. This service has always been well- attended. While relatives enjoy talking to students who have benefitted from the generous legacy of the donors, students learn more of the complementary concepts of attachment and detachment through conversing with donors' family members.

Teamwork

Another component of this first set of GMC outcomes is to 'learn and work effectively within a multi-professional and multidisciplinary team' and to reflect, learn and teach others. Dissecting within a group encourages teamwork, and 87% (Q5, Fig. 1) of students agreed that the course had improved their skills in this regard.

In previous years, students would assign different roles to everyone in the table group, with students taking turns to perform each task. One student would read out dissection instructions while two or three dissected; another would complete the Donor Medical History sheet, with others learning on skeletons, VH Dissector™ tutorials or pre-dissected demonstration donors. This kind of self-directed learning encourages active discussion and teaches students how to work with others. It enables them to discover the best ways of expressing their findings to the team. Writing the table tribute together also encourages communication and collaboration.

Outcomes 2: Professional Skills

Doctors are expected to demonstrate wide-ranging and appropriate skills in clinical practice. Correct diagnosis and medical management require the safe and effective performance of practical procedures, as well as the ability to communicate well with patients and colleagues. Dissection provides valuable experience in practical skills, underpinned by an appreciation of anatomical variation and pathology. Undertaken as part of a team, dissection also provides opportunities for the refinement of communication skills. Several examples of these benefits are discussed below.

Manual Dexterity

The GMC states that graduates should be able to 'perform ... practical skills and procedures safely and effectively'. Dissection introduces the general aspects of practical procedures, such as safe handling of sharps and use of personal protective equipment. Table 1 shows 90% (Q3, Fig. 1) and 92% (Q4, Fig. 1) of students agreed that they had learnt these principles. The majority agreed that dissection has made them feel better prepared for learning clinical procedures such as venepuncture (84%, Q14, Fig. 1), as well as improving their ability to work safely and thus protect their patients (82%, Q15, Fig. 1).

Dissection also aids in the acquisition of haptic skills, resulting in increased manual dexterity, which is beneficial for all clinicians (Older 2006; Chambers and Emlyn-Jones 2009; Talarico, 2010). 83% (Q6, Fig. 1) of students agreed that they had developed such skills. Dissection encourages tactile exploration, enabling students to appreciate the 3D relationships of anatomical structures (Jones et al., 2001). Pre-COVID, a competitive-entry internship held in the summer vacation enabled students to learn meticulous dissection and produce high-quality anatomical prosections that were subsequently used as teaching specimens.

During the pandemic, as only one student could dissect at any one time due to occupancy restrictions in the DR, each student in fact had more time to dissect than was possible previously, when eight students were allocated to each donor. The quality of the dissections this year have therefore been of a higher standard than in past years. Many students were provided with finer instruments and acquired an enhanced degree of manual dexterity, as well as achieving satisfaction from the production of superior dissections. The digital forums provided on the VLE platform, where students would record any interesting findings after each session, enabled the maintenance of team-building opportunities provided by group dissection.

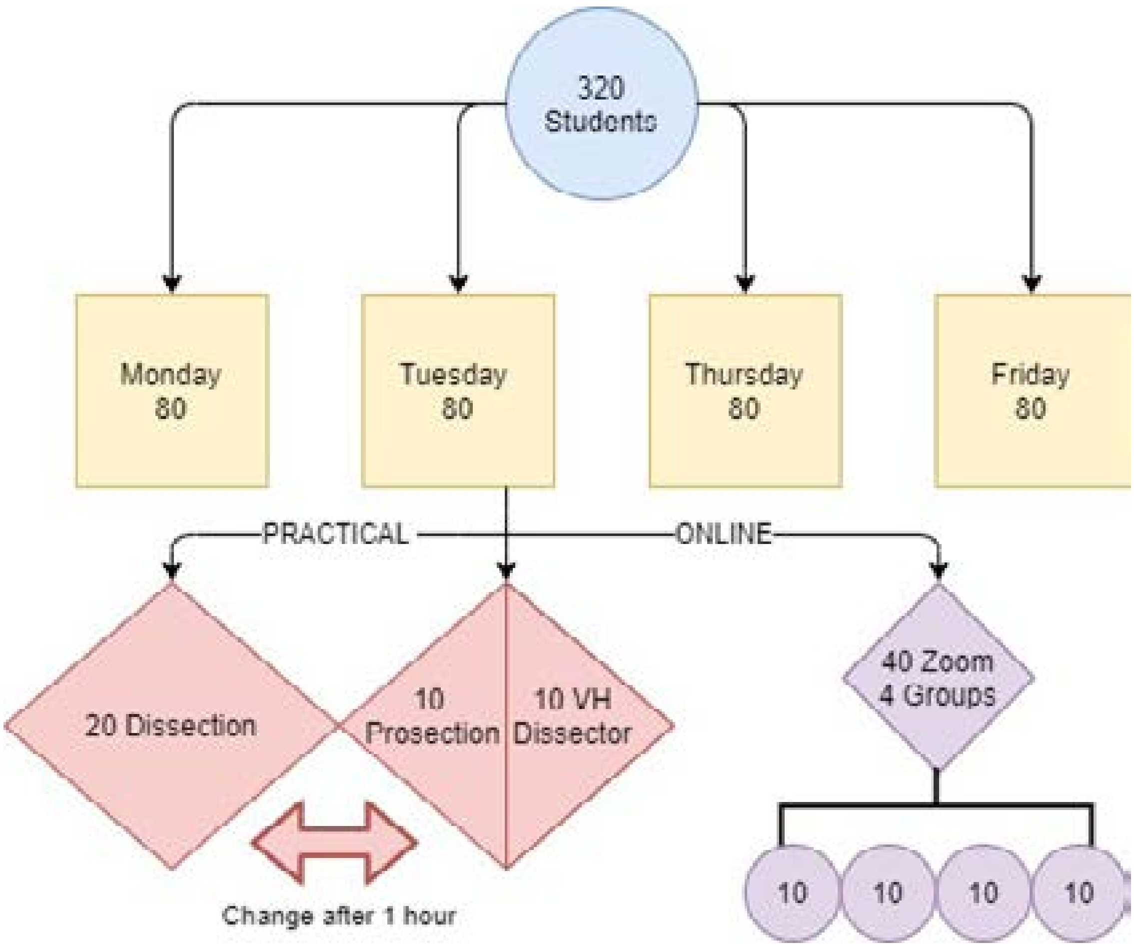

Fig. 2.- Division of first year student cohort into teaching groups. The student cohort was divided into 4 groups of 80 students each, with each group further subdivided into two subgroups. One subgroup would attend a practical dissection session while the other participated in online Zoom™ sessions.

Communication Skills

The ***Outcomes for Graduates*** also requires clinicians to 'communicate effectively ... with patients, ... and with colleagues' and 'use information effectively and safely in a medical context'. Dissection introduces students to the language of medicine, allowing them to become proficient in describing human anatomy and associated pathologies (Granger 2004; Thompson and Marshall, 2020): a key skill in discussions with colleagues at multidisciplinary meetings. During practical classes, students would use a range of appropriate vocabulary to interact with anatomists, surgeons, radiologists and technicians. Table 1 shows that 92% (Q7, Fig. 1) of students felt more able to have these discussions due to the dissection program.

Throughout the pandemic, online Zoom™ sessions have complemented DR teaching. Led by practicing and retired clinicians, each session includes discussion of the anatomical aspects of clinical cases, supplemented by radiological and surgical images. The students are allocated to breakout rooms, where discussion is facilitated by demonstrators, and students are nominated to present these cases once breakout discussions have concluded and everyone reconvenes in the main meeting room. Such presentations have provided students with enhanced opportunities to develop communications skills in ways that would not have been previously available.

Anatomical Variation

The anatomical features of individuals do not necessarily conform to the uniform descriptions in textbooks and models (Bergman, 2011). Dissection-based teaching impresses this diversity upon students from the start, as clinicians must recognise anatomical variation to practise safely (Willan and Humpherson, 1999; Ellis, 2002). Dissection also allows appreciation of the abundance of connective tissue, variable amount of fat, and the texture of different structures. While these are not easily shown in models or prosections, they are vitally important when performing clinical procedures (Korf et al., 2008). A lack of knowledge of anatomical variation may result in misdiagnosis and poor clinical practice (Aziz et al., 2002). With the increasing use of medical imaging, clinicians are more likely to observe anatomical variation and need to make decisions regarding its significance. Many clinicians are concerned that inadequate knowledge will lead to iatrogenic injuries (Fitzgerald et al., 2008; Standring and Larvin, 2015), which is especially pertinent as minimal access surgery or interventional procedures places greater demands on anatomical knowledge. As Marks Jr (2000) states that newer, complex 3D techniques may be more difficult to teach due to inadequate 3D understanding by today's graduates, it is even more important to maintain cadaveric dissection which teaches 3D anatomy and highlights anatomical variations.

In recent years, the number of medical negligence claims made to insurance companies for errors during surgical and other procedures due to a lack of anatomical knowledge continues to increase (Ellis, 2002), while surgical consultants bemoan the insufficient level of anatomical knowledge among their trainees. The commonest reason for compensation payouts in vascular and general surgery is injury to underlying structures. This may partly be due to changes in medical training at undergraduate and postgraduate level, stressing the need for dissection experience as well as higher standards in membership examinations.

The DR accommodates over 40 donor tables, meaning students are introduced to anatomical variation from the outset of their training. Table 1 shows that 95% (Q12, Fig. 1) of students agreed that the dissection course had developed their awareness of anatomical variation, with 93% (Q13, Fig. 1) acknowledging its importance for future clinical practice. Previously, apart from observing variations in their own donor, students could easily visit other donor tables. However, as students are discouraged from moving around the DR this year, demonstrators would inform the lead anatomist of any points of interest so that they can be shown as a video- broadcast on the DR touchscreens at the end of the session for all students to observe. Simultaneously, this is recorded and uploaded to the VLE for viewing by the whole student cohort. Thus, students have been able to observe a greater range of variation than they would previously have encountered in the DR, and can also return to the recordings for further study.

Pathology and Procedures

Another facet of this second set of outcomes is to ‘diagnose and manage clinical presentations’. The students discover many pathological conditions as they dissect, including diseases such as emphysema, congestive cardiac failure, cirrhosis, hiatus hernia and various malignancies. Students also learn about interventional procedures that had been performed on their donors, including stents placed for superior vena caval obstruction, ureteric stents for hydronephrosis and coronary artery bypass grafting. These findings facilitate discussions on the indications for such procedures and potential complications, providing a distinctly clinical focus. Through dissection and observing diseases in donors, 80% (Q10, Fig. 1) of students agreed that they had an increased awareness of pathological findings and medical conditions.

Whereas in previous years, students were provided with the available medical information and cause of death relating to their donors, from last year it was decided that this information would be withheld until the end of the year. At a specified teaching session, students would present their pathological findings and suggest a possible cause of death. As COVID-19 had by then supervened, these presentations were moved online, with the sessions being enhanced by a pre-recorded lecture from a palliative care consultant on the completion of the Medical Cause of Death Certificate (MCCD). Students were then allocated to breakout rooms, where the actual cause of death of their donor was revealed. They then discussed their pathological findings and the likely end-of-life trajectories for their donors. These sessions were facilitated by senior students from the Clinical School who had received teaching on the MCCD and palliative care. A representative from each table group then gave a brief presentation in the main meeting room on their conclusions. These discussions and presentations were more wide-ranging than in previous years and student feedback was very positive. This was also a good example of the spiral curriculum (Bruner, 1960), as these topics would be revisited by students in their Clinical School years.

Outcomes 3: Professional Knowledge

The third set of outcomes defined by the GMC relates to the scholarly application of a doctor’s knowledge to patient care. Doctors “must recognize the biomedical principles of health and disease, and integrate [them] to the care of patients”. An anatomy course based on cadaveric dissection provides an excellent foundation for students to develop an enquiring mind. Furthermore, the availability of human tissue enables research that is clinically relevant and directly applicable to diagnosis and management. The ways in which students can be involved are described below.

Data Collection

Throughout the academic year, students in the DR would contribute to clinically relevant studies by recording observations and making measurements. Such projects have included investigation of lung fissures, relationship of the femoral vessels and disposition of the renal arteries. Data collection acted primarily to teach and increase engagement with the relevant anatomy, as well as encouraging students to dissect more carefully in the region of interest. Students considered these research projects to be a worthwhile part of the course, and felt that they were particularly successful in teaching anatomical variation and clinical relevance, as well as demonstrating that anatomy is a “living science”. A number of students indicated that the projects taught the scientific method and made them more likely to engage with research in future.

Research Projects

In their third year, students intercalate and engage in a year of specialist study. This is an integral and compulsory part of the University of Cambridge medical course.

The amount of cadaveric material available has enabled numerous research projects to be undertaken, answering anatomical questions that have been raised in clinical practice. Each year, several third-year students will choose to work on an anatomical research project.

Senior students in the Clinical School have also chosen to engage in anatomical research during Student Selected Components or Medical Electives. The findings from these studies have been presented at national and international conferences, and have led to the publication of several papers in peer-reviewed journals.

Clinical Questions

Anatomical research can be used to answer a variety of clinical questions that have arisen in practice. The GMC indicates that medical graduates should be able to "explain the relevant scientific processes underlying common and important disease processes" and "analyse clinical phenomena and conduct appropriate critical appraisal and analysis of clinical data". Asking questions such as *where*, *how* and *why* encourage students to think critically, formulate hypotheses and devise strategies to solve the problems being posed. Over many years, the kinds of investigations that have been undertaken in the DR have produced results that are directly applicable to clinical practice.

Through dissection-based research projects, students have investigated key clinical questions including: mapping safe zones for the insertion of trochars for arthroscopic ports (Bartlett et al., 2018), formulating a novel categorisation for the configuration and mobility of the colon to improve colonoscopic practice (Lam et al., 2020), and understanding the pathogenesis of the Segond fracture through microCT and virtual biopsy of sub-entheseal sites in cadaveric tibial specimens (Mullins et al., 2020). There remain numerous clinical questions that can be answered with relevant anatomical research, and many students who have done so during their preclinical years continue to pursue original research with scientific rigour after qualification.

CONCLUSION

In summary, a dissection-based anatomy course enables students to achieve key elements of the three sets of *Outcomes for Graduates* stipulated by the GMC in the UK. Dissection offers a lot more than the imparting of basic anatomical knowledge, as it also equips students with essential professional values, behaviors, skills and knowledge. The foundations of these professional principles are cemented in the relationships cultivated by the students with both donors and colleagues in the dissection room. The generosity of donors permits students to err and to learn, providing invaluable opportunities to improve their understanding of anatomical variations and pathology as an excellent foundation for future clinical practice.

Despite the challenges posed by COVID-19, cadaveric dissection has remained a core element of the University of Cambridge anatomy course. An innovative blended learning program has combined interactive online teaching with in-person practical classes. Student feedback at the end of this current term has been overwhelmingly positive with regard to their dissection experience, and reinforces the importance of maintaining this irreplaceable way of learning, which has always been considered to be the "gold standard" for anatomy education.

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REFERENCES

ALI A, KHAN ZN, KONCZALIK W, COUGHLIN P, EL SAYED S (2015) The perception of anatomy teaching among UK medical students. *Bull R Coll Surg Engl*, 97: 397-400.

AZER SA, EIZENBERG N (2007) Do we need dissection in an integrated problem based learning course? Perceptions of first and second year medical students. *Surg Radiol Anat*, 29: 173.

AZIZ MA, MCKENZIE JC, WILSON JS, COWIE RJ, AYENI SA, DUNN BK (2002) The human cadaver in the age of biomedical informatics. *Anat Rec*, 269: 20-32.

BARTLETT JD, LAWRENCE JE, KHANDUJA V (2018) What Is the risk posed to the lateral femoral cutaneous nerve during the use of the anterior portal of supine hip arthroscopy and the minimally invasive anterior approach for total hip arthroplasty? *Arthroscopy*, 34: 1833-1840.

BERGMAN RA (2011) Thoughts on human variations. *Clin Anat*, 24: 938-940.

BRASSETT C, COSKER T, DAVIES DC, DOCKERY P, GILLINGWATER TH, LEE TC, MILZ S, PARSON SH, QUONDAMATTEO F, WILKINSON T

(2020) COVID-19 and anatomy: Stimulus and initial response. *J Anat*, 237: 393-403.

BRUNER J (1960) *The process of education*. Harvard University Press, Cambridge, Massachusetts.

CAMBRIDGE UNIVERSITY (2016) Body of work: the silent teacher helping students learn anatomy. Youtube. Available from: https://www.youtube.com/watch?v=yrVkm_JtdVQ

CHAMBERS J, EMLYN-JONES D (2009) Keeping dissection alive for medical students. *Anat Sci Educ*, 2: 302-303.

DINSMORE CE, DAUGHERTY S, ZEITZ HJ (1999) Teaching and learning gross anatomy: Dissection, prosection, or "both of the above?" *Clin Anat*, 12: 110-114.

DYER GS, THORNDIKE ME (2000) Quidne mortui vivos docent? The evolving purpose of human dissection in medical education. *Acad Med,* 75: 969-979.

ELLIS H (2001) Teaching in the dissecting room. *Clin Anat*, 14: 149-151.

ELLIS H (2002) Medico-legal litigation and its links with surgical anatomy. *Surgery*, 20: 1-2.

ESCOBAR-PONI B, PONI ES (2006) The role of gross anatomy in promoting professionalism: a neglected opportunity! *Clin Anat*, 19: 461-467.

FITZGERALD JE, WHITE MJ, TANG SW, MAXWELL-ARMSTRONG CA, JAMES DK (2008) Are we teaching sufficient anatomy at medical school? The opinions of newly qualified doctors. *Clin Anat*, 21: 718-724.

GENERAL MEDICAL COUNCIL, OUTCOMES FOR GRADUATES (2018) Available from: https://www.gmc-uk.org/education/standards-guidance-and-curricula/standards-and- outcomes/outcomes-for-graduates

GRANGER NA (2004) Dissection laboratory is vital to medical gross anatomy education. *Anat Rec*, 281B: 6-8.

GRANGER NA, CALLESON D (2007) The impact of alternating dissection on student performance in a medical anatomy course: Are dissection videos an effective substitute for actual dissection? *Clin Anat*, 20: 315-321.

GREGORY SR, COLE TR (2002) The changing role of dissection in medical education. *JAMA*, 287: 1180-1181.

ALEXANDER J (1970) Dissection vs prosection in the teaching of anatomy. *J Med Educ*, 45: 600-606.

JOHNSON JH (2002) Importance of dissection in learning anatomy: Personal dissection versus peer teaching. *Clin Anat*, 15: 38-44.

JONES LS, PAULMAN LE, THADANI R, TERRACIO L (2001) Medical student dissection of cadavers improves performance on practical exams but not on the NBME Anatomy subject exam. *Med Educ Online*, 6: 2.

JONES NA, OLAFSON RP, SUTIN J (1978) Evaluation of a gross anatomy program without dissection. *J Med Educ*, 53: 198-205.

JONES P (1988) Thomas Lorkyn's Dissections, 1564/5 and 1566/7. *Trans Camb Bibliogr Soc*, 9: 209-229.

KORF HW, WICHT H, SNIPES RL, TIMMERMANS JP, PAULSEN F, RUNE G, BAUMGART-VOGT E (2008) The dissection course - necessary and indispensable for teaching anatomy to medical students. *Ann Anat*, 190: 16-22.

LAM J, WILKINSON J, BROWN J, SPEAR M, BRASSETT C (2020) Exploration of colonic looping patterns in undisturbed cadaveric specimens. *Clin Anat*, https://doi.org/10.1002/ca.23702, online ahead of print.

LEMPP HK (2005) Perceptions of dissection by students in one medical school: beyond learning about anatomy. A qualitative study. *Med Educ*, 39: 318-325.

MARKS JR SC (2000) The role of three-dimensional information in health care and medical education: The implications for anatomy and dissection. *Clin Anat*, 13: 448-452.

MCLACHLAN JC, REGAN DE BERE S (2004) How we teach anatomy without cadavers. *Clin Teach*, 1: 49-52.

MULLINS W, JARVIS GE, OLUBOYEDE D, SKINGLE L, POOLE K, TURMEZEI T, BRASSETT C (2020) The segond fracture occurs at the site of lowest sub-entheseal trabecular bone volume fraction on the tibial plateau. *J Anat*, 237: 1040-1048.

NNODIM JO, OHANAKA EC, OSUJI CU (1996) A follow-up comparative study of two modes of learning human anatomy: by dissection and from prosections. *Clin Anat*, 9: 258-262.

OLDER J (2004) Anatomy: a must for teaching the next generation. *Surgeon*, 2: 79-90.

OVERBECK-ZUBRZYCKA D, KRISHNAN A, HAMILTON D, SEARLE RF, STANSBY G (2012) Tomorrow's Doctors: Students' satisfaction with a prosection based undergraduate anatomy course. *Ann R Coll Surg Engl*, 94 Supl 1: 1-4.

PAWLINA W, LACHMAN N (2004) Dissection in learning and teaching gross anatomy: Rebuttal to McLachlan. *Anat Rec*, 281B: 9-11.

REHKÄMPER G (2016) Human dissection in medical education: more than just anatomy. *GMS J Med Educ*, 33: Doc68.

ROLLESTON H (1932) The Cambridge Medical School: A Biographical History. Cambridge University Press Archive.

SARMA HHP, ISLAM M (2015) Impact of dissection on under graduate and post graduate study in medical colleges. *Sch J App Med Sci*, 3(2A): 551-554.

STANDRING S, LARVIN M (2015) Anatomy teaching: the cruellest cut - a progress report. *Br R Coll Surg Engl*, 93: 16-18.

TALARICO JR EF (2010) A human dissection training program at Indiana University School of Medicine-Northwest. *Anat Sci Educ*, 3: 77-82.

TALARICO JR EF (2012) A change in paradigm: Giving back identity to donors in the anatomy laboratory. *Clin Anat*, 26: 161-172.

THOMPSON AR, MARSHALL A (2020) Participation in dissection affects student performance on gross anatomy practical and written examinations: results of a four year comparative study. *Anat Sci Educ*, 13: 30-36.

WILLAN PLT, HUMPHERSON JR (1999). Concepts of variation and normality in morphology: Important issues at risk in modern undergraduate medical courses. *Clin Anat*, 12: 186-190.

WILSON AB, MILLER CH, KLEIN BA, TAYLOR MA, GOODWIN M, BOYLE EK, BROWN K, HOPPE C, LAZARUS MA (2018) Meta-analysis of anatomy laboratory pedagogies. *Clin Anat*, 31(1): 122-133.

WINKELMANN A (2007) Anatomical dissection as a teaching method in medical school: a review of the evidence. *Med Educ*, 41(1): 15-22.

YEAGER VL (1996) Learning gross anatomy: Dissection and prosection. *Clin Anat*, 9: 57-59.

Teaching embryology through information technologies during Sars-Cov-2 pandemic at University of Costa Rica Medical School: experience and results

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SUMMARY

In March 2020, due to the onset of the pandemic caused by the SARS-COV-2 virus, a series of restrictions were implemented by the Costa Rican Government for all education at the primary, secondary and university levels. These restrictions necessitated the adaptation of all courses to a 100% virtual modality, thereby transforming the methodologies and evaluation of lessons and laboratories. With respect to embryology at the University of Costa Rica (UCR) School of Medicine, two different approaches were used: Problem-Based Learning (PBL) and Embryology Laboratories with histological images of embryos and fetuses by systems, both through Moodle™ Lessons. The creation of a large databank of two-dimensional (2D) and three-dimensional (3D) images of embryos and fetuses supported the theoretical content of the course, and was available to students for daily use. The scopes of both approaches were evaluated by students using two different methods: a digital questionnaire and a focus group. The questionnaire responses showed a strong preference for PBL modules, whereas laboratories did not have such a positive perception. In both evaluations, students highlighted the importance of assistance with questions by professors, the objectives of the course and access to clinical cases. The application of embryological concepts through PBL clinical cases allowed students to develop greater interest in the subject and better integration of theoretical concepts. Embryology is a course that can be given 100% virtual, but it is essential that students play a more active role in the learning process.

Key words: Education – Embryology – Laboratory – Problem-based Learning – Sars-Cov-2

ABBREVIATIONS

Electronic Learning (E-Learning)

Learning Management Systems (LMS)

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Mediated Technology Teaching Support Unit (METICS)

Problem-Based Learning (PBL)

Self-Directed Learning (SDL)

Three-dimensional 3D

Two-dimensional 2D

University of Costa Rica (UCR)

Virtual Learning Environments (VLEs)

Virtual Mediation Environment (VME)

INTRODUCTION

The University of Costa Rica is the only public university that offers a Bachelor´s Degree in Medicine and Surgery. The UCR School of Medicine has been graduating professionals since 1969. The medical education curriculum consists in 6 years (divided into 12 semesters). The first year is composed of basic sciences, humanity courses, culture and art. The next 4 years, students are enrolled in clinical subjects (i.e., rotations) and supervised practices, followed by a year-long internship in public hospitals. Approximately, 130 students are admitted annually, with an annual promotion of 90-100 students.

Embryology is a course during the third semester of the second year, along with subjects of morphological sciences (i.e., descriptive and topographic anatomy, histology and neuroanatomy). It is a 17-week collegiate course that is held once a week, consisting of 2 hours of theoretical classes and 2 hours of laboratories. Approximately 120 students are enrolled, allowing several teachers to develop theoretical lessons and collaborate with laboratories, with the guidance of a general coordinator for the course.

During 2020, the world faced a global emergency with the SARS-COV-2 virus. At the start of March 2020 and during the first semester at UCR School of Medicine, this virus was detected in the population. The Ministry of Health implemented protective measures such as suspension of in-person lessons at all educational centers. Therefore, it was necessary to adapt courses to a 100% virtual modality, thus transforming the teaching methodologies and evaluation of lessons and laboratories. This change led to the construction of a set of teaching and learning strategies and methods that allowed students to learn comprehensively through remote activities and using online resources (eLearn Center, 2015).

Virtual education is an alternative for students to maintain interaction and presence in a course through different virtual environments; resulting in an integration of their education with activities such as work or family (Guaña-Moya et al., 2015). This method of learning requires a paradigm shift in student's behavior, in which they must depart from a model based on imitation, and have a more active role in their training. This is known as Self-Directed Learning (SDL), a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes. Students can learn through research methods, observation and processes of reflection that allow an exchange of ideas and knowledge in Virtual Learning Environments (VLEs), and using different technological resources such as Learning Management Systems (LMS) (Guaña-Moya et al., 2015).

Using VLEs Guaña-Moya et al. (2015) showed that the development of digital interactions led to a rupture of geographical, psychological barriers and pedagogical methodologies, giving way to the creation of LMS as management and interaction spaces for learning. Among the LMS most used in higher education, it is worth highlighting software such as Moodle™ (*Moodle Pty, Ltd.,* West Perth, Australia) a Free Open Source Learning Environment, Blackboard™ (*Blackboard learn*, Washington D.C., United States), Classroom™ (*G Suite for Education, Google,* California, United States), Zoom™ (*Zoom Video Communications, Inc.,* California, United States) Edmodo™ (*Edmodo, Inc.*, California, United States) another Free Open Source Learning Environment, and Canva™ (*Canva, Pty Ltd*, simplified graphic design tools software and website, Sidney, Australia), which allow the possibility of sharing resources and activities such as forums, pdf files, wikis and exams. These platforms also allow virtual environments where teacher-student, student-student and administrative-teacher-student interactions are developed (Gómez Galán, 2017, “E-learning Moodle”, 2006)de tanta implementación para los campus virtuales de la Educación Superior, y el reciente modelo pedagógico que ofrece el fenómeno MOOC (Massive Online Open Courses

The use of VLEs in higher education requires, both from the teacher and the student, the development of basic digital skills that allow them to use the technologies, considered essential for the development of electronic learning (E-learning), defined as “a proposal planned by the teacher in VLEs or LMS classroom for students to develop a learning experience from the guidelines and resources provided” (Area Moreira et al., 2014) the results of an assessment survey on this experience completed by the students are included.”,”author”:[{“dropping-particle”:””,”family”:”Area Moreira”,”given”:”Manuel”,”non-dropping-particle”:””,”parse-names”:false,”suffix”:””},{“dropping-particle”:””,”family”:”Borrás Machado”,”given”:”José”,”non-dropping-particle”:””,”parse-names”:false,”suffix”:””},{“dropping-particle”:””,”family”:”Sannicolás”,”given”:”María”,”non-dropping-particle”:””,”parse-names”:false,”suffix”:””}],”container-title”:”Revista interuniversitaria de formación del profesorado”,”id”:”ITEM-1”,”issue”:”1”,”issued”:{“date-parts”:[[“2014”]]},”note”:”«alfabetización tecnológica»: En la misma se pone de manifiesto que la formación docente en TIC debe tener en cuenta no solo la adquisición de las habilidades de uso de las herramientas tecnológicas, sino que también destaca la adquisición de las competencias y los conoci-mientos tanto teóricos como procedimentales para emplearlas de forma innova-dora y creativa en situaciones de enseñanza-aprendizaje.\n\nPérez Gómez (2010, 53. The main advantages of using LMS are the ability to centralize learning, timely updating of material, flexible scheduling, pacing (i.e., SDL), and support for real-time student tracking (Aloia & Vaporciyan, 2019). It has been suggested that the role of the teacher in this type of course should be very active, so that he/she is in constant contact with the students, using strategies such as audios, videos, synchronous and asynchronous discussions, practical activities and other online tools to involve students and keep them interested in the topic of study (Nortvig et al., 2018).

The UCR has developed the Mediating Technologies Teaching Support Unit (METICS), which since 2006 has accompanied teachers in the process of adopting technologies and blended learning, through training, resources for self-learning and the management of the Virtual Institutional Platform for Learning (i.e., Virtual Mediation Environment (VME), based on Moodle™ v. 3.8, 2020). This article presents how the teaching strategy of the Embryology Course was approached, from a 100% virtual modality, describing the work methodology, as well as the evaluation by the students of the first semester implementation measured with a questionnaire and a focus group.

MATERIALS AND METHODS

Subject Cohort

The course was attended by 120 students and 6 teachers. A total of 44 second-year medical students who passed the embryology course in the first semester of the year 2020 participated in this study. Of these 44 students, all completed the survey instrument and 14 participated in focus groups. Surveys were done with anonymity using google forms (for more information on the survey consult the authors).

Course Structure

The Embryology Course was designed with two learning methods, PBL and Embryology Laboratories with histological images of embryos and fetuses by systems, both learning methods were made available through Moodle™ Lessons. Both methods were designed with specific learning outcomes of what students should be able to do when they successfully complete a learning experience. These learning outcomes were written in a student-centered, measurable fashion that was concise, meaningful, and achievable.

PBL Sessions. During PBL sessions students were required to analyze “real-life” clinical problems and to investigate possible solutions through the integration of prior skills, theory, and practice. This approach is supported by prior research that documented the PBL cases allowed students to apply ideas to real experiences and improved educational practice, as well as learning outcomes and knowledge retention (Olmedo et al., 2013).

Students were confronted with nine learning modules designed with VME, using spaces for text and image content and diagnostics through false or true, single or multiple choice and concept relationship questions. These were carried out in parallel with synchronous sessions that allowed a greater group follow-up, where the students had the opportunity to resolve questions and improve knowledge by working with each other and with the faculty tutors (as part of the PBL process).

Embryology Laboratory. The online laboratory was composed of nine sessions through the study of histological slides in laboratory modules designed with VME, composed of explanatory and visual contents divided by systems that correlated to topics didactic sessions. These were carried out in a synchronous way where students could examine self-identified gaps in knowledge with guidance of faculty as he/she progressed in the laboratory, through a Zoom™ platform. Students were responsible to recognize structures in histological images of embryos and fetuses that had previously been explained in the content of the didactic lesson. This is an active methodology that places students at the center of the learning process (eLearn Center, 2015).

Evaluation

To assess the usefulness of the learning methodology and to obtain feedback for possible improvements (i.e., areas of weakness and strength), two methods were used: a survey instrument and a focus groups.

Survey Instrument. A *digital, survey instrument* was constructed, which consisted of a set of questions that were designed to generate the necessary data to achieve the objectives of the research project (Bernal, 2010). This questionnaire consisted of six sections: (1) personal data, (2) use of the tools and resources available in the course, (3) PBL methodology, (4) laboratory methodology, (5) use of the VME, and (6) narrative comments with respect to the application of teaching techniques. The survey instrument was generated using Google Forms and sent electronically to the all students who completed the course, of which only 44 people completed the questionnaire (for more information on the survey email the authors).

Focus Groups. Focus groups were compose of randomly selected group of students to discuss and develop, based on personal experience, a topic relative to the structure and usefulness of the teaching modalities in this online course (Salinas and Cárdenas, 2009) which, according to Mella (2020), can be applied to a minimum of six people for the application to be valid. A total of 14 students from VLEs elected to participate in focus groups that were conducted virtually through the Zoom™ platform. Focus groups proceeded through three phases of discussion with respect to each learning experience in the VLE: (1) question generation about perceptions of the course (where answers were systematized through a WordCloud created on the Mentimeter™ platform (Mentimeter AB, Stockholm, Sweden), (2) questions and discussions about the course methodology, and (3) feedback with respect to course content.

RESULTS

A total of 44 (of 120) students completed the survey instrument. Students ranked the usefulness of learning tools as “not helpful”, “little useful” and “very useful”. Most students (40) ranked PBL, laboratory modules and synchronous classes as “very useful”, followed by virtual exams (37), claims delivery (28) and forums (12) (Fig. 1). Most students (24) found forums as “little useful” and there remainder (14) ranked forums as “not helpful” (Fig. 1). Few students (3) indicated that virtual examination “were not helpful” (Fig. 1).

A Wordle™ (i.e., WordCloud or Tag Cloud) is a visual representation of words, where the size of each word is proportional to the number of times it appears. Thus, the more a specific word appears in a source of textual data (i.e., such as a speech, blog post, or database), the bigger and bolder it appears in the WordCloud. WordClouds help to analyze customer satisfaction. Focus groups generated adjectives (i.e., noun descriptors) that qualitatively described the online embryology course, and these words were input into a WordCloud Generator to visualize the results (Fig. 2). The words most used in describing the course in order of decreasing frequency were: interesting (mostly used), abstract, essential, life, cute, and beautiful.

In the WordCloud (Fig. 2) elaborated during the meeting with focus groups, it can be observed that the central and larger words were the most used by the students who participated in the meeting. These adjectives that quality the embryology course were: Interesting and Abstract (in majority), followed by Essential, Life, Cute and Beautiful.

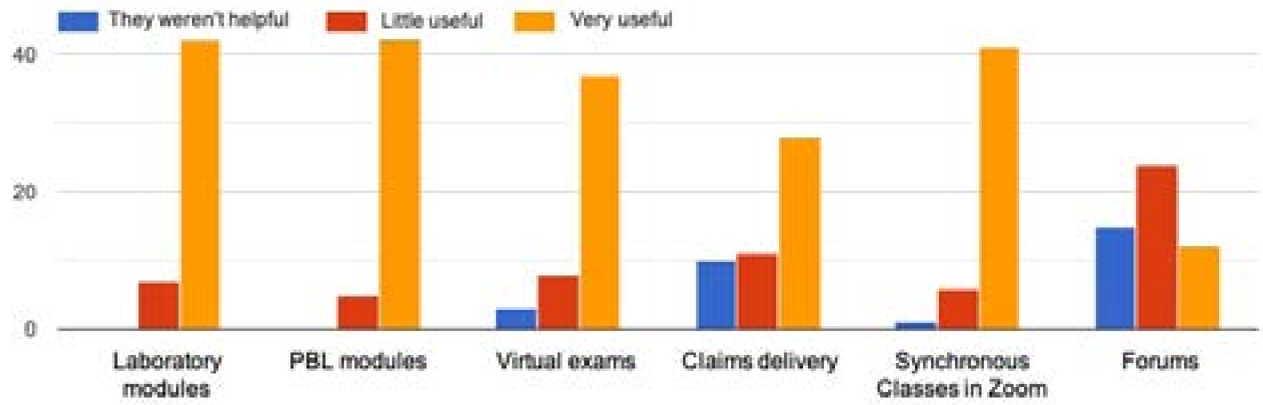

Fig. 1.- Evaluation of E-Learning Activities in Embryology. Graphical representation of student survey results qualitatively ranking the usefulness of learning tools in the virtual embryology course at the University of Costa Rica School of Medicine. Claims Delivery refers to appeals of the tests that students take to the teacher. Forums were a space for dialogue type chat in the virtual classroom.

Fig. 2.- WordCloud generated from the Focus Group Meeting for the Virtual Embryology Course. Students were asked to identify four words that for them described the course. Words were entered into a WordCloud Generator that yielded this artistic construct, a visual representation of words, where the size of each word is proportional to the number of times it appears. Thus, the more a specific word appears in a source of textual data the bigger and bolder its significance. *Translation:* Interesante (interesting), abstracto (abstract), esencial (essential) desarrollo embriológico (embryo development), inherente a la vida (inherent in life), niños (children), dinámico (dynamic), curioso (curious), pensativo (Thoughtful), 2D (2D), bebés (babies), concepción (conception), fácil (easy), génesis (genesis), imaginación 4d (imagination 4d), felíz (happy), hermoso (beautiful), adecuado (suitable), feto (fetus), organizado (organized) proceso (process) denso (dense), complejo (complex), ordenado (order) desarrollo (development), académico (academic), importante (important) monótono (monotonous), embarazo (pregnancy), nuevo (new), lindo (cute), vida (lifetime) and casos (cases).

According to VME records, there was an average of 2732 weekly visits to PBL sessions, with a maximum of 3674 visits in the first week and a minimum of 2023 visits in the last week of the semester. Further, in the responses on the survey instrument, the PBL modules were rated as very useful with respect to:

- content,
- explanation of problems,
- complementary resources (i.e., radiographs, etc.),
- and patient history.

However, there was a less positive perception towards the wording of questions and answers within PBL sessions. The majority of students (76.9%) preferred multiple-choice questions, and the remainder of the students were split (11.5% each) between single-choice and matching type questions (Fig. 3A). In focus groups, PBL represented the most positive methodology, which according to the participants allowed a closer approach to the professional reality, provoking motivation and interest in the subject.

For the laboratory modules, there was an average of 5250 visits per week, with 5439 visits in the first week. In contrast to the decline in visit in PBL during the final week of the course, there was an increase in visits/usage of laboratory modules (i.e., 6021 visits in the last week of the semester). In response to the survey instrument, students indicated that the laboratory modules were particularly useful. The most highly rated aspects were the explanation of the problem and the supplementary resources. Likewise, aspects of image description, question writing and answer writing were rated as very effective or effective. With respect to assessment of student learning in laboratories, 34.6% of the respondents favored multiple- choice questions, 44.2% favored single-choice questions, and the remaining 21.5% favored matching questions (Fig. 3B). In the focus group, the laboratories did not have a positive perception.

For both methodologies, students emphasized the importance of access to professors (1) to assist in resolving questions about materials that caused confusion after study and investigation and (2) to assist in comprehensive understanding of course objectives. Students also stressed that when access to patients was denied or limited (as in the SARS-COV-2 pandemic), it was positive and useful to have access to clinical cases in virtual environments.

DISCUSSION

Some of the most important challenges presented by E-learning are the creation of VLEs

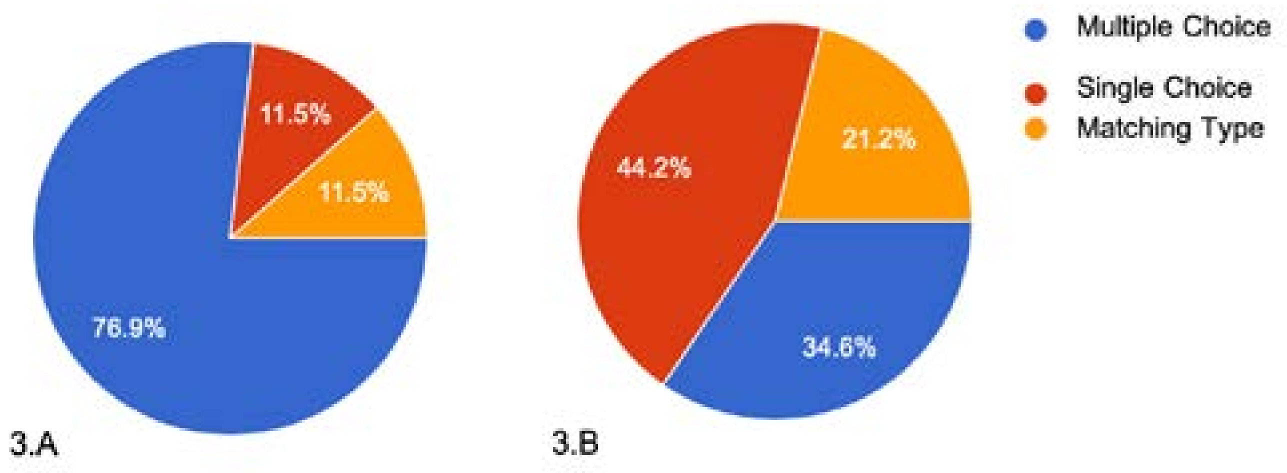

Fig. 3.- Pie chart graphs of preferred evaluation methods in PBL vs. Virtual Laboratories in the E-Learning Embryology Course that the University of Costa Rica School of Medicine. **(A)** PBL and **(B)** Laboratories.

suitable for online teaching and learning, as well as the creation of a community that provokes meaningful experiences and supports social interactions. In addition, the process of social inclusion should not be forgotten, in order to facilitate access to technologies to the whole society without social, geographical or economic distinction (Mojarro et al., 2015; Nortvig et al., 2018).

The Embryology course at UCR, taught in the first semester of 2020, was a clear example of the resolution of these challenges, where the use of tools such as VLEs, the VME, Moodle™ and Zoom™ helped to make a 100% virtual course with synchronous laboratories accessible to numerous students at the same time. In addition, the use of the VME as the site that hosted the virtual classroom of the course allowed for a repository of course content. The Moodle™ Lessons tool was useful for developing both the PBL and the virtual laboratories, and the Moodle™ Exams tool allowed for the development of single-choice exams and recognition and integration of images analyzed throughout the course in didactic, PBL and laboratory sessions. Furthermore, the application of embryological, theoretical concepts in clinical cases through the PBL allowed students to develop a greater interest in the subject, while obtaining a better integration of theoretical concepts.

Finally, analyzing the perception of the course provided by the students in the focus group and the perception of faculty, highlighted one of the most important skills needed by medical students during formative years and throughout as career in medicine – SDL. This concept first established by Knowles (1975) describes a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes. SDL relies on the basis that learners become increasingly self-directed as they mature. In particular SDL skills become increasingly important with distance education or E-Learning, such as during the SARS-COV-2 pandemic, and the application of SDL depends on pedagogical approach (Sáez et al., 2018; Murad et al., 2010). As such, SDL requires an adaptation to the revised methodologies of transforming an in-person course to an E-Learning course (Sáez et al., 2018; Murad et al., 2010). In addition, methods of assessment and evaluation must also be adapted to E-Learning (i.e., E-Assessment) where students can be evaluated with clear criteria, contributing to the assessment, promoting greater self-awareness of their interventions and professional practice.

Therefore, it is suggested that the design of E-Learning courses incorporate SDL integration of work among peers for problem-solving. Even further, this is a skill and a concept that is established and required in clinical practice and professional service.

Like other universities during the pandemic, a tremendous task faced by faculty at UCR was the need to rapidly develop online tools and resources. This involved the digitization of, and obtaining new histological, images of embryos and fetuses in part due to the poor quality of the existing collection. However, this allowed the incorporation of a large number of images, photographed from the microscopes, of different organs, embryo systems, human fetuses and fetuses of different animal species, thereby providing content to the virtual laboratories that could be accessed and examined from any location and at any time. Also, the 100% virtual course facilitated the creation of a large bank of 2D and 3D images of embryos and fetuses to support the theoretical content of the course, which will be available to students for future courses.

Limitations. There are several limitations to the present work that require continued study and evaluation in additional offerings of the online embryology course at UCR. First, the reason for the drastic drop in PBL attendance during the final week of the course remains unclear. It might be suggested that the reason for this was a decreased need for review by students and increased mastery of the subject/material. Another possible explanation might be time management at the end of the course, and/or increased need for laboratory review. The latter might be supported by the results of the present work that showed an increase in virtual laboratory attendance that corresponded to the time course of decreased attendance in PBL. Further, the increased recurrence of laboratory visits toward the end of the semester may have been due to the proximity to the laboratory exam, which was held at the end of the semester. It should also be noted that student narrative feedback suggested that laboratories were limited by the difficulty in understanding the 2D images and the lack of integration with clinical concepts. Lastly, during this first implementation of the online embryology course at UCR, the integration of histological images in the subject was not evaluated other than through laboratory notebooks, which may have resulted in less understanding of concepts.

CONCLUSIONS

The results of the present work show that a 100% E-Learning embryology course can be done with positive student outcomes using PBL, focus groups and virtual laboratories. Adaptation in the SARS-COV-2 pandemic exposed the need for high-quality teaching (i.e., resource) materials that facilitate SDL and the integration of theoretical knowledge with histological images in embryology. Finally, for success of the E-Learning environment, it is important transform education where the most active role is that of the student, so that he/she can construct his/her knowledge with the help and guidance of faculty and at the same time strengthen SDL skills.

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REFERENCES

ALOIA L, VAPORCIYAN AA (2019) E-Learning trends and how to apply them to thoracic surgery education. *Thorac Surg Clin*, 29(3): 285-290.

AREA MOREIRA M., BORRÁS MACHADO J, SANNICOLÁS M (2014). La formación del maestro 2.0: el aprendizaje por tareas en entornos b-learning. *Revista Interuniversitaria de Formación del Profesorado*, 28(1): 51-66.

BERNAL C (2010) Metodología de la investigación. 3rd ed. Pearson, Colombia.

E-LEARN CENTER (2015) Metodologías docentes. Cataluña, España: *Universitat Oberta de Catalunya.*

E-LEARNING MOODLE (2006) A la cabeza del mercado de aprendizaje a distancia Innovación Educativa. *Innovación Educativa,* 6(31): 59-71.

GÓMEZ GALÁN J (2017) Interacciones Moodle-MOOC: presente y futuro de los modelos de e-learning y b-learning en los contextos universitarios. *EccoS – Revista Científica*, (44): 241-257.

GUAÑA-MOYA E, LLUMIQUINGA-QUISPE S, ORTIZ-REMACHE K (2015) Caracterización de entornos virtuales de enseñanza aprendizaje (EVEA) en la educación virtual. *Ciencias Holguín*, 21(4): 1-16.

KNOWLES M (1975) Self-directed learning: A guide for learners and teachers. Association Press, New York.

MOJARRO Á, RODRIGO D, ETCHEGARAY, CENTENO MC (2015) Educación personalizada a través de e-Learning. *Alteridad*, 10(1). https://doi.org/10.17163/alt.v10n1.2015.02

MURAD MH, COTO-YGLESIAS F, VARKEY P, PROKOP L, MURAD AL (2010) The effectiveness of self-directed learning in health professions education: a systematic review. *Med Edu*, 44: 1057-1068.

NORTVIG AM, PETERSEN AK, BALLE SH. (2018) A literature review of the factors influencing e-learning and blended learning in relation to learning outcome, student satisfaction and engagement. *Electronic Journal of E-Learning*, 16(1): 45-55.

OLMEDO J, GÓMEZ M, PINTOR M (2013). Estrategias innovadoras en el aula: implementación de un objeto virtual de aprendizaje. *Revista Educación y Humanismo*, 16(26): 58-72. Available at: http://revistas.unisimon.edu.co/index.php/educacion/article/view/2347/2239

SÁEZ FM, DÍAZ AE, PANADERO E, BRUNA DV (2018) Revisión sistemática sobre competencias de autorregulación del aprendizaje en estudiantes universitarios y programas intracurriculares para su promoción. *Formación Universitaria*, 11(6): 83-98. https://doi.org/10.4067/s0718-50062018000600083

SALINAS P, CÁRDENAS M (2009) Métodos de investigación social (2nd ed.). Intiyan, Quito-Ecuador.

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COVID-19 and distance learning: do students studying Gross Anatomy find favour with the change in pedagogic approach?

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SUMMARY

In response to the COVID-19 pandemic, many universities have suspended face-to-face academic activities, replacing the more traditional methods of teaching and learning with technological approaches.

The use of online platforms at the University of Sassari in Italy allowed the maintenance of theoretical classes and examinations for gross anatomy during the 'lockdown'.

The aim of this study was to assess the attitudes of medical and non-medical students studying gross anatomy and/or undertaking examinations through online platforms during the COVID-19 pandemic 'lockdown'. Microsoft TEAMS ® online platform was made available by the University of Sassari to enable interactions between students and teachers. Students were surveyed on a voluntary basis using an anonymous questionnaire on the virtual *Google Form* platform.

326 students participated in the survey. Ratings for the quality of distance teaching and learning were high, with 80% of students scoring 5 or 4 on the Likert scale. 60% of students rated as 'very good or 'good' the quality of teacher-student interactions during the distance-learning lessons. The different connection modes (i.e., mobile line or landline) had no bearing upon the perceived quality of the distance learning. When asked to make a choice between distance learning and face-to-face tuition, a high percentage of students expressed a preference for face-to-face tuition (76%). Our findings indicate that, while students retain a preference for more traditional, face-to-face, teaching and learning approaches, the use of online classes and examinations in gross anatomy were perceived as being beneficial during the emergence of the COVID-19 pandemic.

Key words: COVID-19 pandemic – Distance teaching – Distance learning – Gross anatomy – Student's attitudes

INTRODUCTION

The COVID-19 pandemic resulting from the novel coronavirus infection (SARS-CoV-2) has, at

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the time of writing, caused the deaths of 464,465 people globally (COVID-19 Map - Johns Hopkins Coronavirus Resource Center, 2020). In response to the pandemic, governments worldwide have imposed unprecedented containment measures, mainly by means of 'lockdowns' ordered to restrict the movements of the population (with the exception of key workers) (Moszkowicz et al., 2020). Additionally, people have been exhorted to work from home and to adopt 'smart working practices'.

For universities, face-to-face academic activities have generally been suspended and technological approaches to teaching and learning have replaced more traditional methods. In response, anatomists have promptly responded to the emergency situation by implementing distance educational programs (Evans et al., 2020). It can be argued that the situation has merely resulted in an acceleration of educational change that was already ongoing for anatomy courses (e.g., Sugand et al., 2010). Indeed, during recent times a wide variety of electronic resources has provided new opportunities for anatomical educators and, according to some reports, has been widely accepted by the present digital generation of students (e.g., Shaffer, 2004; Monrouxe, 2010; McMenamin et al., 2014; Losco et al., 2017; Trelease et al., 2016; Sotgiu et al., 2020). However, others have reported that students still prefer to be taught by practical means (e.g., Moxham and Moxham, 2007; Kerby et al., 2011).

At the University of Sassari in Italy, theoretical classes and examinations of anatomy were maintained during the 'lockdown'. Thanks to institutional support, the use of online platforms allowed the students to continue learning remotely and without interruption. Microsoft and CRUI (Conference of Italian Universities Rectors) have signed the "Education Transformation Framework Agreement" (https://www.fondazionecrui.it/ict-convenzioni/microsoft/) in order to create a climate of technological and cultural progress among students and to provide universities with the most innovative technological tools to ensure high educational quality. Nevertheless, the rapid, and complete, shift from lecture-based classes to the use of online resources was a real challenge for teachers and for students.

The primary purpose of this study was to assess the attitudes of medical and non-medical students studying gross anatomy and/or undertaking examinations through online platforms during the COVID-19 pandemic 'lockdown'. Considering the potential technological limitations, our initial hypothesis was that students would feel disadvantaged by online teaching. Furthermore, we hypothesized that the lack of face-to-face interactions between students and teachers would favor student dropout from the courses.

MATERIALS AND METHODS

Students at the University of Sassari attended distance anatomy lectures and/or examinations during the 'lockdown' period (March 8th and May 19th). Table 1 shows the various courses involved and Table 2 lists the lectures given online.

Table 1. Online courses conducted at the University of Sassari (2020).

Course	Student number	Availability of online classes and/or examinations	Number of online classes
Medicine & Surgery (Year 1)	139	Classes	24
Dentistry (Year 1)	21	Classes	12
Physiotherapy (Years 1 &2)	54	Classes (Examinations also for 28)	12
Biological Sciences (Year 1)	61	Classes (Examinations also for 38)	12
Medicine & Surgery (Year 2)	51	Examinations	0
Nursing (Year 1)	87	Examinations	0
Physical Education (Year 1)	17	Examinations	0
Pharmacy (Year1)	10	Examinations	0
Pharmaceutical Chemistry and Technology (Year 1)	10	Examinations	0

Table 2. Online classes conducted at the University of Sassari (2020)**.**

Topic	Medicine &Surgery	Dentistry	Physiotherapy	Biological Sciences
General organization of human body. Anatomical terms.	X			X
Locomotor system: general features	X			X
Bones: general features	X			X
Fibrous joints: synarthroses	X			
Cartilaginous joints: amphiarthroses	X			
Synovial joints: diarthroses	X			
Cervical and thoracic spine	X			
Lumbar and sacral spine	X			
Vertebral joints and discs	X			
Human pelvis 1	X			
Human pelvis 2	X			
Splanchnocranium: general features	X	X		
Splanchnocranium: jaw	X	X		
Neurocranium bones	X		X	
Cranial cavities	X	X	X	
Muscles: general features	X	X		X
Mimic muscles	X	X		
Masticatory muscles	X	X		
Neck muscles	X	X		
Mouth 1		X		
Mouth 2		X		
Tongue		X		
Teeth		X		
Salivary glands		X		
Upper limbs: bones	X			
Upper limbs: joints	X			
Upper limbs: muscles	X			
Lower limbs: bones	X			
Lower limbs: joints	X			
Integumentary system				X
Mammary gland				X
Respiratory system				X
Digestive system				X
Digestive system				X
Urinary system				X
Male urogenital system				X
Female urogenital system				X
Spinal cord			X	
Spinal nerves: cervical plexus			X	
Brachial plexus			X	
Lumbosacral plexus			X	
Brainstem			X	
Cranial nerves			X	
Thalamus			X	
Cerebellum			X	
Cerebral cortex			X	
Basal ganglia			X	

Teaching of anatomy was through lectures only. Practical anatomy sessions were not included in the online classes. During lockdown all classes were prepared *ab initio*.

Only full-time staff members provided for student-teacher interaction, with a ratio of 1:1, in individual meetings when requested by students. During the lectures, the interaction occurred simultaneously with all students.

Every student who participated in this study attended face-to-face courses in the first semester (from October to January). Of the students who attended online classes (Table 1), only physiotherapy students experienced gross anatomy in the first semester. The other students (medicine and surgery, dentistry, biological sciences) attended the anatomy course in the second semester for the first time.

The method of examination of anatomy prior to the pandemic has consisted of an oral test in which students are questioned on topics that have been taught in class. The final grade awarded is on a 30-point scale and comprises an average of the evaluations of staff members for the microscopic anatomy, gross anatomy and neuroanatomy parts of the anatomy curriculum. During the lockdown period, the method of assessing students' knowledge remained unchanged. The only difference was the use of the online platform to interact with students.

The universities need to transfer high volume of data for education, research and administrative activities. The University of Sassari has a fiber optic network named GARR. The GARR network interconnects with very high-capacity universities, research centers, libraries, museums, schools and other places where education, science, culture and innovation are produced throughout the national territory. GARR is an optical fibre infrastructure that uses the most advanced communication technologies and develops over about 15,000 km between main line and access links. Currently the highest available capacity for a user site connection is 200 Gbps.

The students who attended online lectures and/or examinations were surveyed on a voluntary basis using an anonymous questionnaire on the virtual *Google Form* platform. Microsoft TEAMS ® (Microsoft Corp., Redmond, WA) online platform was made available by the University of Sassari to enable interactions between students and teachers.

Invitations to participate in the survey were sent by email to all the students. The email included a detailed description of the study, information as to its purpose, and a link to the questionnaire.

The questionnaire was developed by teaching staff at the University of Sassari and consisted of 18 questions. Questions 1 to 5 provided demographic data, including gender, the courses attended, the online platform used for connection, the type of Internet connection, and the type of educational activity performed. Questions 6 to 18 comprised five-point Likert scale questions (1 = very poor, 2 = poor, 3 = neutral, 4 = good, and 5 = very good) or simple response questions to assess the quality of the Internet connection, the quality of distance teaching and learning for gross anatomy, the value of online instructional materials supplied by the teachers, the quality of student-teacher interactions during lectures, the support received from teachers after lessons and before examinations, the efficacy of support in resolving students' issues, the impact of distance education on anatomy examination performance and the students' preferences concerning distance versus face-to-face education. Following the initial email invitation on 22 April, three reminders were sent out during the three following weeks and the survey was closed on 13 May.

Ethical approval was not required, as the survey was part of a course audit.

Statistical analysis

The data collected were recorded in an EXCEL database for statistical processing. An *ad hoc* electronic form was used to collect all study variables. Variables were described with absolute and relative (percentage) frequencies. In-between group comparisons of questionnaire items were performed with Chi-squared or Fisher's exact tests. A two-tailed p-value less than 0.05 was considered statistically significant. The statistical software STATA version 16 (StataCorp, TX) was used to perform all statistical computations.

RESULTS

From the overall cohort of 450 students at the University of Sassari, 326 participated in the survey (i.e., a 72% response rate), with 59% of responding students being female. Response rates for the specific courses were 95% for medicine and surgery, 24% for dentistry, 64% for nursing, 87% for physiotherapy, 88% for physical education, 70% for pharmacy, 80% for pharmaceutical chemistry & technology, and 92% for biological sciences.

Table 3 records student attendance data and Table 4 provides information obtained from the questions concerned with demographics. Table 5 compares data between students accessing the online classes using mobile lines or landlines. Table 6 compares the online anatomy classes attended by students on different types of courses (medical courses, medically-related courses and non-medical courses).

The findings show that 59% of students who responding to the questionnaire were from medicine and surgery, dentistry and nursing courses within the University's Faculty of Medicine, 19% were studying physiotherapy or physical education also within the Faculty of Medicine, and 22% were attending other courses outside the Faculty of Medicine (i.e., biological sciences, pharmacy, or pharmaceutical chemistry and technology). For medicine and surgery, dentistry and nursing, male students were significantly fewer compared with other courses, especially for physiotherapy and physical education ($p<0.0001$). Collectively, 62% of students attended either distance learning classes or examinations, with 38% attending both classes and examinations. In terms of students recording the anatomy lessons, significantly more in the medically-related courses accomplished this (approx. 90% or more) than in the non-medical courses (23%) ($p<0.0001$). For students enrolled on the non-medical courses, 54% of these students stated that they had no opportunity to make recordings while 23% of students reported that occasionally they recorded online lessons. A statistical significance was found ($p=0.001$) between medical and non-medical courses with respect to the opportunities to record lessons.

Most of students followed the anatomy online course through a landline internet connection (72%), whose quality was assessed as good (46%; 4-point Likert scale) and very good (12%; 5-point Likert scale).

The majority of students (93%) declared that the instructional material was always available.

Ratings for the quality of distance teaching and learning were high, with 80% of students scoring 5 or 4 on the Likert scale. For students who recorded the anatomy lessons, many considered this to be 'very useful' (5 on the Likert scale) for the success of their learning ($p=0.007$), even if some students (25, 21% of medical courses and 4, 15% of non-medical courses) considered it 'neutral' (3 on the Likert scale, $p<0.0001$).

With respect to the perceived quality of teacher-student interactions during the distance learning lessons, 60% of students rated this as being 'very good or 'good'. This was particularly appreciated by students attending medical and medical-related courses, who recorded 5 on the Likert scale ($p<0.0001$). Indeed, most students liked the teacher support received both during lessons and before examinations (5 on Likert scale, $p<0.0001$; 4 on the Likert scale, $p=0.01$). Where the rating for teacher support was regarded as 'indifferent' (i.e., 3 on Likert scale), this was significantly higher for students on non-medical courses ($p<0.0001$).

Table 3. Students' attendance for online gross anatomy classes at University of Sassari (2020).

Course	Student number	Number of online classes	Student attendance (Range)	Student attendance (Mean ±SD)	Student attendance (%)
Medicine & Surgery	139	24	98-136	121.3(±10.8)	87%
Dentistry	21	12	18-21	19.7(±0.9)	95%
Physiotherapy	54	12	31-54	49.1(±6.5)	91%
Biological Sciences	61	12	53-61	56.6(±2.5)	93%

N.B. 'Student attendance range' signifies the minimum and the maximum number of students attending an online class. The mean and percentages for student attendance record data relating to the entire online course. Students on courses that underwent only online examinations, and therefore no classes, are not included in this table (i.e., Nursing, Physical Education, Pharmaceutical Chemistry and Technology, and Pharmacy).

On a more positive note, teacher support was considered by 54% of all students to aid resolution where doubts or problems were perceived (when scoring 5 and 4 on the Likert scale for this aspect). This was particularly the case for students attending physiotherapy and physical education (5 on the Likert scale, p=0.02).

Positive responses from the students were discerned with respect to the use of 'distance modalities' for the anatomy examinations and statistically significant differences were not found when courses were compared.

When asked to make a choice between distance learning and face-to-face tuition, a high percentage of students expressed a preference for face-to-face tuition (76%), there being no differences between courses.

Finally, the different connection modes (i.e., mobile line or landline) had no bearing upon the perceived quality of the distance learning.

DISCUSSION

The findings indicate that, while students retain a preference for more traditional, face-to-face teaching and learning approaches, the use of online classes and examinations in gross anatomy were perceived as being beneficial to learning during the emergence of the COVID-19 pandemic. These findings were found for students across a broad range of courses at the University of Sassari, from medicine and surgery to the biological sciences. Thus, there was consistency of opinion from students attending different courses, with different professional requirements and with different learning styles. Furthermore, the type of internet connection did not influence the quality of learning nor students' acceptance of the use of online examinations. Consequently, initial concerns of educators about unstable internet connections, mainly for students living in areas with poor internet services, were not substantiated.

We proposed two initial hypotheses. Firstly, we suggested that students would feel disadvantaged by online teaching. Secondly, we hypothesized that the loss of more traditional face-to-face interactions between students and teachers would favor student dropout from the online courses.

With respect to the first hypothesis, the students did not feel disadvantaged and generally appreciated the benefits to teaching and learning of the online classes. In this context, we should be mindful that the main responsibility of anatomy educators is to ensure efficient transmission of anatomical information and concepts that favor deep understanding. Although in this study we were not able to assess the extent to which deep learning occurred, we are encouraged along this path by the fact that one of the most appreciated aspect of our online courses was the opportunity, approved by nearly all the anatomy teachers, for the students to record lessons.

That students valued being able to record lessons corroborates findings of previous studies reporting that video recordings of lectures are appreciated, since students can repeat the lectures as often as required and at any time and place of their choosing (Nieder et al., 2011).

The student perceptions of lectures made available digitally was generally positive in the current study, and it has been reported in the literature that there is a perceived improvement of teaching and learning (Davis et al., 2009). Video lectures are a convenient revision tool for students and should be viewed as a supplement to live lectures rather than a replacement (Ranasinghe and Wright, 2019).

Furthermore, as students can adjust the speed by which the lecture proceeds, this aids deep understanding and preparation for examinations as suggested by Cardall et al. (2008) and Brockfeld et al. (2018).

For the second hypothesis, one of the major initial concerns for teachers was the 'dropout phenomenon', generally defined as student withdrawal from an educational program without completing the course (de Castro et al., 2016). Because distance education is an approach mainly based on individual autonomy, dropout is a real risk (e.g., Donkin et al., 2019). However, student attendance for the online courses at the University of Sassari ranged from 87% (medicine & surgery) to 95% (dentistry), and the response rate to the questionnaire was high. Thus, our findings do not support the second hypothesis since the dropout was very low.

Table 4. Descriptive analysis.

Variables		**n/N (%)**
Gender	Males	132/326(40.5)
	Females	194/326 (59.5)
Course	Medicine & Surgery	132/326 (40.5)
	Dentistry	5/340 (1.5)
	Nursing	56/326 (17.2)
	Physiotherapy	47/326 (14.4)
	Physical Education	15/326 (4.6)
	Pharmacy	7/326 (2.2)
	Pharmaceutical Chemistry and Technology	8/326 (2.5)
	Biological Sciences	56/326 (17.2)
Type of line used for internet connection	Landline	235/326 (72.1)
	Mobile line	91/326 (27.9)
Activity pursued during lockdown period	Online lectures only	127/326 (39.0)
	Online lectures & examinations	123/326 (37.7)
	Online examinations only	76/326 (23.3)
Assessment of quality of internet connection	Likert scale value 1	1/326 (0.3)
	Likert scale value 2	27/326 (8.3)
	Likert scale value 3	111/326 (34.1)
	Likert scale value 4	149/326 (45.7)
	Likert scale value 5	38/326 (11.7)
Assessment of quality of teaching for the online anatomy lectures	Likert scale value 1	0/218 (0.0)
	Likert scale value 2	4/218 (1.8)
	Likert scale value 3	39/218 (17.9)
	Likert scale value 4	122/218 (56.0)
	Likert scale value 5	53/218 (24.3)
Assessment of the perceived quality of student learning for the online anatomy lectures	Likert scale value 1	0/212 (0.0)
	Likert scale value 2	9/212 (4.3)
	Likert scale value 3	68/212 (32.1)
	Likert scale value 4	106/212 (50.0)
	Likert scale value 5	29/212 (13.7)
Availability of opportunity for students to record lecture	Always	168/225 (74.7)
	Never	33/225 (14.7)
	Sometimes	24/225 (10.7)
Assessment of students who recorded lectures concerning the benefits for learning	Likert scale value 1	0/192 (0.0)
	Likert scale value 2	4/192 (2.1)
	Likert scale value 3	29/192 (15.1)
	Likert scale value 4	4/192 (2.1)
	Likert scale value 5	81/192 (42.2)
The availability of instructional material	Always	212/229 (92.6)
	Never	1/229 (0.4)
	Sometimes	16/231 (6.9)
Assessment of the quality of teacher-student interactions DURING the lesson	Likert scale value 1	5/224 (2.2)
	Likert scale value 2	25/224 (11.2)
	Likert scale value 3	59/224 (26.3)
	Likert scale value 4	99/224 (44.2)
	Likert scale value 5	36/224 (16.1)
Assessment of teachers' support during, or after, the lessons	Likert scale value 1	1/236 (0.4)
	Likert scale value 2	3/236 (1.3)
	Likert scale value 3	46/236 (19.5)
	Likert scale value 4	97/236 (41.1)
	Likert scale value 5	89/236 (37.7)
Assessment of teachers' support before the examinations	Likert scale value 1	0/188 (0.0)
	Likert scale value 2	5/188 (2.7)
	Likert scale value 3	36/188 (19.2)
	Likert scale value 4	81/188 (43.1)
	Likert scale value 5	66/188 (35.1)
Assessment of whether academic support helped resolve problems	Likert scale value 1	2/184 (1.1)
	Likert scale value 2	10/184 (5.4)
	Likert scale value 3	73/184 (39.7)
	Likert scale value 4	69/184 (37.5)
	Likert scale value 5	30/184 (16.3)
Degree of satisfaction with the distance learning modality for examinations	Likert scale value 1	7/185 (3.8)
	Likert scale value 2	9/185 (4.9)
	Likert scale value 3	50/185 (27.0)
	Likert scale value 4	76/185 (41.1)
	Likert scale value 5	43/185 (23.2)
Perception of the extent to which the distance learning modality had a negative impact on examination performance	Likert scale value 1	76/185 (41.1)
	Likert scale value 2	46/185 (24.9)
	Likert scale value 3	35/185 (18.9)
	Likert scale value 4	18/185 (9.7)
	Likert scale value 5	10/185 (5.4)
Preference for distance or face-to-face teachers' support	Distance	49/200 (24.5)
	Face to face	151/200 (75.5)

Table 5. Comparisons between students with mobile lines and landlines.

Variables		Mobile line (N= 91)	Landline (N= 235)	p-value
	n (%)			
Gender Males		34 (37.4)	98 (41.7)	0.47
Females		57 (62.6)	137 (58.3	
Course	Medicine & Surgery	32 (35.2)	100 (42.6)	0.28
	Dentistry	2 (2.2)	3 (1.3)	
	Nursing	22 (24.2)	34 (14.5)	
	Physiotherapy	10 (11.0)	37 (15.7)	
	Physical Education	4 (4.4)	11 (4.7)	
	Pharmaceutical Chemistry and Technology	4 (4.4)	4 (1.7)	
	Pharmacy	1 (1.1)	6 (2.6)	
	Biological Sciences	16 (17.6)	40 (17.0)	
Activity pursued during lockdown period	Online lectures only	35 (38.5)	92 (39.2)	0.50
	Online lectures & examinations	31 (34.1)	92 (39.2)	
	Online examinations only	25 (27.5)	51 (21.7)	
Assessment of quality of internet connection?	Likert scale value 1	0 (0.0)	1 (0.4)	0.71
	Likert scale value 2	7 (7.7)	20 (8.5)	
	Likert scale value 3	36 (39.6)	75 (31.9)	
	Likert scale value 4	37 (40.7)	112 (47.7)	
	Likert scale value 5	11 (12.1)	27 (11.5)	
Assessment of quality of teaching for the online anatomy lectures	Likert scale value 1	0 (0.0)	0 (0.0)	0.74
	Likert scale value 2	1 (1.8)	3 (1.9)	
	Likert scale value 3	11 (19.6)	28 (17.3)	
	Likert scale value 4	28 (50.0)	94 (58.0)	
	Likert scale value 5	16 (28.6)	37 (22.8)	
Assessment of the perceived quality of student learning for the online anatomy lectures	Likert scale value 1	0 (0.0)	0 (0.0)	0.32
	Likert scale value 2	4 (7.8)	5 (3.1)	
	Likert scale value 3	14 (27.5)	54 (33.5)	
	Likert scale value 4	24 (47.1)	82 (50.9)	
	Likert scale value 5	9 (17.7)	20 (12.4)	
Availability of opportunity for students to record lectures	Always	36 (66.7)	132 (77.2)	0.19
	Never	9 (16.7)	24 (14.0)	
	Sometimes	9 (16.7)	15 (8.8)	
Assessment of students who recorded lectures concerning the benefits for learning	Likert scale value 1	0 (0.0)	0 (0.0))	0.60
	Likert scale value 2	2 (4.4)	2 (1.4)	
	Likert scale value 3	7 (15.6)	22 (15.0)	
	Likert scale value 4	17 (37.8)	61 (41.5)	
	Likert scale value 5	19 (42.2)	62 (42.2)	
The availability of instructional material	Always	52 (91.2)	160 (93.0)	0.35
	Never	1 (1.8)	0 (0.0)	
	Sometimes	4 (7.0)	12 (7.0)	
Assessment of the quality of teacher-student interactions DURING the lesson	Likert scale value 1	0 (0.0)	5 (3.0)	0.48
	Likert scale value 2	9 (16.4)	16 (9.5)	
	Likert scale value 3	14 (25.5)	45 (26.6)	
	Likert scale value 4	22 (40.0)	77 (45.6)	
	Likert scale value 5	10 (18.2)	26 (15.4)	
Assessment of the teachers' support during, or after, the lessons	Likert scale value 1	0 (0.0)	1 (0.6)	0.69
	Likert scale value 2	0 (0.0)	3 (1.7)	
	Likert scale value 3	11 (17.5)	35 (20.2)	
	Likert scale value 4	24 (38.1)	73 (42.2)	
	Likert scale value 5	28 (44.4)	61 (35.3)	
Assessment of the teachers' support before the examinations	Likert scale value 1	0 (0.0)	0 (0.0)	0.55
	Likert scale value 2	2 (3.8)	3 (2.2)	
	Likert scale value 3	12 (22.6)	24 (17.8)	
	Likert scale value 4	19 (35.9)	62 (45.9)	
	Likert scale value 5	20 (37.7)	46 (34.1)	
Assessment of whether academic support helped resolve problems	Likert scale value 1	1 (2.0)	1 (0.8)	0.52
	Likert scale value 2	3 (6.0)	7 (5.3)	
	Likert scale value 3	19 (38.0)	54 (40.3)	
	Likert scale value 4	16 (32.0)	53 (39.6)	
	Likert scale value 5	11 (22.0)	19 (14.2)	
Degree of satisfaction with the distance learning modality for examinations	Likert scale value 1	5 (10.2)	2 (1.5)	0.02
	Likert scale value 2	0 (0.0)	9 (6.6)	0.12
	Likert scale value 3	12 (24.5)	38 (27.9)	0.64
	Likert scale value 4	16 (32.7)	60 (44.1)	0.16
	Likert scale value 5	16 (32.7)	27 (19.9)	0.07
Perception of the extent to which the distance learning modality had a negative impact on examination performance	Likert scale value 1	21 (43.8)	55 (40.2)	0.72
	Likert scale value 2	12 (25.0)	34 (24.8)	
	Likert scale value 3	8 (26.7)	27 (19.7)	
	Likert scale value 4	3 (6.3)	15 (11.0)	
	Likert scale value 5	4 (8.3)	6 (4.4)	
Preference for distance or face-to-face teachers' support	Distance	13 (23.2)	36 (25.0)	0.79
	Face to face	43 (76.8)	108 (75.0)	

Table 6. Comparison of the variables between students attending medical courses (medicine & surgery, dentistry, nursing), other medical-related courses (physiotherapy and physical education) and non-medical courses (pharmacy, pharmaceutical chemistry & technology, biological sciences).

Variables		**Medical courses (n= 193)**	**Other medical courses (n= 62)**	**Non-medical courses (n= 71)**	**p-value**
		n (%)			
Gender	Males	74 (38.3)	43 (69.4)	15 (21.1)	<0.0001[1]
	Females	119 (61.7)	19 (30.7)	56 (78.9)	
Type of line for internet connection (Landline)		137 (71.0)	48 (77.4)	50 (70.4)	0.58
Type of line for internet connection (mobile line)		56 (29.0)	14 (22.6)	21 (29.6)	
Assessment of the quality of internet connection?	Likert scale value 1	1 (0.5)	0 (0.0)	0 (0.0)	0.09
	Likert scale value 2	18 (9.3)	5 (8.1)	4 (5.6)	
	Likert scale value 3	59 (30.6)	16 (25.8)	36 (50.7)	
	Likert scale value 4	93 (48.2)	31 (50.0)	25 (35.2)	
	Likert scale value 5	22 (11.4)	10 (16.1)	6 (8.5)	
Activity pursued during lockdown period?	Online lectures only	75 (38.9)	23 (37.1)	29 (40.9)	0.77
	Online lectures & examination	69 (35.8)	27 (43.6)	27 (38.0)	
	Online examinations only	49 (25.4)	12 (19.4)	15 (21.1)	
Assessment of quality of teaching for the online anatomy lectures	Likert scale value 1	0 (0.0)	0 (0.0)	0 (0.0)	0.07
	Likert scale value 2	4 (3.5)	0 (0.0)	0 (0.0)	
	Likert scale value 3	21 (18.6)	6 (12.8)	12 (20.7)	
	Likert scale value 4	68 (60.2)	22 (46.8)	32 (55.2)	
	Likert scale value 5	20 (17.7)	19 (40.4)	14 (24.1)	
Assessment of the perceived quality of student learning for the online anatomy lectures	Likert scale value 1	0 (0.0)	0 (0.0)	0 (0.0)	0.23
	Likert scale value 2	7 (6.4)	0 (0.0)	2 (3.6)	
	Likert scale value 3	37 (33.9)	13 (27.7)	18 (32.1)	
	Likert scale value 4	50 (45.9)	24 (51.1)	32 (57.1)	
	Likert scale value 5	15 (13.8)	10 (21.3)	4 (7.1)	
Availability of opportunity for students to record lectures	Always	108 (89.3)	47 (97.9)	13 (23.2)	<0.0001[2]
	Never	3 (2.5)	0 (0.0)	30 (53.6)	<0.0001[3]
	Sometimes	10 (8.3)	1 (2.1)	13 (23.2)	0.001[4]
Assessment of students who recorded lectures concerning the benefits for learning	Likert scale value 1	0 (0.0)	0 (0.0)	0 (0.0)	-
	Likert scale value 2	4 (3.4)	0 (0.0)	0 (0.0)	0.47
	Likert scale value 3	25 (21.2)	0 (0.0)	4 (15.4)	<0.0001[5]
	Likert scale value 4	49 (41.5)	19 (39.6)	10 (38.5)	0.95
	Likert scale value 5	40 (33.9)	29 (60.4)	12 (46.2)	0.007[6]
The availability of instructional material	Always	112 (90.3)	49 (100.0)	51 (91.1)	0.10
	Never	1 (0.8)	0 (0.0)	0 (0.0)	
	Sometimes	11 (8.9)	0 (0.0)	5 (8.9)	
Assessment of the quality of teacher-student interactions DURING the lesson	Likert scale value 1	2 (1.7)	0 (0.0)	3 (5.4)	0.21
	Likert scale value 2	9 (7.5)	4 (8.3)	12 (21.4)	0.03[7]
	Likert scale value 3	31 (25.8)	9 (18.8)	19 (33.9)	0.21
	Likert scale value 4	57 (47.5)	21 (43.8)	21 (37.5)	0.46
	Likert scale value 5	21 (17.5)	14 (29.2)	1 (1.8)	<0.0001[8]
Assessment of teachers' support during, or after, the lessons	Likert scale value 1	0 (0.0)	0 (0.0)	1 (1.7)	0.46
	Likert scale value 2	3 (2.3)	0 (0.0)	0 (0.0)	0.42
	Likert scale value 3	18 (14.1)	3 (6.1)	25 (42.4)	<0.0001[9]
	Likert scale value 4	63 (49.2)	13 (26.5)	21 (35.6)	0.01[10]
	Likert scale value 5	44 (34.4)	33 (67.4)	12 (20.3)	<0.0001[11]
Assessment of teachers' support before the examinations	Likert scale value 1	0 (0.0)	0 (0.0)	0 (0.0)	-
	Likert scale value 2	4 (4.0)	0 (0.0)	1 (2.2)	0.61
	Likert scale value 3	19 (19.9)	4 (9.5)	13 (28.3)	0.08
	Likert scale value 4	44 (44.0)	12 (28.6)	25 (54.4)	0.05
	Likert scale value 5	33 (33.0)	26 (61.9)	7 (15.2)	<0.0001[12]
Assessment of whether academic support helped resolve problems	Likert scale value 1	2 (2.1)	0 (0.0)	0 (0.0)	1.00
	Likert scale value 2	5 (5.2)	0 (0.0)	5 (10.9)	0.08
	Likert scale value 3	35 (36.1)	14 (34.2)	24 (52.2)	0.13
	Likert scale value 4	42 (43.3)	13 (31.7)	14 (30.4)	0.23
	Likert scale value 5	13 (13.4)	14 (34.2)	3 (6.5)	0.002[13]
Perception of the extent to which the distance learning modality had a negative impact on examination performance	Likert scale value 1	37 (37.4)	21 (48.8)	18 (41.9)	0.18
	Likert scale value 2	30 (30.3)	4 (9.3)	12 (27.9)	
	Likert scale value 3	18 (18.2)	10 (23.3)	7 (16.3)	
	Likert scale value 4	8 (8.1)	7 (16.3)	3 (7.0)	
	Likert scale value 5	6 (6.1)	1 (2.3)	3 (7.0)	
Degree of satisfaction with the distance learning modality for examinations	Likert scale value 1	4 (4.2)	1 (2.3)	2 (4.4)	0.45
	Likert scale value 2	6 (6.3)	0 (0.0)	3 (6.5)	
	Likert scale value 3	26 (27.1)	10 (23.3)	14 (30.4)	
	Likert scale value 4	35 (36.5)	20 (46.5)	21 (45.7)	
	Likert scale value 5	25 (26.0)	12 (27.9)	6 (13.0)	
Preference for distance or face-to-face teachers' support	Distance	26 (24.3)	11 (24.4)	12 (25.0)	1.00
	Face to face	81 (75.7)	34 (75.6)	36 (75.0)	

1. Medical courses VS. Other medical courses p-value <0.0001; Medical courses VS. Non-medical courses p-value= 0.009; Other medical courses VS. Non-medical courses p-value <0.0001.
2. Medical courses VS. Non-medical courses p-value <0.0001; Other medical courses VS. Non-medical courses p-value <0.0001.
3. Medical courses VS. Non-medical courses p-value <0.0001; Other medical courses VS. Non-medical courses p-value <0.0001.
4. Medical courses VS. Non-medical courses p-value= 0.006; Other medical courses VS. Non-medical courses p-value= 0.002.
5. Medical courses VS. Other medical courses p-value= 0.0005; Other medical courses VS. Non-medical courses p-value= 0.005.
6. Medical courses VS. Other medical courses p-value= 0.002.
7. Medical courses VS. Non-medical courses p-value= 0.008.
8. Medical courses VS. Non-medical courses p-value= 0.003; Other medical courses VS. Non-medical courses p-value= 0.0001.
9. Medical courses VS. Non-medical courses p-value <0.0001; Other medical courses VS. Non-medical courses p-value <0.0001.
10. Medical courses VS. Other medical courses p-value= 0.006.
11. Medical courses VS. Other medical courses p-value= 0.0001; Other medical courses VS. Non-medical courses p-value <0.0001.
12. Medical courses VS. Other medical courses p-value= 0.001; Medical courses VS. Non-medical courses p-value= 0.03; Other medical courses VS. Non-medical courses p-value <0.0001.
13. Medical courses VS. Other medical courses p-value= 0.005; Other medical courses VS. Non-medical courses p-value= 0.001.

It was appreciated that loss of face-to-face tuition potentially might lead to reduced interactions between teachers and learners, and consequently to a lower student engagement and motivation. Indeed, the crucial role of social interactions for meaningful learning could have a significant effect, not only on students' performance, but on adherence to the e-learning platform (Luo et al., 2017; Shu and Gu, 2018), and learner-to-instructor interactions underlie effective online courses (Moore, 1993). Consequently, special attention to such interactions is recommended because of their effects on learning outcomes (Martin and Bolliger, 2018). As emerged from our survey, student-teacher interactions were assessed as overall being good. We therefore conclude that 'online teacher's presence' was sufficient to consolidate the relationship with students, decreasing the distance barriers that are intrinsic to distance education. The success of this relationship was also confirmed by students who performed the anatomy examinations as an online activity; many of them asked teachers for help and reported that the support they received was very good and helped resolve problems. This finding is consistent with other published studies, who report that students' academic performance is independent of the modality used to deliver content (Kemp and Grieve, 2014; Meyer et al., 2016). Despite these encouraging results, face-to-face interactions were still preferred by our students. This finding confirms the fundamental role of social interactions in the learning process. We presume that the students' preference of face-to-face learning is derived from the fact that, to some extent, online learning might be disadvantageous in terms of interactive knowledge building between teacher and students (Pei and Wu, 2019). During a face-to-face class, the teacher may notice that one, or more, participants are having specific problems in understanding a topic and will be able to offer help to those students during breaks or after class. Furthermore, the informal interaction with other participants is missing in an online class (e.g., during the class, at breaks, or over lunch). Such interaction can lead to shared experiences (even doubts) that help reinforce what each student has learned.

Some technological issues we experienced could have acted as barriers to e-learning. First, the request to activate immediately a distance learning approach did not allow all anatomy teachers to become rapidly familiar with this educational electronic platform. Until the 'lockdown', more traditional, face-to-face learning was reinforced by, but not completely replaced by, online teaching and learning modalities. Ideally, the change to distance learning should require ample time and it has been estimated that faculty spend on average four to five half days in preparing and using these tools (O'Doherty et al., 2018). Second, it was appreciated that poor quality of internet access and/or the lack of suitable digital devices used for connection (computer, tablet, mobile) could hinder both students and educators (Longhurst et al., 2020), although different connection modes did not influence in our study the perceived quality of distance learning.

The COVID-19 pandemic has affected educational systems worldwide and anatomy education has promptly responded to this emergency. Consequently, much academic activity is now being undertaken on digital platforms (Srinivasan, 2020; Evans et al., 2020; Pather et al., 2020). The present generation of students, said to comprise 'digital natives' (Prensky, 2010), appears to have adapted well to this unexpected change. Our findings support the notion that distance learning plays a key role in anatomy education during the 'lockdown'. Considering the high level of satisfaction relating to the opportunity to record lessons and provide video lecture content which was found in the current study, this could allow students to access course materials at a time of their choosing, thus potentially increasing their engagement. Furthermore, it could be a valid instrument to accommodate students with disabilities.

There are inevitably limitations with surveys of this nature. First, the results are based upon perceptions/attitudes and not upon outcomes of examinations that had not yet occurred at the time of the survey. More importantly, given that this is a confidential and anonymous survey, ethical approval would not be readily forthcoming if an attempt was made to introduce examination data into the analyses. Furthermore, the primary aim of our study was to understand if the emergency situation associated with the pandemic had a negative impact on the transmission of anatomical information and concepts to students. Second, although self-reported questionnaires potentially have a 'demand bias', the anonymity and confidentiality of the survey reduces the risk. Third, surveys dealing with distance learning that are conducted during the 'lockdown' may not indicate levels of acceptance over more traditional approaches once the 'lockdown' is over and society returns to 'normal'. Indeed, it can be argued that the present level of satisfaction with distance learning reflects students' understanding of the unusual circumstances and their gratitude that some effort was made to provide some form of tuition. This has implications to the view that the change in teaching and learning to online approaches could, or should, continue once the pandemic is over. Indeed, anatomists often express the view that electronic tuition is an adjunct to, but not a substitute for, more traditional face-to-face teaching. Furthermore, it has been reported that students greatly prefer practical means of tuition over electronic tuition (Moxham and Moxham, 2007; Kerby et al., 2011), and these attitudes are supported by the present findings. Finally, single university findings on educational approaches can be criticised for conveying local circumstances, and not national or international situations. However, apart from the difficulties of conducting national or international surveys, it has to be borne in mind that data from single universities provide essential material for subsequent meta-analyses.

REFERENCES

BROCKFELD T, MÜLLER B, DE LAFFOLIE J (2018) Video versus live lecture courses: a comparative evaluation of lecture types and results. Med Educ Online, 23(1): 1555434. doi: 10.1080/10872981.2018.1555434.

CARDALL S, KRUPAT E, ULRICH M (2008) Live lecture versus video-recorded lecture: are students voting with their feet? Acad Med, 83(12): 1174-1178.

COVID-19 MAP - JOHNS HOPKINS CORONAVIRUS RESOURCE CENTER (2020) https://coronavirus.jhu.edu/map.html

DAVIS S, CONNOLLY A, LINFIELD E (2009) Lecture capture: making the most of face-to-face learning. Eng Educ, 4(2): 2-4.

DE CASTRO E LIMA BAESSE D, GRISOLIA AM, FIGUEIREDO DE OLIVEIRA AE (2016) Pedagogical monitoring as a tool to reduce dropout in distance learning in family health. BMC Med Educ, 16: 213. doi: 10.1186/s12909-016-0735-9.

DONKIN R, ASKEW E, STEVENSON H (2019) Video feedback and e-Learning enhances laboratory skills and engagement in medical laboratory science students. BMC Med Educ, 19(1): 310. doi: 10.1186/s12909-019-1745-1.

EVANS DJR, BAY BH, WILSON TD, SMITH CF, LACHMAN N, PAWLINA W (2020) Going virtual to support anatomy education: A STOPGAP in the Midst of the Covid-19 Pandemic. Anat Sci Educ, doi: 10.1002/ase.1963.

KEMP N, GRIEVE R (2014) Face-to-face or face-to-screen? Undergraduates' opinions and test performance in classroom vs. online learning. Front Psychol, 5: 1278. doi: 10.3389/fpsyg.2014.01278.

KERBY J, SHUKUR ZN, SHALHOUB J (2011) The relationships between learning outcomes and methods of teaching anatomy as perceived by medical students. Clin Anat, 24: 489-497.

LONGHURST GJ, STONE DM, DULOHERY K, SCULLY D, CAMPBELL T, SMITH CF (2020) Strength, weakness, opportunity, threat (SWOT) analysis of the adaptations to anatomical education in the United Kingdom and Republic of Ireland in response to the Covid-19 pandemic. Anat Sci Educ, doi: 10.1002/ase.1967.

LOSCO CD, GRANT WD, ARMSON A, MEYER AJ, WALKER BF (2017) Effective methods of teaching and learning in anatomy as a basic science: A BEME systematic review: BEME guide no. 44. Med Teach, 39(3): 234-243. doi: 10.1080/0142159X.2016.1271944.

LUO N, ZHANG M, QI D (2017) Effects of different interactions on students' sense of community in e-learning environment. Comput. Educ, 115: 153-160.

MARTIN F, BOLLIGER DU (2018) Engagement matters: Student perceptions on the importance of engagement strategies in the online learning environment. Online Learning, 22(1): 205-222. doi:10.24059/olj.v22i1.1092.

MCMENAMIN PG, QUAYLE MR, MCHENRY CR, ADAMS JW (2014) The production of anatomical teaching resources using three-dimensional (3D) printing technology. Anat Sci Educ, 7(6): 479-486. doi: 10.1002/ase.1475.

MENA-GUACAS AF, VELANDIA R CA (2020) Interaction through mobile technology in short-term university courses. Heliyon, 6(2): e03287. doi: 10.1016/j.heliyon.2020.e03287.

MEYER AJ, INNES SI, STOMSKI NJ, ARMSON AJ (2016) Student performance on practical gross anatomy examinations is not affected by assessment modality. Anat Sci Educ, 9(2): 111-120. doi: 10.1002/ase.1542.

MICROSOFT-CRUI AGREEMENT https://www.fondazionecrui.it/ict-convenzioni/microsoft/

MONROUXE LV (2010) Identity, identification and medical education: Why should we care? Med Educ, 44: 40-49.

MOORE MJ (1993) Three types of interaction. In: Harry K, John M, Keegan D (eds.). *Distance education theory*. Routledge, New York, pp 19-24.

MOSZKOWICZ D, DUBOC H, DUBERTRET C, ROUX D, BRETAGNOL F (2020) Daily medical education for confined students during COVID-19 pandemic: A simple videoconference solution. Clin Anat, doi: 10.1002/ca.23601.

MOXHAM BJ, MOXHAM SA (2007) The relationships between attitudes, course aims and teaching methods for the teaching of gross anatomy in the medical curriculum. Eur J Anat, 11: 19-30.

NIEDER GL, BORGES NJ, PEARSON JC (2011) Medical student use of online lectures: exam performance, learning styles, achievement motivation and gender. Med Sci Educator, 21(3): 222-228.

O'DOHERTY D, DROMEY M, LOUGHEED J, HANNIGAN A, LAST J, MCGRATH D (2018) Barriers and solutions to online learning in medical education - an integrative review. BMC Med Educ, 18(1): 130. doi: 10.1186/s12909-018-1240-0.

PATHER N, BLYTH P, CHAPMAN JA, DAYAL MR, FLACK NAMS, FOGG QA, GREEN RA, HULME AK, JOHNSON IP, MEYER AJ, MORLEY JW, SHORTLAND PJ, ŠTRKALJ G, ŠTRKALJ M, VALTER K, WEBB AL, WOODLEY SJ, LAZARUS MD (2020) Forced disruption of anatomy education in Australia and New Zealand: an acute response to the Covid-19 pandemic. Anat Sci Educ, 13(3): 284-300. doi: 10.1002/ase.1968.

PEI L, WU HU (2019) Does online learning work better than offline learning in undergraduate medical education? A systematic review and meta-analysis. Med Educ Online, 4(1): 1666538. doi: 10.1080/10872981.2019.1666538.

PRENSKY M (2010) Teaching Digital Natives: Partnering for Real Learning. 1st Ed. Corwin Press, Thousand Oaks, CA, p 224.

RANASINGHE L, WRIGHT L (2019) Video lectures versus live lectures: competing or complementary? Med Educ Online, 24(1): 1574522.

SHAFFER K (2004) Teaching anatomy in the digital world. N Engl J Med, 351(13): 1279-1281.

SHU H, GU X (2018) Determining the differences between online and face-to-face student–group interactions in a blended learning course. Internet High Educ, 39: 13-21.

SOTGIU MA, MAZZARELLO V, BANDIERA P, MADEDDU R, MONTELLA A, MOXHAM B (2020) Neuroanatomy, the Achille's heel of medical students. A systematic analysis of educational strategies for the teaching of neuroanatomy. Anat Sci Educ, 13(1): 107-116. doi: 10.1002/ase.1866.

SRINIVASAN DK (2020) Medical students' perceptions and an anatomy teacher's personal experience using an e-learning platform for tutorials during the Covid-19 crisis. Anat Sci Educ, 13(3): 318-319. doi: 10.1002/ase.1970.

SUGAND K, ABRAHAMS P, KHURANA A (2010) The anatomy of anatomy: a review for its modernization. Anat Sci Educ, 3: 83-93.

TRELEASE RB (2016) From chalkboard, slides, and paper to e-learning: How computing technologies have transformed anatomical sciences education. Anat Sci Educ, 9(6): 583-602. doi: 10.1002/ase.1620.

An alternate focus of POCUS in medical education: how anatomy knowledge is essential for ultrasound skills, rather than how ultrasound can improve anatomy learning

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SUMMARY

Anatomy is a foundational science in medical education and anatomical knowledge is central to the practice of medicine. However, there is concern about declining curricula time devoted to anatomy and reduced perceived importance of cadaveric anatomy by many university administrations. The importance of anatomy education and research is evident during the current COVID-19 pandemic and should be emphasized. Medical diagnostic imaging is crucial in the diagnosis and ongoing assessment of affected patients; therefore, anatomy expertise is paramount. Point-of-care ultrasound (POCUS) is effective not only in triage of critically ill and infectious patients in emergency departments, but also in rural and remote medicine. Accurate ultrasound image acquisition and interpretation relies on sound anatomical knowledge, particularly surface anatomy and anatomical relations between structures. Incorporating ultrasound into medical curricula provides an opportunity for multimodal, active, experiential learning in a clinical context, increasing students' engagement and motivation. However, although ultrasound is promoted to enhance anatomy learning, there is limited evidence of this. It is proposed here that the focus of POCUS in medical education is reversed, to instead highlight the importance of anatomical education as a pre-requisite for ultrasound skills. Using ultrasound as formative assessment and clinical application of anatomical knowledge is pedagogically sound, but importantly, is also a way to promote and preserve anatomy. Emphasizing that anatomy expertise underpins ultrasound (and other imaging) competence, physical examination, and therefore medical care can help to re-establish the central importance of anatomy education and research in medical education and for optimal medical practice around the world.

Key words: Anatomy – Medical education – POCUS – Ultrasound – COVID-19

ABBREVIATIONS:

COVID-19: novel coronavirus disease 2019

Point-of-care ultrasound: POCUS

INTRODUCTION

The COVID-19 pandemic highlights the importance of anatomy education and research

The COVID-19 pandemic that has continued throughout 2020 and beyond highlights the crucial importance of best medical practice and competent

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medical practitioners. Anatomical knowledge is central to the practice of medicine, and anatomy is a foundational science in medical education. The importance of anatomy education and research is evident with respect to the knowledge and expertise demands of this global health crisis, and should be emphasized. COVID-19 has also highlighted the importance of medical diagnostics (Jankowski et al., 2020), and in particular, the utility of point-of-care ultrasound (POCUS). POCUS enables real-time assessment and clinical decision making at the bedside, to guide optimum, safe and efficient management and treatment of patients (Schrift et al., 2020). With large numbers of critically ill patients in hospital, and infection control paramount in a pandemic, a portable ultrasound that reduces the movement of patients and the need for multiple operators is the safest option (Schrift et al., 2020). Indeed, POCUS has been used during COVID-19 for initial patient screening and segregation, and in-patient management from triage to intensive care (Bhoi et al., 2021). Further, point of care treatment facilitates early recognition and treatment of critically ill patients in emergency departments, and directly impacts survival rates (Rooney et al., 2014). Therefore, medical graduates need to be competent and confident in using ultrasound for visualization of internal structures, and accordingly, ultrasound has been incorporated into medical curricula in many countries (Griksaitis et al., 2012; Fakoya, 2013; So et al., 2017; Ang et al., 2018; Knudsen et al., 2018; Liu et al., 2019; Menegozzo et al., 2019; Minardi et al., 2019; Zawadka et al., 2019; Alexander et al., 2020; Hoffmann et al., 2020; Oteri et al., 2020; Wong et al., 2021).

Sound anatomical knowledge is essential for optimal ultrasound image acquisition and accurate image interpretation. However, the discourse around ultrasound in medical education is mostly about how ultrasound can be used to improve anatomy knowledge or physical examination skills. While it is not denied that ultrasound can be a beneficial tool in learning and teaching anatomy, and is a valuable imaging technique in medicine, it is proposed here that the discussion should reverse the focus to the importance of anatomical knowledge and expertise in optimal use of ultrasound (and other) imaging in medical practice. It is easy to marvel at what POCUS allows us: seeing the structure, movements, and anatomical relationships in real-time. However, being able to distinguish between different tissues and organs, and decide normal versus pathological, is dependent on sound understanding of the foundational anatomy. Therefore, it is imperative that anatomy education is preserved and promoted at all levels, as being essential to optimal use of imaging techniques, and patients' health outcomes. This is difficult in the current era of declining curricular time devoted to anatomy, and reduced perceived importance of cadaveric anatomy by many university administrations. However, it is not just human advances that highlight the importance of anatomy to medicine. The coronavirus responsible for COVID-19 is now recognized as affecting multiple organ-systems, including the lungs as well as cardiovascular, gastrointestinal and liver, renal and neurological structures (Roberts et al., 2020). Accordingly, if ever there was a need for competent medical practitioners and researchers with equally in-depth and broad knowledge of the human body, it is now.

This review will include an overview of POCUS and considerations of the pedagogical aspects of incorporation of ultrasound into medical curricula. A novel aspect is the proposal to re-phrase and re-focus the view of POCUS in medical education. This can be an opportunity to emphasize the necessity of anatomical knowledge as a prerequisite for expertise in ultrasound, rather than the potential for ultrasound to improve anatomy learning. The increasing importance of ultrasound expertise in diverse medical and health settings across the globe can be used as a platform to preserve and promote the importance of anatomy learning and teaching.

ULTRASOUND USE IN MEDICAL PRACTICE AND EDUCATION

POCUS is increasingly used in diverse global healthcare settings

Since the turn of the century, ultrasound technology has evolved considerably with the development of hand-held, portable ultrasound machines that are both easy to use and inexpensive (Shapiro et al., 2002; Ivanusic et al., 2010; Hoppmann et al., 2011; Griksaitis et al., 2012). POCUS enables the clinician to obtain ultrasound images of a patient at the point of care, in real time, and directly correlate these images with the patient's signs and symptoms. This can improve traditional examination techniques, and guide diagnosis and treatment (Moore et al., 2011). Globally, there is increased use of POCUS among primary care providers and non-specialists, including in rural and remote regions (Sorensen et al., 2019), at the Mount Everest base camp and International Space station, and in disaster areas and battlefields (Moore et al., 2011). With real impact on diagnostic processes and clinical decision making in these diverse settings, ultrasound imaging is increasingly considered a core clinical skill required by all medical practitioners (Hoppmann et al., 2011).

POCUS is increasingly included in medical curricula

Advances in ultrasound technology and its increased use in medical practice have prompted its inclusion in a number of medical curricula worldwide (Shapiro et al., 2002; Tshibwabwa et al., 2005; Butter et al., 2007; Ivanusic et al., 2010; Griksaitis et al., 2012; Stringer et al., 2012; Bahner et al., 2013). The United Kingdom Anatomical Society's core regional anatomy syllabus for undergraduate medicine does include to "interpret standardized diagnostic images", including ultrasound (Smith et al., 2016). Within medical curricula, ultrasound is mostly used as a learning and teaching tool in anatomy and clinical skills; however, this is not consistent within or between countries. Reasons and benefits for adopting ultrasound can be categorized into three domains of: learning; knowledge; and skills (Table 1). Ultrasound enables multimodal and active learning whereby students can view living and dynamic anatomy in a clinically relevant context. It also provides an experience in ultrasound image interpretation and potentially even ultrasound image acquisition, which is pertinent to their future training and practice (Hoffmann et al., 2020). However, there is limited evidence that ultrasound increases long-term anatomical knowledge or physical examination skills. It is better to promote the necessity of anatomical expertise for both physical examination and ultrasound skills, rather than the potential for ultrasound to improve these. Ultrasound is more appropriate as a meaningful learning activity for formative assessment and clinical application of anatomy, preferably after cadaveric learning, which will in turn reinforce the foundational anatomical knowledge.

BENEFITS AND LIMITATIONS OF ULTRASOUND IN MEDICAL EDUCATION

Ultrasound can modernize the anatomy curriculum via multimodal learning

Due to the well-documented decline in time allocation to anatomy education, the subject of anatomy needs to evolve with medical curricula changes and maximize the learning benefits of different teaching methods (Estai et al., 2016). Multimodal learning is recommended to enhance and stimulate learning in anatomy (Drake et al., 2014). Indeed, the majority of medical students have multimodal learning style preferences, with combinations of visual, auditory, read/write and kinesthetic, and like to be exposed to a variety of teaching methods (Kharb et al., 2013). Ultrasound literally provides a different view of anatomy. This is beneficial with respect to exposing students to varied learning opportunities and several perspectives on the same content (Drake et al., 2014; Jamniczky et al., 2017; Knudsen et al., 2018).

Ultrasound can increase student engagement due to active learning and clinical relevance

Perhaps, the most immediate and apparent outcome of teaching anatomy using ultrasound is increased student motivation and engagement (Griksaitis et al., 2012). This is attributed both to participation in active and experiential learning, and to the fact that ultrasound also brings significance and clinical relevance to the learning because it facilitates direct application of anatomical knowledge. Ultrasound is unique amongst imaging modalities in its interactivity, with students able to actually practice this technique, rather than just interpret images (Miles, 2005). Students prefer the opportunity to be hands-on (Allsop et al., 2021), which also increases their skills in ultrasound image interpretation (Knudsen et al., 2018). Interactive activities and experience-based learning facilitates a learner-centered approach, engages students, increases interest in anatomy, and promotes deep learning and understanding in a meaningful context (Estai et al., 2016).

Providing a clinical context in anatomy is pedagogically beneficial because it promotes increased knowledge retention and deep learning (Estai et al., 2016). Overall, reports of student feedback in relation to inclusion of ultrasound in the anatomy component of the medical curriculum are positive, including perceived learning benefits (Smith et al., 2016); however, this is likely attributed purely to increased student engagement and interest (Butter et al., 2007). This remains beneficial and suggests that increased student engagement, intrinsic motivation and positive learning experiences in anatomy will result in students, themselves, promoting the importance of anatomy in medical education and clinical practice.

Ultrasound alone does not necessarily increase students' ultrasound image interpretation ability or anatomical knowledge

Incorporating ultrasound into the anatomy curriculum enables students to apply their anatomical knowledge to use the technology, and to simultaneously apply the technology to a real context of living anatomy. However, although there is widespread positive student feedback that the use of ultrasound increases their anatomical knowledge (Tshibwabwa et al., 2005; Ivanusic et al., 2010; Hoppmann et al., 2011; Bahner et al., 2013), none of these are supported by empirical evidence with defined (or quantitative) outcome measures. Indeed, one study reported no increase in students' scores in anatomy after ultrasound (Liu et al., 2019), while another that compared the use of ultrasound with that of cadaveric prosections for teaching cardiac anatomy found these were of equal educational benefit (Griksaitis et al., 2012). A recent systematic and critical review demonstrated no improvement of

Table 1. Summary of the reported impacts of including ultrasound in medical curricula on learning, knowledge and skills.

Domain	Effectors	Outcomes	References
Learning	Multimodal learning	Increased student engagement	(Miles, 2005; Sugand et al., 2010; Pascual et al., 2011; Drake et al., 2014; Estai et al., 2016)
	Active learning with clinical relevance	Positive student feedback	(Shapiro et al., 2002; Ivanusic et al., 2010; Stringer et al., 2012; Hoppmann et al., 2011, Minardi et al., 2019; Allsop et al., 2020; Wong et al., 2021)
Knowledge	Anatomical knowledge	Student perceptions: improved knowledge and/or useful for learning	(Shapiro et al., 2002; Stringer et al., 2012; Hoppmann et al., 2011; Jamniczky et al., 2017)
		Empirical data: limited increase	(Griksaitis et al., 2012; Alexander et al., 2020)
		Empirical data: no effect	(Feilchenfeld et al., 2017; Knudsen et al., 2018)
	Ultrasound image interpretation	Student perceptions: improved	(Shapiro et al., 2002; Hoppmann et al., 2011; Jamniczky et al., 2017)
		Empirical data: limited increase	(Knudsen et al., 2018)
		Empirical data: improved	(Tshibwabwa et al., 2005)
Skills	Ultrasound use and image acquisition	Student perceptions: improved	(Moscova et al., 2015)
		Empirical data: limited increase	(Ang et al., 2018; Alexander et al., 2020)
		Empirical data: improved	(Tshibwabwa et al., 2005; Menegozzo et al., 2019)
	Physical examination	Student perceptions: limited increase	(Shapiro et al., 2002; Hoppmann et al., 2015; Arora et al., 2017)
		Empirical data: limited improvement	(Butter et al., 2007; Feilchenfeld et al., 2017; Wong et al., 2021)
		Empirical data: improved	(Liu et al., 2019; Oteri et al., 2020)

students' understanding of anatomical concepts after use of ultrasound (Feilchenfeld et al., 2017). Similarly, with respect to ultrasound knowledge and image interpretation skills, there are several reports that students perceive these are improved (Moscova et al., 2015; Ang et al., 2018; Menegozzo et al., 2019; Alexander et al., 2020); however, only two studies reported quantitative improvements (Knudsen et al., 2018; Tshibwabwa et al., 2005). Nevertheless, increased exposure to imaging is essential since this is how medical graduates will encounter anatomy: as living anatomy or imaging (Hoffmann et al., 2020).

Reports of students' perceptions of their skills and knowledge are limited since these are subjective and may not reflect quantitative measures of these attributes (Sweetman et al., 2013). Indeed, students' confidence scores in their responses to image-based questions increased after an ultrasound course; however, these did so irrespective of correctness of response, and were not correlated to the latter (Zawadka et al., 2019). It is likely difficult to demonstrate additional effects of ultrasound on learning outcomes, and at a minimum, no detrimental effects have been reported. The focus should remain on first improving anatomical knowledge with traditional teaching and learning methods, and then providing students with the opportunity to apply and assess this via ultrasound. This will also help them to gain skills relevant to this imaging modality. The necessity for medical students to have sufficient anatomical knowledge to understand ultrasound can be used to promote and preserve anatomy, rather than promoting the inclusion of ultrasound in a medical curriculum to teach and learn anatomy.

Ultrasound may improve skills in ultrasound image acquisition and physical examination, but competence in both of these is dependent on anatomical knowledge

Standardized ultrasound diagnostic protocols are increasingly developed and incorporated into routine diagnosis and procedures (So et al., 2017). Therefore, including ultrasound in the curriculum can provide students with skills in ultrasound acquisition, and increase their confidence in this technology in their future medical practice. Indeed, first year medical students, who were exposed to POCUS, reported greater perceived utility of this and greater likelihood of adoption later (Arora et al., 2017). However, there are concerns that students focus more on the technology itself, and that this contributes to reduced communication and physical examination skills (Shapiro et al., 2002; Hoppmann et al., 2011). Moreover, ultrasound is not available everywhere around the world; this is particularly relevant in remote locations and developing countries (Lagrone et al., 2012). Therefore, the focus should remain that competitive medical graduates need to be clinically capable with strong foundational anatomical knowledge, and not rely upon technologies such as ultrasound.

With respect to the impact of ultrasound on physical examination skills, the majority of students agreed that ultrasound enhanced their physical examination skills (Shapiro et al., 2002; Hoppmann et al., 2011; Wong et al., 2021), though in one study, simply seeing patients improved this to the same extent (Shapiro et al., 2002). Empirical findings include that POCUS increased students' physical examination understanding and performance (Liu et al., 2019) and their physical examination skills and confidence (Oteri et al., 2020; Wong et al., 2021). However, a recent systematic and critical review concluded that there was minimal evidence for, and minimal benefit of, ultrasound teaching in physical examination (Feilchenfeld et al., 2017). In any case, ultrasound should only be an adjunct to physical examination after observation, palpation, percussion and auscultation (Kumar et al., 2020). Physical examination requires knowledge of anatomical relationships between structures and surface anatomy landmarks, and using ultrasound while learning physical examination provides students feedback on these in real time (So et al., 2017; Oteri et al., 2020; Wong et al., 2021). Therefore, the best fit of ultrasound in the curriculum is after establishment of core anatomical knowledge, and as a mode of formative assessment and clinical application of anatomy content.

ANATOMICAL KNOWLEDGE UNDERPINS ULTRASOUND SKILLS

In a medical curriculum, ultrasound should complement and follow learning with cadaveric anatomy to build on this knowledge

It is imperative that ultrasound does not replace learning anatomy using cadaveric specimens. This unique, haptic learning experience teaches students three-dimensional relations and variability of human anatomy, and other important skills, including professionalism (Swartz, 2006; Riederer et al., 2015). Integration of ultrasound with traditional cadaveric anatomy teaching will enhance medical students' comprehension of anatomy (Fakoya, 2013) and also retain the importance of anatomy for comprehension of ultrasound (Miles, 2005; Ivanusic et al., 2010). Because ultrasound can provide a link between students' initial understanding of cadaveric anatomy and their future clinical context of assessment of patient anatomy (So et al., 2017), it is best that anatomy knowledge precedes ultrasound experience. Prior to clinical application of their knowledge, medical students should have first gained a thorough understanding of anatomical structures, including their locations, relations between organs, and surface anatomy features (Shapiro et al., 2002; Standring, 2012). Ideally, ultrasound should be incorporated into multiple stages of the curriculum to improve assimilation of knowledge (Sweetman et al., 2013). Longitudinal integration of imaging technology is also an opportunity to increase vertical integration of anatomy throughout the medical curriculum, and re-establish the central importance of anatomy education in the medical school curriculum (So et al., 2017).

A new focus for POCUS: Ultrasound as application and formative assessment of anatomical knowledge, which is itself essential for ultrasound competence

Assessment is one of the strongest influences on learning, both in higher education generally, and medical education specifically (Phillips et al., 2013). However, though assessment drives students' learning, this is not always positive: while formative assessment promotes a deep approach to learning, summative assessment can encourage a surface approach to learning (Al-Kadri et al., 2012). The use of ultrasound to obtain appropriate images of internal anatomy and accurately interpret these is an ideal formative assessment of anatomical understanding via its clinical application. Because ultrasound use provides students with immediate feedback on where internal organs are in relation to surface anatomy and other structures (Jamniczky et al., 2017; So et al., 2017; Oteri et al., 2020; Wong et al., 2021), it offers an ideal formative assessment opportunity. Indeed, the best way for formative assessment to impact on learning and metacognition is via the effective use of feedback (Taras, 2008). Further, students engage in a deeper learning approach when formative assessment encourages active learning, requires higher-level cognitive processing, understanding and application of content, and addresses gaps in knowledge (Al-Kadri et al., 2012). Application of anatomy via ultrasound as formative assessment of this knowledge certainly meets all these points, and offers a clinically relevant way to assess and apply anatomical knowledge and understanding.

RECOMMENDATIONS AND CONCLUSIONS

Incorporating ultrasound into medical curricula can improve quality learning and teaching, and student engagement. Given the increased use of POCUS in diverse global settings, it is imperative that the emphasis is on graduating medical professionals who are competent to use ultrasound. Sound anatomy knowledge underpins medical diagnostic imaging, and this highlights the importance of promoting and preserving anatomy in medical education for best medical practice around the world.

REFERENCES

AL-KADRI HM, AL-MOAMARY MS, ROBERTS C, VAN DER VLEUTEN CPM (2012) Exploring assessment factors contributing to students' study strategies: Literature review. *Med Teach,* 34(suppl. 1): S42-S50.

ALEXANDER SM, POGSON KB, FRIEDMAN VE, CORLEY JL, HIPOLITO CANARIO DA, JOHNSON CS (2020) Ultrasound as a learning tool in bachelor-level anatomy education. *Med Sci Educ,* 1-4. doi: 10.1007/s40670-020-01170-1.

ALLSOP S, GANDHI S, RIDLEY N, SPEAR M (2021) Implementing ultrasound sessions to highlight living anatomy for large medical student cohorts. *Trans Res Anat*, 22: 100088.

ANG J, DOYLE B, ALLEN P, CHEEK C (2018) Teaching bedside ultrasound to medical students. *Clin Teach,* 15(4): 331-335.

ARORA S, CHEUNG AC, TARIQUE U, AGARWAL A, FIRDOUSE M, AILON J (2017) First-year medical students use of ultrasound or physical examination to diagnose hepatomegaly and ascites: a randomized controlled trial. *J Ultrasound,* 20(3): 199-204.

BAHNER DP, ADKINS EJ, HUGHES D, BARRIE M, BOULGER CT, ROYALL NA (2013) Integrated medical school ultrasound: Development of an ultrasound vertical curriculum. *Crit Ultrasound J,* 5(1): 1-9.

BHOI S, SAHU AK, MATHEW R, SINHA TP (2021) Point-of-care ultrasound in COVID-19 pandemic. *Postgrad Med J,* 97(1143): 62-63.

BUTTER J, GRANT TH, EGAN M, KAYE M, WAYNE DB, CARRIÓN-CARIRE V, MCGAGHIE WC (2007) Does ultrasound training boost Year 1 medical student competence and confidence when learning abdominal examination? *Med Educ,* 41(9): 843-848.

DRAKE RL, PAWLINA W (2014) Multimodal education in anatomy: The perfect opportunity. *Anat Sci Educ,* 7(1): 1-2.

ESTAI M, BUNT S (2016) Best teaching practices in anatomy education: A critical review. *Ann Anat,* 208: 151-157.

FAKOYA FA (2013) Integrating ultrasound technology into teaching gross anatomy: Point of order! *Med Educ Online,* 18, doi: 10.3402/meo.v18i0.20888.

FEILCHENFELD Z, DORNAN T, WHITEHEAD C, KUPER A (2017) Ultrasound in undergraduate medical education: a systematic and critical review. *Med Educ,* 51(4): 366-378.

GRIKSAITIS MJ, SAWDON MA, FINN GM (2012) Ultrasound and cadaveric prosections as methods for teaching cardiac anatomy: A comparative study. *Anat Sci Educ,* 5(1): 20-26.

HOFFMANN B, BLAIVAS M, ABRAMOWICZ JS, NIELSEN MB, BADEA R, BRADEN B, CANTISANI V, CHAMMAS MC, CUI XW, DONG Y, GILJA OH, HARI R, LAMPRECHT H, NISENBAUM H, NOLSØE CP, NÜRNBERG D, PROSCH H, RADZINA M, RECKER F, SACHS A, SAFTOIU A, SERRA A, VINAYAK S, WESTERWAY S, CHOU YH, DIETRICH CF (2020) Medical student ultrasound education, a WFUMB position paper, Part II. A consensus statement by ultrasound societies. *Med Ultrason,* 22(2): 220-229.

HOPPMANN RA, RAO VV, POSTON MB, HOWE DB, HUNT PS, FOWLER SD, PAULMAN LE, WELLS JR, RICHESON NA, CATALANA PV, THOMAS LK, WILSON LB, COOK T, RIFFLE S, NEUFFER FH, MCCALLUM JB, KEISLER BD, BROWN RS, GREGG AR, SIMS KM, POWELL CK, GARBER MD, MORRISON JE, OWENS WB, CARNEVALE KA, JENNINGS WR, FLETCHER S (2011) An integrated ultrasound curriculum (iUSC) for medical students: 4-year experience. *Crit Ultrasound J,* 3(1): 1-12.

IVANUSIC J, COWIE B, BARRINGTON M (2010) Undergraduate student perceptions of the use of ultrasonography in the study of "Living Anatomy". *Anat Sci Educ,* 3(6): 318-322.

JAMNICZKY HA, COTTON D, PAGET M, RAMJI Q, LENZ R, MCLAUGHLIN K, CODERRE S, MA IWY (2017) Cognitive load imposed by ultrasound-facilitated teaching does not adversely affect gross anatomy learning outcomes. *Anat Sci Educ,* 10(2): 144-151.

JANKOWSKI M, MOZDZIAK P, KEMPISTY B (2020) COVID-19 spotlights medical diagnostics. *Science,* 368(6493): 839.

KHARB P, SAMANTA PP, JINDAL M, SINGH V (2013) The learning styles and the preferred teaching-learning strategies of first year medical students. *J Clin Diag Res,* 7(6): 1089-1092.

KNUDSEN L, NAWROTZKI R, SCHMIEDL A, MÜHLFELD C, KRUSCHINSKI C, OCHS M (2018) Hands-on or no hands-on training in ultrasound imaging: A randomized trial to evaluate learning outcomes and speed of recall of topographic anatomy. *Anat Sci Educ,* 11(6): 575-591.

KUMAR R, SINGH R (2020) Model pedagogy of human anatomy in medical education. *Surg Radiol Anat,* 42(3): 355-365.

LAGRONE LN, SADASIVAM V, KUSHNER AL, GROEN RS (2012) A review of training opportunities for ultrasonography in low and middle income countries. *Trop Med Int Health,* 17(7): 808-819.

LIU RB, SUWONDO DN, DONROE JH, ENCANDELA JA, WEISENTHAL KS, MOORE CL (2019) Point-of-care ultrasound: does it affect scores on standardized assessment tests used within the preclinical curriculum? *J Ultrasound Med,* 38(2): 433-440.

MENEGOZZO CAM, CAZOLARI PG, NOVO FDCF, COLLEONI R, UTIYAMA EM (2019) Prospective analysis of short-and mid-term knowledge retention after a brief ultrasound course for undergraduate medical students. *Clinics,* 74: e1087.

MILES KA (2005) Diagnostic imaging in undergraduate medical education: An expanding role. *Clin Radiol,* 60(7): 742-745.

MINARDI J, RESSETAR H, FOREMAN T, CRAIG K, SHARON M, BASSLER J, DAVIS S, MACHI A, COTTRELL S, DENNE N, FERRARI N, LANDRETH K, PALMER B, SCHAEFER G, TALLAKSEN R, WILKS D, WILLIAMS D (2019) Longitudinal ultrasound curriculum incorporation at west Virginia university school of medicine: A description and graduating students' perceptions. *J Ultrasound Med*, 38(1): 63-72.

MOORE CL, COPEL JA (2011) Current concepts: Point-of-care ultrasonography. *New Engl J Med,* 364(8): 749-757.

MOSCOVA M, BRYCE DA, SINDHUSAKE D, YOUNG N (2015) Integration of medical imaging including ultrasound into a new clinical anatomy curriculum. *Anat Sci Educ*, 8(3): 205-220.

OTERI V, OCCHIPINTI F, GRIBAUDO G, MARASTONI F, CHISARI E (2020) Integration of ultrasound in medical school: effects on physical examination skills of undergraduates. *Med Sci Educ,* 30(1): 417-427.

PHILLIPS AW, SMITH SG, STRAUS CM (2013) Driving deeper learning by assessment. an adaptation of the revised Bloom's taxonomy for medical imaging in gross anatomy. *Acad Radiol,* 20(6): 784-789.

RIEDERER BM, BUENO-LÓPEZ JL, AYER R, REBLET C, CADAS H, PUYAL JP (2015) Practical teaching of preclinical anatomy. *Eur J Anat,* 19(2): 205-213.

ROBERTS CM, LEVI M, MCKEE M, SCHILLING R, LIM WS, GROCOTT MPW (2020) COVID-19: a complex multisystem disorder. *Br J Anaesthes,* 125(3): 238-242.

ROONEY KD, SCHILLING UM (2014) Point-of-care testing in the overcrowded emergency department - Can it make a difference? *Crit Care*, 18(6): 692.

SCHRIFT D, BARRON K, ARYA R, CHOE C (2020) The use of POCUS to manage ICU patients with COVID-19. *J Ultrasound Med*, doi: 10.1002/jum.15566.

SHAPIRO RS, KO PP, JACOBSON S (2002) A pilot project to study the use of ultrasonography for teaching physical examination to medical students. *Comp Biol Med,* 32(6): 403-409.

SMITH CF, FINN GM, STEWART J, ATKINSON MA, DAVIES DC, DYBALL R, MORRIS J, OCKLEFORD C, PARKIN I, STANDRING S, WHITEN S, WILTON J, MCHANWELL S (2016) The Anatomical Society core regional anatomy syllabus for undergraduate medicine. *J Anat,* 228(1): 15-23.

SO S, PATEL RM, OREBAUGH SL (2017) Ultrasound imaging in medical student education: Impact on learning anatomy and physical diagnosis. *Anat Sci Educ,* 10(2): 176-189.

SORENSEN B, HUNSKAAR S (2019) Point-of-care ultrasound in primary care: a systematic review of generalist performed point-of-care ultrasound in unselected populations. *Ultrasound J,* 11: 31.

STANDRING S (2012) Evidence-based surface anatomy. *Clin Anat,* 25(7): 813-815.

STRINGER MD, DUNCAN LJ, SAMALIA L (2012) Using real-time ultrasound to teach living anatomy: An alternative model for large classes. *NZ Med J,* 125(1361): 37-45.

SWARTZ WJ (2006) Using gross anatomy to teach and assess professionalism in the first year of medical school. *Clin Anat,* 19(5): 437-441.

SWEETMAN GM, CRAWFORD G, HIRD K, FEAR MW (2013) The benefits and limitations of using ultrasonography to supplement anatomical understanding. *Anat Sci Educ,* 6(3): 141-148.

TARAS M (2008) Summative and formative assessment: Perceptions and realities. *Act Learn High Educ,* 9(2): 172-192.

TSHIBWABWA ET, GROVES HM (2005) Integration of ultrasound in the education programme in anatomy. *Med Educ,* 39(11): 1148.

WONG CK, HAI J, CHAN KYE, UN KC, ZHOU M, HUANG D, CHENG YY, LI WH, YIN LX, YUE WS, TSE HF, YEUNG P, YIP PS, LI VKS, CHAN A, CHEUNG M, CHEUNG CW, LAU CP, SIU CW (2021) Point-of-care ultrasound augments physical examination learning by undergraduate medical students. *Postgrad Med J,* 97(1143): 10-15.

ZAWADKA M, GRACZYŃSKA A, JANISZEWSKA A, OSTROWSKI A, MICHAŁOWSKI M, RYKOWSKI M, ANDRUSZKIEWICZ P (2019) Lessons learned from a study of the integration of a point-of-care ultrasound course into the undergraduate medical school curriculum. *Med Sci Mon,* 25: 4104-4109.

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Anatomy Education during COVID-19: review of teaching methods and thematic map

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SUMMARY

COVID-19 from Wuhan China has affected almost all aspects of normal life across the world. Anatomy education, previously reliant on traditional methods (i.e., face-to-face teaching and dissection) has had to rapidly adapt to the growing constraints of COVID-19. This literature review aims to gain insight in current themes and trends surrounding anatomy education and evaluate which teaching methods are most effective during COVID-19.

Relevant search terms were used to identify articles on MEDLINE and EMBASE databases using OVIDSP. Exclusion criteria included duplicates, irrelevant articles, and articles not in English or with full text available. A thematic map was constructed and explored by evaluating full texts of articles. Furthermore, articles reporting on the effectiveness of teaching methods were analyzed further according to the strength of analysis, country, teaching methods, and issues identified. Following the primary search strategy and exclusion strategy, 23 articles were included in the thematic map. Themes expanded upon included innovation, preparation, and the new vs old. Within this, 8 articles had comments on the effectiveness of teaching methods used during COVID-19. Short videos combined with discussion, quizzes, and interactive software appear to be more useful than long videos and Power-Point presentation. The authors recommend anatomy educators incorporate only effective mixed online learning methods in combination with traditional teaching methods where possible as local restrictions change. The authors also stress the importance of adequate preparation to prevent sudden and drastic interruptions in teaching.

Key words: Anatomy Teaching – Education – Anatomy – Technology – Teaching – COVID-19

INTRODUCTION

COVID-19, also known as the Corona Virus Disease 2019 first originated from Wuhan China in December 2019 (Singhal, 2020). It primarily affects the respiratory system and is transmitted via inhalation of infected droplets. This has resulted in over 2.5 million deaths and over 113 million confirmed cases worldwide (WHO, 2020). With the aim of reducing mortality and morbidity from COVID-19, countries have implemented restrictions, consequently, affecting almost all aspects of normal life (Ayittey et al., 2020).

Anatomy education, previously reliant on face-to-face contact and practical sessions, has had to rapidly adapt to the growing constraints of

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COVID-19. Many institutions have abruptly stopped traditional teaching methods (i.e., face-to-face teaching and dissection) and have alternatively adopted a plethora of alternative teaching methods that adhere to local estrictions (Ayittey et al., 2020). This may take the form of virtual lectures, interactive online classrooms, self-directed study, social media, spatial anatomy software, and video streaming.

Despite an increasing amount of interest and development in non-traditional anatomy teaching over the previous years, traditional teaching methods remained common practice and arguably the gold-standard of anatomy education worldwide (Older, 2004; Brassett et al., 2020; Parker and Randall, 2020). If such teaching practices are no longer available, the next best alternative should be used. This literature review aims to gain insight into the current themes, thoughts, and trends surrounding anatomy education and to evaluate which teaching methods are most effective during COVID-19.

MATERIALS AND METHODS

Relevant search terms were used to identify articles on MEDLINE and EMBASE databases using OVIDSP from January 2019 to December 2020 (Table 1). Article titles and abstracts were screened and excluded for duplication and irrelevance. Articles not in English or with full text available were excluded. A thematic map was created by reading the main text of all remaining articles. A list of themes, ideas, and points of discussion were gathered to construct a narrative view of the current thoughts surrounding anatomy education during COVID-19.

Table 1. Search strategy. This table depicts the primary search strategy used to identify articles suitable for review. Each line was entered into the search engine OVIDSP. Sars (severe acute respiratory syndrome), ti. (title), ab. (abstract), exp (explode), yr (year).

Line	Searches
1	(covid* or sars or coronavirus or pandemic* or endemic*).ti,ab.
2	(medical student* or teach* or education* or school*).ti,ab. or Students, Medical/ or exp Education, Medical/
3	exp anatomy/ or anatomy.ti,ab.
4	1 and 2 and 3
5	limit 4 to yr="2019 -Current"

Articles that gave a perspective on the effectiveness of teaching methods adopted were analyzed further. The level of evidence was determined based on whether effectiveness was opinion-based, observational, or consisted of a cohort study.

RESULTS

Using the proposed search strategy 71 articles were identified (Fig. 1). Screening excluded 29 duplicates, 18 irrelevant articles, and 1 article not in English. The remaining 23 articles were used to create a thematic map (Fig. 2). Articles were from 14 countries worldwide primarily from the United Kingdom (n=8), United States (n=6), and India (n=4). Main themes expanded upon included innovation, preparation, uncertainty, and the new vs old (the comparison of 'new' non face-to-face teaching methods with 'old' traditional methods).

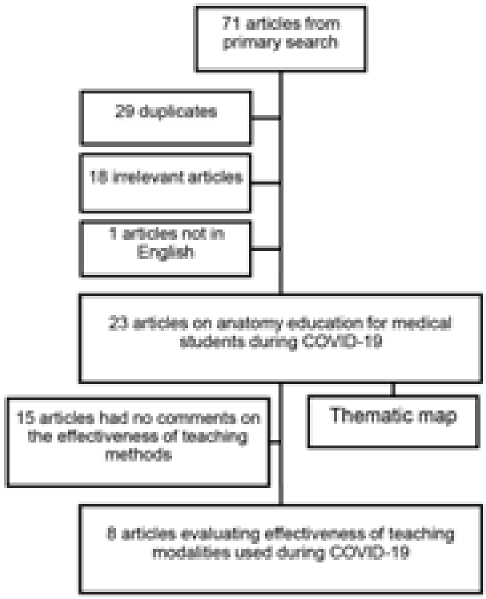

Fig. 1.- Flowchart showing the article selection process. This flowchart illustrates how articles were selected for final review following the primary search strategy. Seventy-one articles were identified from the primary search strategy (Table 1). Twenty-three of these articles were deemed suitable for final review and production of a thematic map. Following this, 8 articles that commented on the effectiveness of teaching methods during COVID-19 were analysed further (Table 2).

Of the 23 articles included, 8 articles had comments on the effectiveness of teaching methods used during COVID-19; 2 were cohort studies, 5 were observational analysis, and 1 was opinion-based (Table 2).

Short videos combined with discussion, quizzes, and interactive software appear to be more useful than long videos and Power-Point presentation

(Table 2). There is a consensus that traditional teaching methods (i.e., face-to-face teaching and dissection) remain the gold-standard of anatomy education.

Fig. 2.- Thematic map on anatomy education during COVID-19. This thematic map visualises the main themes identified during the review process. Themes were created and developed after reviewing the main text of 23 articles identified following the selection process. The three main themes were innovation, preparation, and the new vs old (the comparison of 'new' non face-to-face teaching methods with 'old' traditional methods). Substandard teaching is a common concern surrounding all three main themes. Alongside innovation, articles have a sense of optimism and repeatedly speculate what the future of anatomy might hold. The lack of preparation has evidently proved a challenge for anatomy educators during COVID-19 with some cancelling all anatomy assessment.

DISCUSSION

Despite the wealth of teaching methods and resources described during COVID-19, it is evident there is a lack of research evaluating effectiveness (Table 3). Most articles are observational and did not investigate satisfaction, thoughts, or anatomy knowledge of medical students. Despite this, some important conclusions can be deduced (Table 2).

Power-Point presentation slides were not effective; all articles commenting on Power-Point viewed it negatively (Patra et al., 2020; Singal et al., 2020b). Although Power-Point slides can be rich in information, they can be lengthy and offer little interaction with the student. Teaching resources and methods used during COVID-19 must therefore focus on keeping students engaged.

Video in the form of pre-recorded lectures, short clips, and live discussion all seem to be beneficial (Evans et al., 2020; Naidoo et al., 2020; Patra et al., 2020; Roy et al., 2020; Singal et al., 2020b; Srinivasan, 2020). These methods appear to bridge the gap between complete independent study and face-to-face teaching. Authors have described multiple issues and concerns with the use of video and technology (Brassett et al., 2020; Byrnes et al., 2020; Franchi, 2020; Longhurst et al., 2020; Moszkowicz et al., 2020; Patra et al., 2020; Roy et al., 2020; Singal et al., 2020b; Srinivasan, 2020). Simply, students must have sufficient equipment and internet connectivity to participate, this may disproportionally affect students from poorer socioeconomic backgrounds.

Students prefer traditional teaching methods over distance learning used during COVID-19. Singal et al. (2020b) reported that 90% of students wished to return to traditional teaching methods. Instead of trying to completely move away from traditional methods, maybe educators should be trying to incorporate aspects of traditional methods where possible. Dissection may be possible during COVID-19; Ross et al. (2020) conclude that dissection is possible and essential.

Many medical schools have used anatomy software in addition to the above teaching methods (Table 3). They share some of the benefits dissection provides; students can orientate themselves around a three-dimensional (3D) virtual space, add and remove anatomical layers, and receive information on the anatomy being visualized. Anatomy software is likely to be beneficial during COVID-19 despite the lack of articles commenting on their effectiveness.

The wider use of 'alternative' teaching methods may see anatomy education change for the future. It is perceivable that their use, in combination with traditional teaching methods can be more effective than standalone traditional teaching methods.

Interestingly, some educators may turn to the use of social media (Facebook, Twitter, YouTube, and Instagram) for anatomy teaching during COVID-19. Although their role is likely to be more of a supportive one, the validity of such teaching must be explored. Iwanaga et al. 2020 conclude that social media can increase student engagement and facilitate quick student to teacher communication. In addition, the level of engagement by students can be easily monitored and has previously been shown to be directly related to performance (Jaffar and Eladl, 2016). In contrast, social media platforms were not inherently designed for learning and may act as distractors, subsequently reducing engagement and quality of learning.

Hall and Border (2020) describe the outreach of the University of Southampton SotonBrainHub anatomy dedicated YouTube channel and Instagram account. Strikingly, their following is primarily an international one with only 5% coming from the United Kingdom (country of origin). With the availability of social media and the abundance of resources from highly motivated individuals, educators may pick and choose anatomy resources to promote to their students or simply gain inspiration from.

Thematic Map

The main themes identified include innovation, preparation, and the new vs old. These will be expanded upon further (Fig. 2).

Innovation

Innovation appears to be a reoccurring topic in most articles. Authors stress that COVID-19 has heightened the need for development and change (Brassett et al., 2020; Byrnes et al., 2020; Franchi, 2020; Iwanaga et al., 2020; Longhurst et al., 2020; Moszkowicz et al., 2020; Ooi et al., 2020; Pather et al., 2020; Patra et al., 2020; Roy et al., 2020; Saverino, 2020; Singal et al., 2020a,b; Srinivasan, 2020). This has subsequently increased the amount of thought, research, and investment into alternative teaching strategies. Thus, there is a sense of optimism that anatomy education will benefit in the long term (Byrnes et al., 2020; Naidoo et al., 2020; Srinivasan, 2020; Bond and Franchi, 2021).

When narrowing innovation down to individual anatomy faculties, there has been lots of enthusiasm by teachers and students to produce novel material (Brassett et al., 2020; Chiuta et al., 2020; Hall and Border, 2020; Iwanaga et al., 2020; Ooi et al., 2020; Pather et al., 2020; Patra et al., 2020; Pearson, 2020; Ross et al., 2020; Roy et al., 2020). By developing and exposing students to different resources and teaching methods, an individual's learning needs are more likely to be reached. Some students might even be more satisfied and learn more effectively during COVID-19 than with traditional methods. This introduces the argument that innovation from COVID-19 should not be ignored and certainly not forgotten if normality returns.

Preparation

Most institutions worldwide were thrown by COVID-19 suddenly and un-expectantly. Some describe a lack of preparation with an opportunistic trial and error approach when adapting (Hall and Border, 2020; Jones, 2020; Patra et al., 2020; Pearson, 2020; Singal et al., 2020b). Hall and Border (2020) use the term "damage control" giving the impression of sub-standard teaching. Consequently, strategies enrolled may not have had thorough scrutiny and were likely to involve what the anatomy faculty were familiar with. The quality of such anatomy education would in turn be directly dependent on the prior knowledge, adaptability, and work ethos of each anatomy faculty.

Anatomy assessment has been significantly affected because of online learning. Probity becomes a significant issue that has resulted in some institutions cancelling or postponing all anatomy assessment (Evans et al., 2020; Jones, 2020; Longhurst et al., 2020; Singal et al., 2020b). Without assessment, students may find themselves with less confidence and motivation to learn. These decisions may be the consequence of a lack of preparation; with alternative strategies available (formative assessment, open-book examination, and probity software), it becomes difficult to justify the complete omission of assessment.

Moving forward, anatomy education will likely continue to take major shifts in teaching practices. In a continually evolving environment such as COVID-19, a plan for differing levels of restrictions can help reduce pressures on faculty and promote high-quality anatomy education throughout changes.

New vs old

The comparison of 'new' teaching methods with 'old' traditional ones is an idea that is commonly explored. The idea stems from the notion that if teaching practices were to change, they must be

Table 2. Effectiveness of anatomy teaching modalities during COVID-19. This table evaluates 8 articles that commented on the effectiveness of teaching methods used during COVID-19. Author, year, country of origin, and article summary are reported on. Each teaching modality has been documented as effective (+) or not effective (-) based on author comments or data supplied. Comments on issues identified regarding teaching modalities were recorded and the level of evidence for each article was rated as follows: 1 = Opinion article, 2 = Observational study, and 3 = Cohort study.

Author, year	Country	Summary	Modalities available/ adopted (effective +, not effective -)	Issues identified	Strength of evidence
Evans et al. 2020	Australia Singapore Canada United Kingdom United States	Review of anatomy education during COVID-19	50 minute pre-recorded lectures - 5-7 minute videos + Mini-quiz + Case study + Interactive technology + Discussion +	Obstacles in creating anatomy videos Assessment probity Engagement online	2
Moszkowicz et al. 2020	France	Review of anatomy videoconference teaching during COVID-19	Google Hangouts +	Student non-attendance	2
Naidoo et al. 2020	United Arab Emirates	Design and evaluation of a pedagogical framework for anatomy education during COVID-19	YouTube + WhatsApp + Microsoft Teams + Pre-recorded lectures +	Adoption of new frameworks may not be widely accepted by instructors	2
Patra et al. 2020	India	Anatomists perception on teaching during COVID 19	Power-Point - YouTube links - Zoom - WebEx - Google Meet - Pre-recorded lectures + Google Classroom + Online quiz+	Network issues are common when utilising distance learning	2
Ross et al. 2020	United States	Letter in reply to Saverino, D. 2020 promoting the use of cadaveric dissection during COVID-19	Cadaveric dissection +	Dissection during COVID-19 must incorporate extra precautions	1
Roy et al. 2020	India	199 students' perceptions on Zoom based flipped classed anatomy sessions	Zoom +	It is difficult for students to keep up with daily distance lessons. Internet issues, security threats, non-availability of physical resources, and lack of planning need to be addressed	3
Singal et al. 2020b	India	Perceptions of 80 first-year dental/ medical students on digital anatomy education.	Power-Point - Google form/ Google thread assessment - Pre-recorded lectures +	Availability of technology, internet speed, and digital skills Availability of physical study material Attendance, student engagement, self-motivation, lack of college experience Assessment probity	3
Srinivasan 2020	Singapore	Medical student's and an anatomist's perception of an e-Learning platform	Zoom +	Computer tiredness No 3D appreciation of anatomy online	2

Table 3. Anatomy teaching resources during COVID-19. This table lists all teaching resources identified by the 23 articles selected for review and thematic map (Fig. 1).

Category	**Resource**
Anatomy software	3D4 Medical, Acland's Atlas of Anatomy, An@tomedia, Anatomus, Anatomy TV™, BioDigital Human/Studio, IMAIOS, La Trobe, Netter 3D Anatomy, OpenStax, VH Dissector Touch, Visible Body Atlas of Human anatomy, Visible Human Project
Novel resources	3-D printing, Anatomical drawing, Body painting, Cadaveric dissection, Clay work, Formative assessment, In-house notes, Peer teaching, Power-Point, Video recorded lectures, Virtual Learning Environment
Video conferencing/ streaming	Big Blue Button, Chime, Google Meet, Hangouts, Microsoft Teams, Skype, Spaces, Udemy, Webex, Zoom
Social media	Instagram, Facebook, Twitter, WhatsApp
Assessment	Google Form, Google Thread, Practique
Collaboration platforms	Blackboard, Canvas, DFNconf, Google Classroom, Google drive, Microsoft teams, Slack, Vevox
Virtual/ augmented reality	Daydream, Gear VR, Google Cardboard, HoloLens, Sectra, Sketchfab
Video streaming	BrainHub, Kaptura Capture, Panapto, YouTube

equally or more effective than the current ('old') teaching methods.

Articles had overwhelmingly preferred traditional teaching methods ('old') over alternative ('new') ones used during COVID-19 (Brassett et al., 2020; Roy et al., 2020; Singal et al., 2020b; Byrnes et al., 2020; Evans et al., 2020; Franchi, 2020; Iwanaga et al., 2020; Jones, 2020; Longhurst et al., 2020; Moszkowicz et al., 2020; Pather et al., 2020; Bond and Franchi, 2021). It may be difficult to appreciate 3D structures and ensure good quality learning from a distance. Whether one is better than the other is uncertain, and the lack of studies looking at experience and outcome measures makes comparison difficult.

Instead of viewing this as a battle between the new vs old, maybe the benefits and negatives of teaching methods can be equalized through what Moszkowicz et al. (2020) refer to as a 'blended' approach. The use of online learning alongside face-to-face teaching where possible. This approach takes the best of both worlds and may provide students with the highest quality education available.

Limitations

A lack of research into anatomy teaching methods during COVID-19 coupled with primarily low strength observational analysis limits the power of any conclusions made. Bias in such studies is likely to be present and often do not evaluate cost-effectiveness or educational outcomes. Studies may have been missed from the primary search and were subsequently not included in this article.

CONCLUSIONS

In contrast to the promise of innovation in online anatomy teaching methods, there is a consensus that traditional teaching methods remain superior. The authors, therefore, recommend anatomy educators incorporate only effective mixed online learning methods in combination with traditional teaching methods where possible as local restrictions change. The authors also stress the importance of adequate preparation to prevent sudden and drastic interruptions in teaching and identify the need for further high strength studies analyzing the effectiveness of online anatomy teaching methods.

REFERENCES

AYITTEY FK, AYITTEY MK, CHIWERO NB, KAMASAH JS, DZUVOR C (2020) Economic impacts of Wuhan 2019-nCoV on China and the world. *J Med Virol*, 92: 473-475.

BOND G, FRANCHI T (2021) Resuming cadaver dissection during a pandemic. *Med Educ Online*, 26: 1842661.

BRASSETT C, COSKER T, DAVIES C, DOCKERY P, GILLINGWATER T (2020) COVID-19 and anatomy: Stimulus and initial response. *J Anat*, 237: 393-403.

BYRNES KG, KIELY PA, DUNNE CP, MCDERMOTT KW, COFFEY JC (2020) Communication, collaboration and contagion: "Virtualisation" of anatomy during COVID-19". *Clin Anat*, 34: 82-89.

CHIUTA SL, ARGYRIOU A, AHARI D, SARA X, CLAYTON B, CABALEIRO C (2020) Medical students responding to the COVID-19 pandemic:

Creating an anatomy webinar series to cover missed teaching sessions. *BMJ*, 369: m2160.

EVANS D, BAY B, WILSON T, SMITH C, LACHMAN N, PAWLINA W (2020) Going virtual to support anatomy education: A STOPGAP in the Midst of the Covid-19 pandemic. *Anat Sci Educ*, 13: 297-283.

FRANCHI T (2020) The impact of the Covid-19 pandemic on current anatomy education and future careers: a student's perspective. *Anat Sci Educ*, 13: 309-312.

HALL S, BORDER S (2020) Online neuroanatomy education and its role during the coronavirus disease 2019 (COVID-19) lockdown. *World Neurosurg*, 139: 628.

IWANAGA J, LOUKAS M, DUMONT AS, TUBBS RS (2020) A review of anatomy education during and after the COVID-19 pandemic: Revisiting traditional and modern methods to achieve future innovation. *Clin Anat*, 34: 108-114.

JAFFAR A, ELADL M (2016) Engagement patterns of high and low academic performers on facebook anatomy pages. *J Med Educ Curric Dev*, 3: 1-8.

JONES DG (2020) Ethical responses to the Covid-19 pandemic: implications for the ethos and practice of anatomy as a health science discipline. *Anat Sci Educ*, 13: 549-555.

LONGHURST GJ, STONE DM, DULOHERY K, SCULLY D, CAMPBELL T, SMITH CF (2020) Strength, Weakness, Opportunity, Threat (SWOT) analysis of the adaptations to anatomical education in the United Kingdom and Republic of Ireland in response to the Covid-19 pandemic. *Anat Sci Educ*, 13: 301-311.

MOSZKOWICZ D, DUBOC H, DUBERTRET C, ROUX D, BRETAGNOL F (2020) Daily medical education for confined students during coronavirus disease 2019 pandemic: A simple videoconference solution. *Clin Anat*, 33: 927-928.

NAIDOO N, AKHRAS A, BANERJEE Y (2020) Confronting the challenges of anatomy education in a competency-based medical curriculum during normal and unprecedented times (COVID-19 Pandemic): pedagogical framework development and implementation. *JMIR Med Educ*, 6: e21701.

OLDER J (2004) Anatomy: A must for teaching the next generation. *Surgeon*, 2: 79-90.

OOI SZY, OOI R (2020) Impact of SARS-CoV-2 virus pandemic on the future of cadaveric dissection anatomical teaching. *Med Educ Online*, 25: 1.

PARKER E, RANDALL V (2020) Learning beyond the basics of cadaveric dissection: a qualitative analysis of non-academic learning in anatomy education. *Med Sci Educ*, 10: 1-7.

PATHER N, BLYTH P, CHAPMAN JA, DAYAL MR, FLACK NAMS, FOGG QA, GREEN RA, HULME AK, JOHNSON IP, MEYER AJ, MORLEY JW, SHORTLAND PJ, ŠTRKALJ G, ŠTRKALJ M, VALTER K, WEBB AL, WOODLEY SJ, LAZARUS MD (2020) Forced disruption of anatomy education in Australia and New Zealand: An acute response to the Covid-19 pandemic. *Anat Sci Educ*, 13: 284-300.

PATRA A, KUMAR R, CHAUDHARY P (2020) COVID 19 reflection/experience on teaching-learning and assessment: story of anatomy teachers in India. *Anat Sci Int*, 96: 174-175.

PEARSON S (2020) Anatomy: Beyond the COVID-19 pandemic. *Acad Med*, 95(11): e1.

ROSS CF, PESCITELLI MJ, SMITH HF, WILLIAMS JM (2020) Teaching anatomy with dissection in the time of COVID-19 is essential and possible. *Clin Anat*, doi: 10.1002/ca.23640.

ROY H, RAY K, SAHA S, GHOSAL AK (2020) A study on students' perceptions for online zoom-app based flipped class sessions on anatomy organised during the lockdown period of COVID-19 epoch. *J Clin Diagnostic Res*, 14: AC01-04.

SAVERINO D (2020) Teaching anatomy at the time of COVID-19. *Clin Anat*, doi: 10.1002/ca.23616.

SINGAL A, BANSAL A, CHAUDHARY P (2020a) Cadaverless anatomy: Darkness in the times of pandemic Covid-19. *Morphologie*, 104: 147-150.

SINGAL A, BANSAL A, CHAUDHARY P, SINGH H, PATRA A (2020b) Anatomy education of medical and dental students during COVID-19 pandemic: a reality check. *Surg Radiol Anat*, 1-7. doi: 10.1007/s00276-020-02615-3.

SINGHAL T (2020) A review of coronavirus disease-2019 (COVID-19). *Indian J Pediatr*, 87(4): 281-286.

SRINIVASAN DK (2020) Medical students' perceptions and an anatomy teacher's personal experience using an e-learning platform for tutorials during the Covid-19 crisis. *Anat Sci Educ*, 13: 318-319.

WHO (2021) WHO Coronavirus Disease (COVID-19) Dashboard. URL: https://covid19.who.int/ [Accessed 28/02/2021].

SECTION 3

ANATOMICAL DONOR PROGRAMS AND MORTUARY SCIENCES - FEASIBILITY AND FUTURE.

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Building bridges with Anatomy: can continuing education in mortuary sciences transform the profession?

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SUMMARY

Human cadavers have long been used to teach anatomy to different cohorts of students. In order to preserve human cadavers these specimens are embalmed using different chemicals by an embalmer with a background in mortuary sciences. The training within mortuary schools is primarily technical based and geared towards the funeral services profession. Meanwhile, embalmers operating within anatomy departments require a different skillset that is currently learned on the job. With the current advancement, there is a need to transform mortuary sciences into a rigorous research-based discipline. For this reason, students and graduates from Cincinnati College of Mortuary Sciences were invited via email to take part in an online questionnaire. The goal is to gauge their interest in continuing education (CE) courses that would prepare them for a career as an embalmer in an academic institution. Eighty-one participants took part in this study. From the 81 participants, 54.3% expressed great interest in learning research skills, 65.4% expressed great interest in conducting research on preservation, 74.1% expressed great interest in advancing their anatomical knowledge and 70.4% expressed great interest in advancing their dissection skills. When asking the participant of their interest in a summer CE certificate that will help them develop those skills, 66.7% expressed great interest in completing such a program. A CE program providing advanced training in the above-mentioned topics could help transform the embalming profession into a rigorous research-based discipline. Further research is required to investigate the success of such CE programs in equipping graduates with the needed skillset.

Key words: Anatomy – Embalming – Mortuary Sciences – Continuing Education

INTRODUCTION

Human anatomy as a discipline has generally been defined as a branch of biology that deals with the structure of organisms (Jones, 2000). Several sub disciplines fall under the anatomical sciences such as gross anatomy, microscopic anatomy (histology), neuroscience and embryology. From those sciences, gross anatomy is taught to a wide range of students completing different degree programs such as medicine, dentistry, physical/occupational therapy, mortuary sciences, engineering, and art (Balta et al., 2019a). Gross anatomy is primarily taught through lectures and followed by a laboratory practical that might include cadaveric dissection, prosections, plastic

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models, plastinated specimen or computer-based resources (Balta et al., 2020). Using human cadavers to teach human anatomy has been described as a superior method to solidify the taught anatomical knowledge and gain other skills (Korf et al., 2008). This teaching method has not changed for centuries, but the main difference has been the process through which the human materials are obtained.

Human cadavers used to teach anatomy are primarily obtained through body donation programs that are housed within academic units at most universities. Donors sign consent forms before death or are donated after death by their next of kin (laws vary per state). After the donor is received through the body donation program, an embalmer or an anatomy morgue technician will start the process of preparing the body for its use (McHanwell et al., 2020). This process will usually include documenting any observation upon the receipt of the body along with introducing a new identification method, followed by embalming. Embalming is a process of introducing chemicals into the body to slow down the decomposition process and reduce any risk of biological hazard (Balta et al., 2015). Anatomy morgue technicians are trained on how to embalm a human cadaver as part of their degree in mortuary sciences. While this process is somehow similar, there is a huge difference in how the body is prepared for a funeral service compared to its use in academia (Balta et al., 2015).

When preparing a body for a funeral service, the goal is to preserve the body for a short period of time, which ranges between a few of days to a week. Meanwhile, in an anatomy department the preservation period of human material can range between a few months to several years (Balta et al., 2015). Moreover, funeral directors have a huge focus on the aesthetic part of the process, which is not the priority of an anatomy morgue technician. In addition to the use of human material in anatomy, there has been an increasing use of human material in clinical training and the development of medical equipment (Balta et al., 2017). This increasing demand has led to the development of a new research area referred to as Alternative Preservation Techniques. Ideally, the goal of those techniques is to preserve the body for the longest period possible while retaining similar conditions to that of an unembalmed cadaver (Balta et al., 2019b). The embalming chemicals and protocol utilized during alternative preservation techniques is different to that used in the training of funeral directors in the mortuary science program.

The requirement needed to become licensed as a funeral director/embalmer varies between different states with different institutions offering an Associate or Bachelor’s degree in mortuary sciences. However, there is a minimum educational experience required as outlined by three different sources. Those sources are the Manual on Accreditation (2009) and Curriculum Manual (2010) both published by the American Board of Funeral Service Education along with the Funeral Service Practitioner National/State Board Examination Content Online published by the International Conference of Funeral Service Examining Boards (ICGSEB, 2005). The subjects covered in a mortuary science curriculum range from the sciences of embalming, anatomy, restorative art, microbiology, pathology, and chemistry, to the arts including funeral directing, psychology and counseling, ethics, business management, sociology, accounting, and history of embalming. In the state of Ohio, graduates from a mortuary science program are required to take the National Board Exams to become eligible for a license which is earned upon completion of a 1-year apprenticeship under the supervision of a licensed embalmer. Completing those steps ensure the registration as a funeral director in the State of Ohio and to maintain this license, 18 Continuing Education (CE) hours are required every 2-year license term.

In a study by Balta et al. in 2015, authors discuss the need to transform the embalming profession into a research-based discipline to meet the need of alternative preservation techniques within medicine. For this reason, the aim of this study is to investigate the awareness of mortuary science students and graduates of this gap and their interest in pursuing a graduate degree in anatomical embalming and research.

MATERIALS AND METHODS

Study Design

An online questionnaire was developed through OSU Qualtrics^{XM}. The questionnaire was then validated by Cincinnati College of Mortuary Science (CCMS) faculty members who completed the questionnaire and provided feedback. This feedback was used to make the necessary changes to the questionnaire.

Emails were used to send out invitations to CCMS current students and graduates that were currently on the college Listserv. The invitation email provided participants with information about the project, how to provide informed consent and take part in the study.

Questionnaire

The questionnaire was divided into two main sections as demonstrated in the attached supplementary document. The first section included questions that aimed at collecting data about the participants' backgrounds. In the second part, students were asked about their awareness of existing careers outside the funeral profession along with their interest in advancing their anatomical knowledge, cadaver dissection skills and research skills. Moreover, participants were also asked about their interest in a summer certificate program to advance the above-mentioned skills along with the option of an online component.

Ethical Approval

Ethical approval was granted for this project by the Cincinnati College of Mortuary Sciences Leadership Board.

RESULTS

Background demographic data was initially collected from all survey participants (n=81). The population of individuals who completed the questionnaire consisted of 77.8% females and 17.3% males, with 4.94% preferring not to specify gender. The majority of participants were aged 20-23 years at 43.2%, followed by 27-30 years at 22.2%, 24-26 years at 16.1%, > 30 years at 13.6%, and < 20 years at 4.9%. The current states of residence among participants included California (3.7%), Florida (1.2%), Illinois (1.2%), Indiana (12.4%), Kentucky (7.4%), Michigan (1.2%), Ohio (67.9%), Oklahoma (1.2%), Virginia (2.5%) and West Virginia (1.2%). These demographic data are summarized in Table 1.

Highest academic degree of participants was reported as follows: 34.6% specified a science bachelor's degree, 19.8% a non-science bachelor's degree, 1.2% a science master's degree, 1.2% a non-science master's degree, and 43.2% specified "other" as their highest level of degree. Of the individuals that specified a highest degree of "other", 65.7% earned an associate's degree, and 34.3% earned a high school diploma. Among those that specified high school diploma as their highest degree, 16.7% were currently working on a bachelor's degree at the time the survey was conducted.

Table 1. Demographics of mortuary science student survey participants in percentages.

<table>
<tr><th>Demographics</th><th colspan="5">Percentage of Students</th></tr>
<tr><td>Age</td><td><20 years (4.9%)</td><td>20-23 years (43.2%)</td><td>24-26 years (16.1%)</td><td>27-30 years (22.2%)</td><td>>30 years (13.6%)</td></tr>
<tr><td>Previous Degree</td><td>Science Bachelor's (34.6%)</td><td>Non-Science Bachelor's (19.8%)</td><td>Science Master's (1.2%)</td><td>Non-Science Master's (1.2%)</td><td>Other (43.2%)</td></tr>
<tr><td>Occupation</td><td>Student (59.2%)</td><td>Part-time Employment (16.1%)</td><td>Full-time Employment (24.7%)</td><td colspan="2">Unemployment (0%)</td></tr>
<tr><td>Areas of Profession</td><td>Funeral Profession (81.8%)</td><td colspan="2">Academic Institution (6.1%)</td><td colspan="2">Other (12.1%)</td></tr>
<tr><td>Gender</td><td>Male (17.3%)</td><td colspan="2">Prefer not to specify (4.9%)</td><td colspan="2">Female (77.8%)</td></tr>
</table>

Regarding occupation of those surveyed, 59.3% were students, 16.1% were part-time employees, 24.7% were full-time employees, and 0% were unemployed. Of those employed, 81.8% worked in the funeral profession, 6.1% worked in an academic institution, and 12.1% specified their work as “other”. Areas of work specified as “other” included fields of pathology, tattoo artistry, nursing and animal rescue.

Along with demographic information, survey participants were asked several questions regarding their awareness of career opportunities outside of the funeral profession (see Fig. 1). When asked if interested in a career outside of the funeral profession, 33.33% of participants responded “Yes”, 22.2% of participants responded “No” and 44.4% of participants responded “Maybe”. Survey participants were asked if they were aware of career opportunities in their field within academic institutions, to which 34.6% responded “Yes”, 48.6% responded “No” and 17.3% responded “Maybe”.

When asked about interest in gaining work experience within the mortuary unit of an anatomy department, 58.0% of those surveyed responded “to a great extent”, 19.8% responded “to a moderate extent”, 18.5% responded “to a small extent”, and 3.7% responded “not at all”.

Extent of interest in expanding anatomical knowledge yielded the following results: 74.1% “to a great extent”, 11.1% “to a moderate extent”, 14.8% “to a small extent”. As shown in Fig. 1., when asked to what extent they were interested in advancing cadaveric dissection skills participants responded “to a great extent” at 70.37%, “to a moderate extent” at 14.8%, “to a small extent” at 9.9%, and “not at all” at 4.9%.

Results of individuals’ interest in learning research skills were as follows: 54.3% “to a great extent”, 21% “to a moderate extent”, 19.8% “to a small extent” and 4.9% “not at all” as demonstrated in Fig. 1. Participants were asked to what extent they were interested in conducting research in alternative preservation methods with responses of 65.4% “to a great extent”, 14.8% “to a moderate extent”, and 19.8% “to a small extent”.

Lastly, participants were asked to what extent they would be interested in completing a summer certificate program established as a collaboration between Cincinnati College of Mortuary Science and The Ohio State University. Students were notified that the certificate program would cover detailed anatomy, alternative preservation techniques and research. The participants responded with the following feedback: 66.7% “to a great extent”, 13.6% “to a moderate extent”, 17.3% “to a small extent” and 2.5% “not at all”. When asked to what extent having this certificate program offered online would be helpful for them, of those surveyed 55.6% responded “to a great extent”, 17.3% “to a moderate extent”, 17.3% “to a small extent” and 9.9% “not at all”.

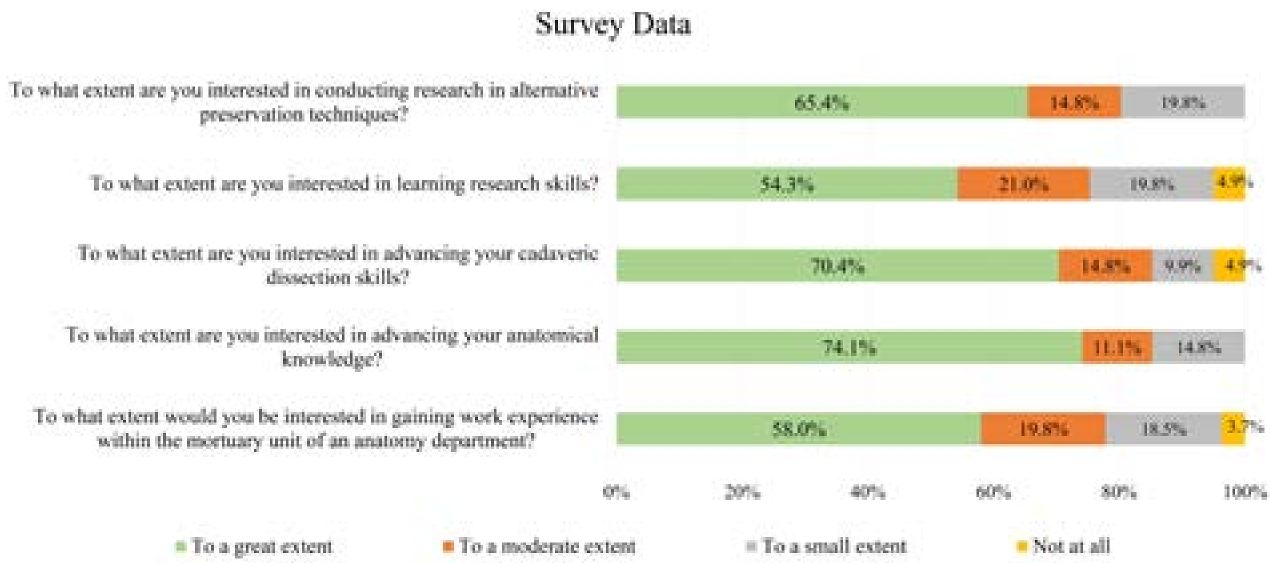

Fig. 1.- Survey response data of mortuary science student participants on five different questions.

Participants were free to leave comments following the survey, and many of the participant comments mentioned their lack of knowledge regarding mortuary career opportunities within academia. Many of these participants were eager to learn more about these additional career opportunities, especially within the field of anatomy.

DISCUSSION

Mortuary Science and Anatomy

With the increased utility of human body donors in academic institutions, there is a need to advance the scholarship on preservation of human body donors. This need has been demonstrated in literature as clinicians and medical equipment companies rely on body donors to improve patient care (Balta et al., 2015). Human body donors are able to provide a safe and reliable simulator to what clinicians will experience in their practice. Moreover, there has recently been an increased interest in using alternative preservation techniques to teach anatomy. This is due to the fact that the currently used embalming methods alter the quality of tissue of the embalmed donors. For this reason, the aim of this study is to start this process and investigate the potential interest within the mortuary science profession.

The operation of body donation programs requires a trained embalmer to preserve the donated human bodies. While some of those embalmers would have a training in mortuary sciences, many of them have learned about the embalming process through experience. This could be due to the lack of regulations associated with the operations of body donation programs or other reasons related to the funeral services profession. Some of these reasons could be related to the annual income received by a funeral director compared to that of an anatomy morgue technician (embalmer). Another reason could be the lack of awareness of potential career opportunities within academic institutions as demonstrated by the findings of this study as only 34.6% expressed their knowledge of such opportunities.

Anatomists lack the training associated with embalming and preservation of the human body. For this reason, there is a need to engage with the discipline experts within mortuary sciences to help advance the discipline. The main challenge associated with this endeavor is that the current mortuary science training program does not prepare its graduates for a career in academia. Even though a bachelor's degree in mortuary sciences is offered at CCMS, many of the graduates exit with an Associate's degree (28.4%) as shown by the findings of this study. That could be due to the fact that only two states (Ohio & Minnesota, USA) require a Bachelor degree to become licensed to practice as a funeral director/ embalmer. This level of training does not provide graduates with enough expertise in anatomy or research to contribute to the scholarship of human cadaveric embalming.

Continuing Education

One of the possible options to provide such training is through a continuing education certification program. Of those who participated in this study, 66.7% expressed great interest in completing a summer certificate program as a collaboration between a college of mortuary sciences and a research focused institution of higher education. This type of training will help mortuary science graduates who are trained to become a funeral director gain expertise necessary for a career in an academic institution. Based on the currently existing mortuary science programs, two main areas were identified for potential growth. The first area is advanced anatomy knowledge accompanied by dissection skills. While all mortuary science programs cover the anatomy of the human body, working in an anatomy department would require a more detailed level of anatomy in order to contribute to the technical support needed for all academic programing. From the participating graduates and trainees 74.1% have expressed great interest in advancing their anatomical knowledge and 70.4% have expressed great interested in advancing their cadaveric dissection.

Another significantly important area of development is within the scholarship of discovery. While embalming dates back to historic civilizations such as the Egyptians, the process is not very well documented and many of the procedures are passed on by word of mouth or within institutional knowledge (Balta et al., 2015). Training embalmers on the process of scientific discovery will help them investigate, assess and document their work to be shared with their community of scholars. This will also enable scholars within the discipline to assess and provide feedback on such work, which will eventually help in increasing rigor of the scholarly work within the discipline. For this reason, participants were asked about their interested in learning research skills and 54.3% have expressed a great interest in learning such skills while 61.4% have expressed great interest in conducting research on alternative preservation techniques.

Even though the goal of such continuing education courses is to increase awareness of embalming jobs within academic institutions as 48.2% of participants indicated that they are not aware of career opportunities and especially that only 44.4% of participants said they were not interested in a career outside the funeral profession, several challenges could phase such initiative. One of the main challenges highlighted by the participants was the lack of confidence in taking on such initiative or as described by one participant *"It is intimidating to think about a job within academic institutions as I don't feel that my degree prepared me for it"*. This goes back to the nature of the profession as it is primarily funeral service professionally oriented as opposed to academia. Other challenges could be internal within academic institutions as development of new programs will require the proof of strong demand which might be difficult to demonstrate as this will address a need within a small profession.

Several factors could limit the findings of this study. One of the main limitations is the fact that this study was conducted with participants from one institution within one part of the United States. A larger study is needed to span the US and potentially at the international level. Another limitation of this study is that some participants are currently registered students who do not have enough working experience to make an informed opinion about career options.

The need for advancement in the training of mortuary science practitioners has been demonstrated. The findings of this study show that participants were interested in advancing their anatomical knowledge, dissection skills, research skills and investigating alternative preservation techniques. Moreover, a continuing education program providing advanced training in the above mentioned topics could help transform the embalming profession into a research-based discipline.

List of Abbreviations:

CE: Continuing Education

CCMS: Cincinnati College of Mortuary Sciences

REFERENCES

AMERICAN BOARD OF FUNERAL SERVICE EDUCATION (2009) Manual on accreditation. St. Joseph, MO: Author.

AMERICAN BOARD OF FUNERAL SERVICE EDUCATION (2010) American Board of Funeral Service Education curriculum manual. St. Joseph, MO: Author.

BALTA JY, CRONIN M, CRYAN JF, O'MAHONY SM (2015) Human preservation techniques in anatomy: A 21st century medical education perspective. *Clin Anat*, 28(6): 725-734.

BALTA JY, CRONIN M, CRYAN JF, O'MAHONY SM (2017) The utility of cadaver-based approaches for the teaching of human anatomy: A survey of British and Irish anatomy teachers. *Anat Sci Educ*, 10(2): 137-143.

BALTA JY, O'KEEFFE GW, SUPPLE B (2019a) Utilizing the scholarship of teaching and learning to design an Anatomy Pedagogy Course. *Eur J Anat*, 23(3): 233-240.

BALTA JY, TWOMEY M, MOLONEY F, DUGGAN O, MURPHY KP, O'CONNOR OJ, CRONIN M, CRYAN JF, MAHER MM, O'MAHONY SM (2019b) A comparison of embalming fluids on the structures and properties of tissue in human cadavers. *Anat Histol Embryol*, 48(1): 64-73.

BALTA JY, O'KEEFFE GW, SUPPLE B (2020) The universal design for learning in anatomical sciences education. *Anat Sci Edu*, 23(3): 233-240.

INTERNATIONAL CONFERENCE OF FUNERAL SERVICE EXAMINING BOARDS (2005) Funeral service practitioner National/State Board Examination content outline—2006. Fayetteville, AR: Author.

JONES DG (2000) What is anatomy? Implications for anatomy as a discipline and for Clinical Anatomy as a journal. *Clin Anat,* 13(2): 151-154.

KORF HW, WICHT H, SNIPES RL, TIMMERMANS JP, PAULSEN F, RUNE G, BAUMGART-VOGT E (2008) The dissection course - necessary and indispensable for teaching anatomy to medical students. *Ann Anat*, 190(1): 16-22.

MCHANWELL S, BRENNER E, CHIRCULESCU AR, DRUKKER J, VAN MAMEREN H, MAZZOTTI G, PAIS D, PAULSEN F, PLAISANT O, CAILLAUD MM, LAFORÊT E (2020) The legal and ethical framework governing Body Donation in Europe - A review of current practice and recommendations for good practice. *Eur J Anat*, 12(1): 1-24.

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Will body donation programs ever be feasible in Africa?

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Dear Editor,

It is a fact that the teaching of human anatomy is the bedrock of medical education and research. Besides, anatomy education without cadaveric dissection is incomplete (Chia and Oyeniran, 2020). In recent times, there have been advances in technological innovations in medical education and anatomical teaching, especially the virtual platforms for cadaveric dissections (Onigbinde et al., 2020). These platforms are either complementing, competing, and or gradually replacing cadaveric dissection. Nonetheless, cadaveric dissection remains the ultimate standard for teaching human anatomy (Onigbinde et al., 2020).

To date, most continents continue to rely either directly or indirectly on wet cadaveric dissection. According to the standard anatomical practices, the International Federation of Associations of Anatomists [IFAA] recommended the reliance on the goodwill of individuals for body donations as the only source of cadavers for anatomical teaching (IFAA, 2020).

According to research studies, the Europeans and a larger percentage of Americans have well-defined ethical and legal frameworks for body donation programs or bequests. In Africa however, there is virtually no organized body donation program while unclaimed bodies remain the ultimate source of cadavers in most medical and research institutions (Habicht et al., 2018; Chia and Oyeniran, 2020; Onigbinde et al., 2020). The question is, when will body donation programs or bequests become the major source of cadavers in Africa?

According to Habicht et al. (2018), black Africans are often unwilling to donate their bodies for academic purposes. Akanaku et al. (2019) further stated some of the contributing factors that might be responsible for such unwillingness and the lack of well-defined body donation programs in Africa. Some of these factors include lack of information, awareness, education, and proper orientation on such schemes. Besides, the rich cultural heritage and customs which are intrinsic attributes of Africans, reinforced with strong religious beliefs are parts of the contributing factors. In fact, the African culture of burying and burial rites cannot be traded for anything, regardless of the cause of death (Akwa and Maingi, 2020). For instance, during the Ebola and Coronavirus disease 2019 [COVID 19] outbreaks, people became cautious and extra careful in handling corpses, however, burial rites seem not to be affected in Africa.

A report documented that between 2014 and 2016, more than 4,000 deaths were recorded in Sierra Leone during the Ebola virus disease outbreak, with a death rate equivalent to about 28.5%. Nonetheless, it was believed that these

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figures were grossly underreported because many people were seen to have hidden their dead to perform the traditional burial rites and customs (Jalloh and Raschid, 2018). Such unsafe burial practices also appeared to have contributed to the surge in the number of reported cases in the country during this period (Jalloh and Raschid, 2018). Moreover, during the current COVID-19 pandemic, the World Health Organization [WHO] discouraged embalmment for COVID-19 related dead bodies and encourage cremation as the best alternative to mitigate disease transmission.

Nevertheless, most African countries continue to perform burial rites, including those that died from COVID-19 related diseases. Gross violations of social distancing protocols were also seen on such occasions (Adebowale, 2020).

As per African culture and belief concerning the dead, it is often believed that unless the whole body of a deceased is buried in the mother earth, the spirit of such an individual will not rest in peace. Besides, death is not seen as the end of life but the beginning of another spiritual journey. It is also seen as a link to the ancestors or forefathers (De Gama et al., 2020). Therefore, the dead must be given the last respect by washing it, oiled, prayed for, and even kept in the house for people to see during wake keep (Akwa and Maingi, 2020). In fact, some Africans prefer to bury their dead inside a room [or the deceased room], rather than being buried in the public cemetery. If burial rites could still be performed in such a challenging time like the COVID-19 pandemic era, just under the guise of paying last respect for the dead, then, where is the ground for a body donation program to thrive?

According to the study conducted by Akanaku et al. (2019) on the attitude of some anatomists in Nigeria towards body donation programs in the country, it was discovered that about 56.1% of the respondents agreed to the nobility in a body donation and such programs. However, only 47.4% of them were willing to campaign for such a scheme in the country.

Amazingly, just 25% were ready to donate their bodies for anatomical purposes, while about 26% were unwilling based on religious grounds. Other reasons for their unwillingness include cultural beliefs, traditions or customs, psychologically not ready, disrespectful behaviors towards cadavers, the fear of being dissected, and consent restrictions from family members and loved ones (Akanaku et al., 2019). Lastly, 28.5% of the respondents failed to give reasons for their unwillingness due to reasons best known to them. Surprisingly, they preferred recommending body donation to others but will neither donate theirs nor recommend it to their relatives or loved ones (Akanaku et al., 2019). The question is if a larger percentage of learned and even professionals in the field of human anatomy were unwilling to donate their bodies, who will?

All these notwithstanding, the continual usage of unclaimed bodies in Africa should be discouraged and must not continue forever. Such practices will only bring back the ugly memories of the dark ages in anatomy where grave robbing and murder were in vogue; bodies of criminals, unclaimed bodies, homeless persons, and prisoners were being used for anatomical discoveries through cadaveric dissections (Jones and Whitaker, 2012; Habicht et al., 2018; Akanaku et al., 2019, Chia and Oyeniran, 2020). Continuous use of such bodies will only contribute to a lack of emotion and respect for cadavers in the dissection hall.

Conclusively, the only thing that is constant in life is change. Just like in Brazil and Taiwan, dramatic changes were seen in body donation programs as a result of public awareness campaigns, and better cultural approaches regarding the dead, body donation, and dissection (Habicht et al., 2018). Therefore, the practice of body donation could also be feasible in Africa, although it might take a longer period, if not eternity, for its full realization and implementation. Besides, such a transition cannot happen overnight but gradually. It must also be compelled by legal and ethical frameworks, together with appropriate cultural approaches and mindset towards the dead. This will help to enhance the readiness and willingness of the people to embrace such a donation scheme.

Public discussions and sensitization, rigorous campaigns on television, radio, newspapers, billboards, flyers, and social media platforms on body donation could also have positive outcomes and contributions. This will help to increase the level of awareness and sensitization on body donation programs. Lastly, advocating for an organ donation rather than a whole body donation could also be a good starting point.

REFERENCES

ADEBOWALE N (2020) Abba Kyari's Burial: SGF Mustapha admits violations of COVID-19 protocols. Premium Times [https://www.premiumtimesng.com/news/headlines/388924-abba-kyaris-burial-sgf-mustapha-admits-violations-of-covid-19-protocols.html] (accessed 2 November 2020).

AKANAKU OC, ANYIOM OP, ONAH IJ, REMIGIUS AP (2019) Evaluating the attitude of Nigerian anatomists towards body donations for medical education. *Biomed Sci*, 5(4): 71.

AKWA TE, MAINGI JM (2020) From Ebola to COVID-19: reshaping funerals and burial rites in Africa. *J Health Commun*, 5(3): 7.

CHIA T, OYENIRAN OI (2020) Ethical considerations in the use of unclaimed bodies for anatomical dissection: a call for action. *Ulutas Med J*, 6(1): 5-8.

DE GAMA BZ, JONES DG, BHENGU TT, SATYAPAL KS (2020) Cultural practices of the Zulu ethnic group on the body and their influence on body donation. *Anat Sci Educ*, 13(6): 721-731.

HABICHT JL, KIESSLING C, WINKELMANN A (2018) Bodies for anatomy education in medical schools: An overview of the sources of cadavers worldwide. *Acad Med*, 93(9): 1293-1300.

INTERNATIONAL FEDERATION OF ASSOCIATIONS OF ANATOMISTS (IFAA) (2020) Best practice guidelines for body donation programmes during the novel Coronavirus pandemic. Online [http://www.ifaa.net/wp-content/uploads/2020/05/IFAA-Statement-on-COVID-19-final-v2.pdf]. (accessed 30 October 2020).

JALLOH YJ, RASCHID M (2018) Evaluating the impact of Ebola on tertiary education in Sierra Leone. Prowibo, doi: 10.13140/RG.2.2.21871.33443.

JONES DG, WHITAKER MI (2012) Anatomy's use of unclaimed bodies: Reasons against continued dependence on an ethically dubious practice. *Clin Anat*, 25(2): 246-254.

ONIGBINDE OA, AJAGBE AO, OYENIRAN OI, CHIA T (2020) Post-COVID-19 pandemic: Standard operating procedures for gross anatomy laboratory in the new standard. *Morphologie*, S1286-0115(20)30093-X. doi: 10.1016/j.morpho.2020.10.004.

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