ORIGINAL ARTICLE

Eur. J. Anat. 24 (2): 141-154(2020)

Small team-based medical imaging of human cadavers: an innovative tool for interdisciplinary learning in Human Gross Anatomy and Radiologic Sciences

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SUMMARY

The purpose of this study was to develop an interdisciplinary activity that merged the disciplines of human gross anatomy and radiology early in the educational process of doctors and radiographers allowing students to use human cadavers to learn anatomy and medical imaging (technique and interpretation) through small-group problem-solving sessions. Over 10 years, 734 student doctors and radiographers were divided into small groups and assigned cadavers. Images of cadavers included x-rays, CT and MRI regional and full-body series. Students problem-solved radiographic parameters and interpreted images. Student radiographers completed a semester project labeling anatomical structures in a CT or MRI series. Student doctors used images during dissection and presented radiographic series to demonstrate understanding of anatomy, radiology and skilled use of image analysis software. Participants completed a 100-question LIKERT Scale survey. Data were analyzed based on overall group, cadaver experience, and radiography experience. Students produced high-quality images for use in the laboratory and classroom, and 95% agreed that this activity helped them to learn anatomy and radiography. Students agreed that x-rays, CT and MRI scans were 92.0%, 91.1% and 90.1% beneficial, respectively, in learning anatomy and radiology, and 90% of participants documented that this program had a positive impact in knowledge and competency development for his or her chosen career. Both radiography and medical students reported that working on inter-professional teams enhanced their knowledge of anatomy and radiology and underscored the importance of partnerships in healthcare. This program serves as a *novel* model for interdisciplinary team-based-learning of human anatomy and radiology.

Key words: Anatomy – Radiology – Cadaver – Interdisciplinary learning – Small group – Team-based

Abbreviations:
3-Dimensional (3-D)
Anteroposterior (AP)
Computed Tomography (CT)
Fluid Attenuated Inversion Recovery (FLAIR)

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Submitted: 12 December 2019. *Accepted:* 28 January, 2020.

Indiana University Northwest (IUN)
Indiana University School of Medicine Northwest (IUSM-NW)
Lateral (Lat)
Magnetic Resonance Imaging (MRI)
Right (RT)
Short T1 Inversion Recovery (STIR)
Weighted (Wtd)

INTRODUCTION

The era of radiological sciences began in 1895 when W.C. Roentgen discovered the use of x-rays in radiographic imaging, which led him to receive the Nobel Prize in Physics in 1901 (Reed, 2011). Further advancements were made when Computed Tomography (CT) was invented in 1972 by British engineer Godfrey Hounsfield of Electric and Music Industries Laboratories (England) and by South Africa-born physicist, Allan Cormack, of Tufts University, Massachusetts (Maizlin and Vos, 2012). The first clinical CT scanners were introduced in 1974, and they were dedicated to head imaging until “whole body” systems became available in 1976 (Maizlin and Vos, 2012). Even further, the discovery and development of magnetic resonance imaging (MRI) is one of the most spectacular and successful events in the history of medical imaging. In 1946, nuclear magnetic resonance was discovered by Felix Bloch (Bloch and Ray, 1946; Luiten, 1999; Lindley, 2006) and Edward Mils Purcell (Purcell and Pound, 1946), but there is a time gap of almost thirty years until the first imaging experiments took place in the 1970s by Paul Lauterbur (Lauterbur, 1989; Luiten, 1999) and Raymond Damadian (Damadian, 1971; Damadian et al., 1976; Luiten, 1999) that resulted in MRI entering clinical practice.

Imaging technologies are becoming more advanced in the medical arena, and provide physicians with the ability to rapidly diagnose disease, monitor treatment and assess patient outcomes (Berdahl et al., 2013; Feinberg and Setsompop, 2013; Pereira et al., 2014). Radiology is a tool that spans throughout all of medicine, and it can be considered a physician’s most frequent encounter with human anatomy (Ganske et al., 2006; Prezzia et al., 2013; Orsbon et al., 2014). In simplest terms, radiology is a branch of medicine, and radiography is the type of technology radiologists employ to do their jobs. Lufler et al. (Lufler et al., 2010) showed that radiographic images are useful for the education of medical students respective to the identification of structures and the understanding of spatial (and anatomical) relationships. Even further, the integration of radiology and radiography into the medical curriculum has been shown to prepare medical students for encountering and interpreting radiographic images in a clinical setting (Talarico, 2010; Lufler et al., 2010; Jack and Burbridge, 2012; Phillips et al., 2012a; 2012b). During the first- and second-year of medical school, radiology provides students with an important perspective of anatomy, not only for identifying anatomical structures but also for observing anatomical variations due to disease. More extensive radiographic study is undertaken by student physicians in their third- and fourth-year clerkships, and then residency and fellowship studies. Thus, it is encouraged that medical students gain experience with radiographic tools not only for academic success but also to ensure the best care for their future patients.

Radiology is being used more to teach anatomy than to teach radiological imaging techniques in practice (Gunderman and Wilson, 2005; Marom and Tarrasch, 2015; Rubin and Blackham, 2015). Yet, rarely does the student doctor learn how to capture the most appropriate radiological image or have direct interaction with the radiologic technologist (aka, radiographer). Conversely, radiography students develop extensive experience with radiographic techniques, but rarely does the student radiographer have the opportunity for studying human anatomy through exposure to human cadaver donors and hands-on, full-body dissection. Radiographers are trained using “phantoms”, and thus never face common problems in obtaining optimal images using “real” human bodies. Like the student doctor, the student radiographer does acquire minimal skills for radiographic interpretation. Using cadavers in radiographic imaging provides a novel educational opportunity for both radiography and medical students by simulating a real clinical encounter with a non- responsive patient, requiring students to think critically about radiographic positioning and technique to obtain optimal medical images and to utilize anatomical knowledge to interpret these images.

In 2007, an interdisciplinary team-based mini-course was created at Indiana University School of Medicine - Northwest (IUSM-NW) to expose students early in their education to the multi-disciplinary aspect of medicine and enhance student understanding of useful technology in order to improve their diagnostic abilities that would aid in diagnosis, patient management and treatment (Talarico, 2010). The purpose of this interactive project was to merge the disciplines of human gross anatomy and radiology in the study of human structure early in the educational process of both the student medical doctor and student radiographer, allowing students to use human cadavers to learn the technique of obtaining medical images and how to interpret the results. Briefly, the program was constructed with three specific aims. First, the program would form an interdisciplinary team-based setting that would serve as a novel model for small group learning involving medical students and student radiographers. Teams of students were facilitated by medical professionals and faculty to problem-solve and teach each other human gross anatomy and radiologic imaging (technique and interpretation) using human cadaveric materials. Second, the program would develop high-quality, advanced medical images for active use in laboratory or lecture of human gross anatomy, neuroscience and radiology. Third, the program would establish a laboratory environment that could foster both independent and team-based learning founded on inter-professional education. An extensive literature survey showed that this is the first time that such a project has been attempted, allowing the student medical doctor and student radiographer to learn human anatomy, medical imaging technique and interpretation side-by-side through the use of human cadavers as imaging subjects. The outcomes of this study and the impact of the program on the professional development of future radiographers and physicians are discussed herein.

MATERIALS AND METHODS

Anatomical Donors

A total of 72 anatomical donors, 60 adult human cadavers and 12 preserved fetuses, were used in this study. All federal and state guidelines were followed regarding the use and care of cadaveric materials, as well as all regulations set forth by the State of Indiana Anatomical Education Program.

Institutional Review Board Approval

This study was conducted under the guidelines regarding the use of human subjects in research, and with the approval, of the Institutional Review Board of IUSM (IRB Protocol No. 1812586407). No incentive (i.e., benefit) was offered to subjects for completion of the survey instrument. All surveys (i.e., responses) were anonymous. Surveys and analyzed data were stored in a secure location in the research facilities of IUSM-NW. Only the investigators (i.e., authors) had access to the surveys/data.

Study Subjects

The study was conducted from 2007 to 2017, and it included a total of 734 participants (i.e., subjects). Study subjects included participants of the International Human Cadaver Prosection Program (Talarico, 2010), first-year medical student doctors and student radiographers. The radiography students included in the study were those enrolled in the radiography program at Indiana University Northwest, Gary, IN (IUN). This cohort was subdivided into teams consisting of student radiographers and non-radiographers (i.e., all other participants (Fig. 1), and each team was assigned to an anatomical donor that the team would follow through the entire process. Participation in this study was voluntary, and all subjects completed the program and the survey instrument. Survey participants were informed that survey results and comments were anonymous.

Structure of Program

Prior to cadaver-based work, non-radiography students received didactic instruction in human gross anatomy and basic medical imaging and interpretation, and student radiographers received formal course instruction focused on image acquisition and technique. Within the program, small groups were randomly organized to have both non-radiography and radiography students, and these small groups were paired with a cadaver to participate in the program activities. Interdisciplinary activities were divided into three sessions: (1) obtaining x-ray images of the cadavers, (2) obtaining CT and MRI images of the cadavers, and (3) discussion of the acquired images and debriefing. Discussion was facilitated by a faculty member or a medical professional (i.e., anatomist, radiographer, or physician), and students would discuss the images in terms of quality, position, anatomy and relevant pathological findings during image acquisition and assessment. Following the conclusion of these sessions, each formal course (i.e., human gross anatomy and radiologic sciences) used the acquired images in laboratory and didactic sessions. Additionally, during the gross anatomy course, medical students also learned how to use imaging software to assist in analyzing and interpreting images.

X-Ray Film Imaging

Plain x-ray imaging was done in the radiology suite located on the second floor of the Dunes Medical Professional Building of the IUSM-NW. The following standard plain films were obtained: (1) anteroposterior (AP) chest, (2) lateral (Lat) chest, (3) AP abdominopelvic, (4) upper extremity (pectoral girdle, brachium, antebrachium and carpus/manus), (5) lower extremity (pelvic girdle, thigh, leg and foot), and (6) AP skull and Lat skull. If anatomic abnormalities or surgical interventions were observed in the cadaver, then the interdisciplinary team decided which additional films and views were appropriate in order to observe the pathology in more detail. Each film was captured and assessed under the professional instruction and supervision of anatomy and radiography faculty, and image captures were done using both non-digital and digital systems.

Advanced Medical Imaging

Full-body, high-resolution CT and MRI imaging was done at Methodist Hospitals Southlake Campus (Merrillville, IN) using a 64-slice CT scanner (General Electric Lightspeed® capable of 3-dimensional (3D) reconstruction and an MRI scanner (General Electric HIGH-Speed MRI). Coronal (frontal), axial (transverse) and sagittal (median) views were generated both digitally and on film. Additional MRI scans included: (a) MRI of the brain

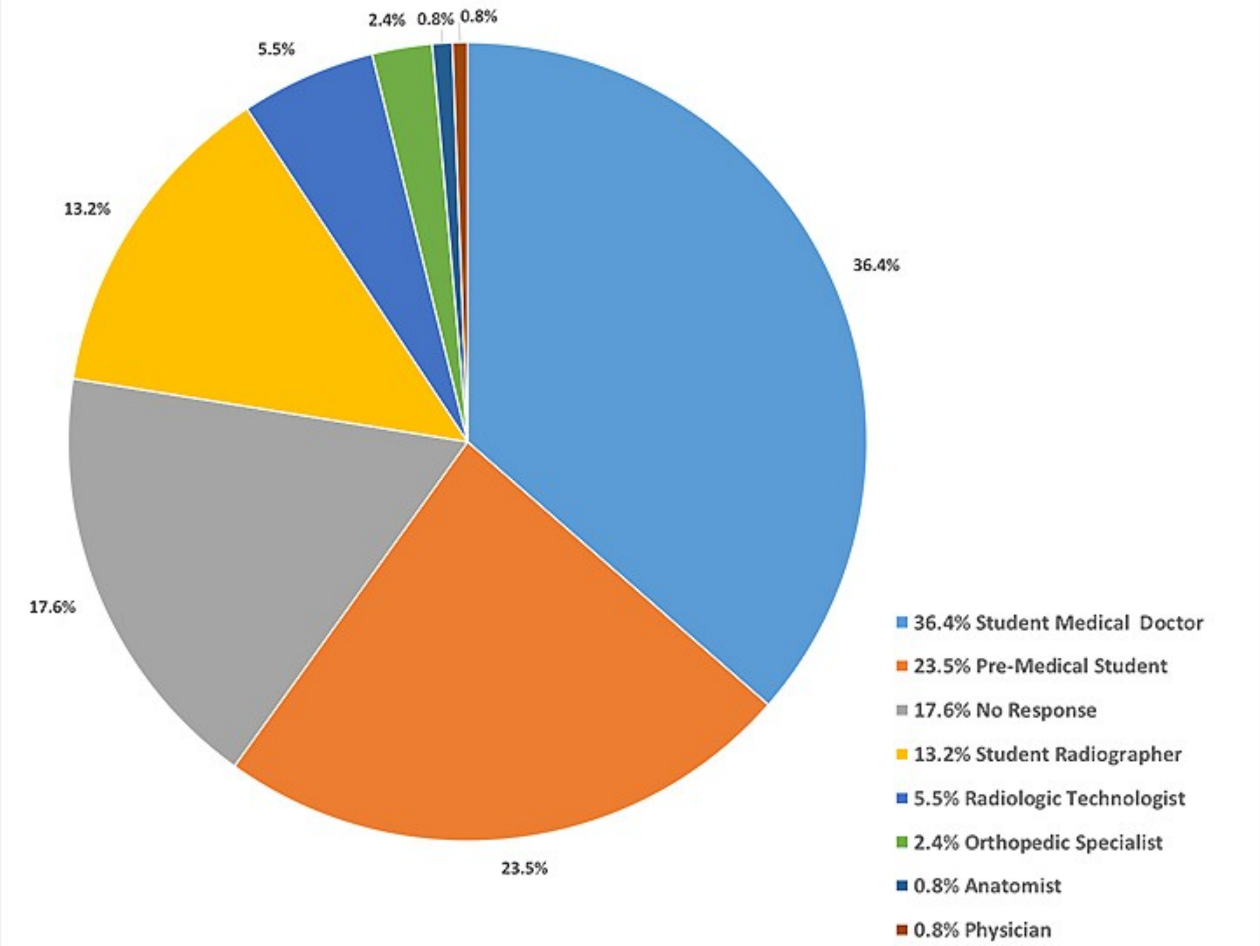

Fig 1. Composition of the subject cohort in this interdisciplinary learning experience. This pie chart describes the subjects used to create interdisciplinary small groups in this study. Each group was assigned to a cadaver that team members worked with through each radiographic modality (i.e., x-ray, CT and MRI). All group members helped to teach each other, participated in image interpretation and discussion of anatomy, and all subjects completed the survey instrument.

including T1-weighted (Wtd) axial and sagittal, T2-Wtd axial, axial diffusion, and Fluid-Attenuated Inversion Recovery (FLAIR) axial scans; (b) MRI of the abdomen and pelvis to include T1- and T2-Wtd sequences in coronal and axial planes; (c) MRI of the knees, hips and shoulders to consist of T1-, T2-Wtd and Short TI Inversion Recovery (STIR) images in at least two planes; (d) MRI of the entire spine including T1- and T2-Wtd sagittal images.

Imaging Analysis

Processing of images, creations of 3-D reconstructions, and quantitative image analyses were done using Konicia PDI Viewer 1.00 V1.0R0.00 (KONICA Minolta, Ramsey, NJ) and TDK CDRS Dashboard V1.0.0.5 (TDK Medical, Minneapolis, MN) for digital x-ray films; eFILM™ Lite™ Viewer 3.0 (Merge Healthcare, Chicago, IL) for radiographic series from CT-Scans; and Philips iSite Viewer (Philips iSite, Amsterdam, Netherlands) for radiographic series from MRI Scans.

Survey Instrument

After the completion of the program, study subjects voluntarily elected to complete an assessment tool to evaluate the program. Blank questionnaires and pencils were located on a table outside of the classroom. On this table was a sealed “drop box”. When subjects were finished with the questionnaire, subjects placed it into the drop box. Access to individual, quiet rooms was made so that subjects could complete the questionnaire in privacy.

The assessment tool comprised a two-part survey. Part I elicited participant information: gender, marital status, year in school or profession, major, undergraduate/graduate institution, and whether or not the subject had prior exposure to work with human cadaver and/or radiographic equipment. Part II comprised of a Likert score questionnaire with a scale of 1 to 5. Scale values were defined as 1 (Strongly Disagree), 2 (Disagree), 3 (Indifferent), 4 (Agree), and 5 (Strongly Agree). Part II was divided into eight subcategories that covered different aspects of the program: (1) overall program, (2) cadaver experience, (3) problem-based learning and imaging experience, (4) radiography laboratory session, (5) anatomy experience, (6) plain x-ray images, (7) CT Scans, and (8)

MRI Scans. Subjects were also asked for constructive narrative feedback and suggestions.

Surveys data were organized and tabulated within a Microsoft® Excel (2011) spreadsheet for analyses, and data were formed into bar graphs and pie charts for visual representation of results.

RESULTS

Study Subjects

Data was collected over ten years from participants that came from a variety of backgrounds. The study cohort consisted of a total of 734 subjects. Study subjects represented 18 states and 5 countries. Survey data were also subdivided by gender, prior experience working with cadavers or prior experience with radiographic imaging techniques. Of the 734 participants, 364 (percent of study cohort = 49.59%) identified as male, 350 (47.68%) identified as female, and 20 participants chose not to indicate a gender. Additionally, 345 (47.00%) participants had prior experience with cadavers, and 331 (45.10%) had prior experience with radiographic imaging techniques.

The participants' level of education ranged from the eleventh grade in high school to professional degrees in healthcare. Participants were further subcategorized by level of education and specific role in the program (Fig. 1). Medical Student Doctors was the largest subcategory of the cohort with 267 participants (percent of study cohort = 36.38%), and the next largest subcategory was pre-medicine students at 172 participants (23.43%). The remainder 295 participants (40.19%) had a professional degree (i.e., Radiologic Technologist, Orthopedic Specialist, Anatomist or Physician) or chose to not respond. The cohort included a total of 154 radiologic technologists (20.98%), which was composed of 96 radiography students and 45 professional radiologic science instructors.

Survey Outcomes

Likert scale data for each response item was individually tabulated in Microsoft® Excel. Responses were rated from 1 (Strongly Disagree) to 5 (Strongly Agree). In addition, Likert scale data for response items on survey instruments were grouped into 5 major comprehensive categories (Table 1). Further, participants were asked to assess the benefit of x-rays, CT and MRI images of cadavers on their ability to learn anatomy and radiology (Table 2). Each item and comprehensive category was further analyzed relative to prior experience with human cadavers (Table 1) and assessment of benefits were compared relative to radiography students vs. non-radiography students (i.e., medical students, etc.) (Table 2). These data are discussed below. The total agreement was determined as the sum of 4 (Agree) and 5 (Strongly Agree).

Overall Program.

The first comprehensive category asked subjects to rate this small-group learning experience as a good use of time, and if they would recommend this learning activity to other students or professionals. Survey participants collectively responded with a 4.61 out of 5. Total agreement for this category was 90.9%, and 3.35% selected either 1 "Strongly Disagree" or 2 "Disagree." The mean for those with prior cadaver experience was 4.61, and the mean for those without cadaver experience was 4.63. One participant commented that "having a wide array of professionals supplementing our learning… was very valuable. The experience of dissecting a cadaver, with an extensive wealth of resources, like radiography, was unique and integral to my learning." Another student stated, "Due to this program, I feel like I have a greater understanding of my role as a future physician, the role of the radiological technician and how we can work together to help patients." One professional noted, "The course strengthened my knowledge of anatomy in ways that will help me translate the information to our students in cadaver laboratory as well as paramedic school."

Hands-on Cadaver Experience.

The second comprehensive category asked participants to reflect on the treatment of the cadavers and rate the statement: "I felt that the cadaver donors were treated with professionalism, respect, and human dignity and that this experience has positively affected my education." (Table 1). Survey participants collectively responded with 4.89 out of 5. 98.3% of participants selected "Agree" or "Strongly Agree", and 0.68% selected either "Disagree" or "Strongly Disagree." Those with prior cadaver experience had a mean of 4.91, and those without prior cadaver experience had a mean of 4.88. A participant commented, "This is my third year participating… I love returning because every cadaver is different, and I learn something new each year." One student wrote, "I have always been a hands-on learner. This experience helps me to really understand anatomy in a way that a book could never teach me." Another subject reflected on human dignity during the fetal cadaver examination: "Being able to obtain [radiographic images] of the fetuses gave a whole new perspective to me in that you are holding in your own two hands this tiny fragile human life, and how precious it is makes you appreciate what we are able to do and accomplish."

Interdisciplinary Team Learning Experience.

The third comprehensive category asked participants to assess the success of small-group sessions in instructing each other in anatomy and radiography (Table 1). The average for overall study participants was 4.79 on a 5 scale. 97.6% of participants selected either "Agree" or "Strongly

Table 1. Survey results of the five major comprehensive categories for Small Team-Based Medical Imaging of Human Cadavers.

Category I. Overall, I found the program to be a good use of my time and would recommend it to others.

Responses	Strongly Disagree	Disagree	Indifferent	Agree	Strongly Agree	Mean
	1	2	3	4	5	
Total Responses	0.82	2.53	5.74	16.47	74.44	4.61
Prior Cadaver Experience	0.94	2.50	6.09	15.94	74.53	4.61
No Cadaver Experience	0.44	2.35	5.13	17.45	74.63	4.63

Category II. I felt that the cadaver donors were treated with professionalism, respect, and human dignity and that this experience has positively affected my education.

Responses	Strongly Disagree	Disagree	Indifferent	Agree	Strongly Agree	Mean
	1	2	3	4	5	
Total Responses	0.19	0.49	1.07	6.89	91.36	4.89
Prior Cadaver Experience	0.16	0.48	0.89	5.48	93.00	4.91
No Cadaver Experience	0.22	0.22	1.18	8.23	90.15	4.88

Category III. I felt that all team members were helpful and worked effectively together to enhance my learning of anatomy and radiography.

Responses	Strongly Disagree	Disagree	Indifferent	Agree	Strongly Agree	Mean
	1	2	3	4	5	
Total Responses	0	0.17	2.27	16.19	81.36	4.79
Prior Cadaver Experience	0	0.30	2.62	15.83	81.24	4.78
No Cadaver Experience	0	0.05	1.96	16.53	81.45	4.79

Category IV. The radiography laboratory session enhanced my learning and understanding of radiographic positions, techniques, equipment, and uses as they pertain to problem solving with different patient types.

Responses	Strongly Disagree	Disagree	Indifferent	Agree	Strongly Agree	Mean
	1	2	3	4	5	
Total Responses	0.11	0.32	3.29	17.11	79.17	4.75
Prior Cadaver Experience	0.24	0.60	3.97	17.43	77.76	4.72
No Cadaver Experience	0.00	0.10	2.74	16.85	80.31	4.77

Category V. The anatomy session enhanced my knowledge of skeletal anatomy, bone markings, visceral anatomy, anatomical relationships, and sectional anatomy while enhancing my use and understanding of anatomical terminology.

Responses	Strongly Disagree	Disagree	Indifferent	Agree	Strongly Agree	Mean
	1	2	3	4	5	
Total Responses	0.05	0.23	4.62	17.00	78.11	4.73
Prior Cadaver Experience	0.00	0.20	5.53	18.44	75.82	4.70
No Cadaver Experience	0.08	0.25	3.89	15.71	80.07	4.75

Agree", 0.17% of participants selected "Disagree" and no participants selected "Strongly Disagree." The mean for participants with prior cadaver experience and those without prior experience was 4.78 and 4.79, respectively. Participants shared reflections on the interdisciplinary team-learning experience. One participant stated, "I liked how the student doctors asked the student radiographers questions and vice versa... It brought us all closer together, and we all learned something about each other's profession." Another participant commented, "as an undergraduate student, this is one of the first times I've worked on an interdisciplinary medical team. It taught me the importance of teamwork and relying on each others' strengths to reach a diagnosis and discuss how to treat the

Table 2. Survey results from the assessment of the benefits of X-Rays, CT and MRI Images of cadavers on ability to learn Anatomy and Radiology.

	Being able to work with a set of radiographic images from a human cadaver donor helped me to learn anatomy and radiology.						
Study Subjects	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**Total Agreement**	**Mean**
Radiography students	0.00	1.06	7.45	6.38	85.11	91.49	4.76
Non-radiography students	0.00	0.91	3.89	20.75	74.45	95.20	4.69

	Plain X-Ray images from my cadaver donor were beneficial in my learning of human anatomy and anatomical relationships.						
Study Subjects	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**Total Agreement**	**Mean**
Radiography students	1.63	0.82	7.34	9.24	80.98	90.22	4.67
Non-radiography students	0.17	1.69	6.12	22.98	69.05	92.03	4.59

	MRI scans from my cadaver donor were beneficial in my learning of human anatomy and anatomical relationships.						
Study Subjects	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**Total Agreement**	**Mean**
Radiography students	0.00	2.15	5.38	7.53	84.95	92.48	4.75
Non-radiography students	0.14	1.65	7.09	23.71	67.41	91.13	4.57

	CT scans from my cadaver donor were beneficial in my learning of human anatomy and anatomical relationships.						
Study Subjects	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**Total Agreement**	**Mean**
Radiography students	0.00	3.23	6.45	4.30	86.02	90.32	4.73
Non-radiography students	0.08	1.54	8.30	24.32	65.76	90.08	4.54

	Lecture, discussion, and radiographic images were useful and I feel that they have contributed to me becoming more competent in my chosen career.						
Study Subjects	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**Total Agreement**	**Mean**
Radiography students	4.55	0.00	22.73	11.36	61.36	72.73	4.25
Non-radiography students	0.17	0.78	11.16	23.53	64.36	87.89	4.51

patient." A different participant commented about educating others within the small groups: "at first it was uncomfortable being put on the spot to teach others, but [the small group sessions] really made me realize my strengths and weaknesses. I was able to help where I could, then I researched the areas I didn't remember." Additionally, a third participant with prior interdisciplinary-team experience stated, "I see the correlation between radiology and medical practice constantly at work. This experience gave me a deeper understanding of the team relationship and what the outcomes of the team dynamics can provide for the patient."

Learning Radiology.

In the fourth category, group participants were asked to rate the effectiveness of his or her experience in the laboratory with respect to understanding radiographic position (i.e., patient orientation and distance relative to radiographic emitter and detector, etc.), techniques and equipment, and the utilization of these aspects for problem-solving with a variety of patient demographics (Table 1). Total responses from participants was a mean of 4.75 on a 5 scale. 96.3% of participants selected "Agree" or "Strongly Agree", and 0.43% of responders selected "Disagree" or "Strongly Disagree." The mean for male and female participants was 4.78 and 4.72, respectively, whereas the mean for those with prior cadaver experience and those without prior cadaver experience was 4.72 and 4.77, respectively. Participant's comments were overwhelmingly positive. As an example, one participant commented that, as a student in healthcare, "we usually see the end products, the images, in class, but it is helpful to understand and appreciate the process required to produce those images." A radiographic student stated, "imaging cadavers eliminated the problem of motion, but created another problem with aligning parts and landmarks. The students had to use critical-thinking skills and teamwork to create a diagnostic image." Another participant stated, "I work in an emergency room and I see radiology films often, but I have never really understood them. This program has helped me to understand what I am looking at and how to decipher the tedious pictures. I look forward to applying my new-found knowledge at work!"

Learning Anatomy.

The fifth category asked participants to assess the statement: "This course enhanced my knowledge of skeletal anatomy, bone markings, visceral anatomy, anatomical relationships, and sectional anatomy while enhancing my use and understanding of anatomical terminology" (Table 1). Overall, the mean rating for participants was 4.73 on a 5 scale. The percent of participants that selected either "Agree" or "Strongly Agree" was 95.10%, and 0.28% of participants selected "Disagree" or "Strongly Disagree." The mean for males and females was 4.77 and 4.69, respectively. The mean for participants with prior cadaver experience and those without prior cadaver experience was 4.70 and 4.75, respectively. Participants comments and reflections were, again, overwhelmingly positive. One participant stated that "experiencing pathology firsthand through the cadavers and identifying structures on radiological images pushed my knowledge to the next level." Another stated that "the radiographs were a great way to supplement learning anatomy. It greatly helped to conceptualize anatomy and reinforce 3-D anatomical relationships." A third participant commented, "I can learn some things from reading a book or listening to a lecture, but for me, hands on in learning anatomy really helped me learn in a very memorable way."

Cadaver Radiographic Imaging Experience.

Interdisciplinary teams of students produced high-quality images for use in the laboratory and classroom (Fig. 2 and Fig. 3), and participants were asked to assess the role of x-rays, CT scans, and MRIs on the impact of their learning experience. Responses from participants for this category were stratified based on professional experience with radiology. The responses of radiographic technologists were evaluated separately from non-radiologic participants, and these responses are depicted in Table 2. For the statement: "Being able to work with a set of radiographic images from a human cadaver donor helped me to learn radiography and anatomy", the mean for radiography participants and non-radiographic participants was 4.76 and 4.69, respectively. A total of 91.49% of radiographic participants selected either "Strongly Agree" or "Agree", 1.06% selected "Disagree", and no participants selected "Strongly Disagree." In the same category, non-radiographic participants, 95.2% selected either "Strongly Agree" or "Agree", 0.91% selected "Disagree" and no participants selected "Strongly Disagree." Radiographic technologist participants either strongly agreed or agreed that x-rays, CT and MRI scans were 90.2%, 90.3% and 92.5%, respectively, beneficial in learning anatomy and radiology. For the same question, 92.0%, 91.1% and 90.1% of non-radiographic technologist participants either strongly agreed or agreed that x-rays, CT and MRI scans, respectively, were beneficial in learning anatomy and radiology.

DISCUSSION

Currently, medical education in the United States is in an era of intensive curricular reform. Further, the prevailing trends in gross anatomy are decreasing the amount of time for dissection while increasing the time for analyzing medical images and for self-directed learning and small-group activities (Gunderman and Wilson, 2005; Lufler et al., 2010; Gunderman and Brown, 2013; Phillips et al., 2013; Rubin and Blackham, 2015). Although every medical student dissects a human cadaver, the actual time devoted to wet laboratory work continues to decrease (Drake et al., 2009; Granger and Calleson, 2007; Rizzolo et al., 2010; Vasan et al., 2011), and radiology is being used more in medical school to teach anatomical structures and relationships (Ganske et al., 2006; Marom and Tarrasch, 2015). In addition to redesigning medical curricula to focus on instruction by organ systems, more emphasis has been placed on "vertical integration" topics, such as pathology, that incorporate multiple subjects of the basic sciences into a clinical setting that spans across all years of medical education, including residency and continuing medical education (Eisenstein et al., 2014). However, human gross anatomy and laboratory dissection are often a medical student's first exposure to pathological presentation of disease in his or her very "first patient" (i.e. the cadaver). Medical imaging allows students to directly compare gross anatomy to radiographic images, and their participation in the acquisition of radiographic images from cadavers prior to anatomical dissection allows students to gain a first-hand perspective of their patient's anatomy while observing the pathological presentation of disease.

Medical practice has become an arena of interdisciplinary teamwork. In order to deliver highly-specialized approaches to medical diagnosis and treatment, the healthcare industry increasingly depends on team- based collaboration between specialized healthcare professionals to address a patient's needs. Thus, medical education is encouraged to follow the same path (Hall and Weaver, 2001; Gunderman et al., 2003; Chen et al., 2010; Huitt et al., 2015). Radiological imaging consists of a unique array of diagnostic techniques (i.e., x-ray, CT, MRI, fusion technology, ultrasound, 3-D imaging, etc.) and analytical software that is used

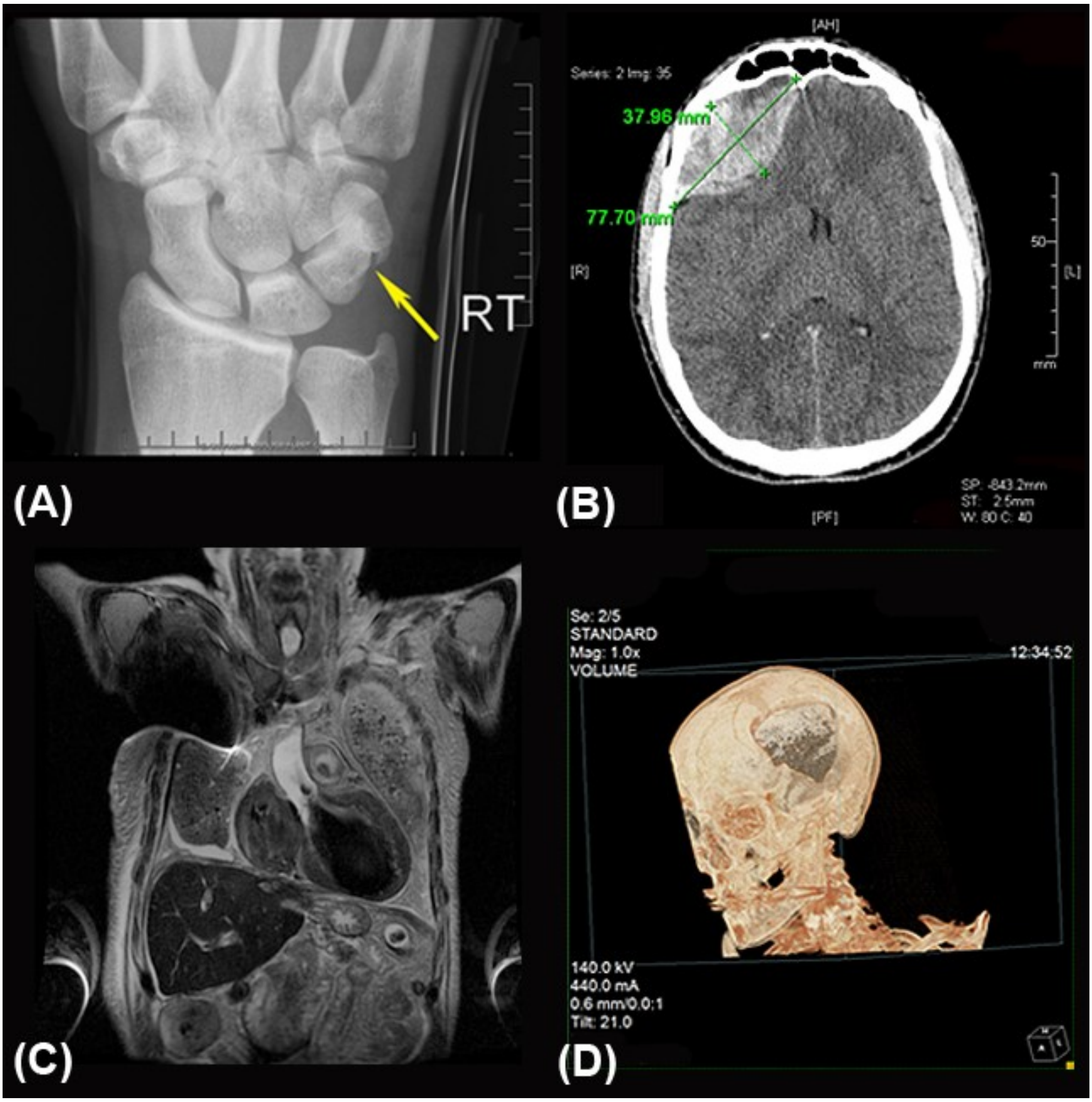

Fig 2. Images produced by Small Group Interdisciplinary Teams. (**A**) Plain X-ray image of the right (RT) carpus using AP projection. A small facture of the scaphoid bone is observed (yellow arrow). (**B**) Axial head CT showing an epidural hematoma measuring 37.96 mm by 77.70 mm. (**C**) T-2 Wtd coronal MRI showing viscera of the thorax and abdomen. (**D**) 3-D CT reconstruction of the skull that was created by students showing a "gap" where a section of a patient's skull was removed to relieve compression of brain tissue secondary to hemorrhage.

throughout medical practice, and it regularly requires interprofessional collaboration (Ganske et al., 2006; Prezzia et al., 2013; Orsbon et al., 2014). As the focus of education turns towards team- and problem-based learning, medical education curriculum is encouraged to include opportunities for students to work on an interdisciplinary team (Hall and Weaver, 2001; Gunderman et al., 2003). Medical education is relying less on didactic techniques and more on small-group, hands-on learning (Collins, 2008; Vasan et al., 2008; Pratten et al., 2014). Small team-based sessions have been shown to improve student exam scores (Vasan et al., 2011; Burgess et al., 2012) and decrease course failure rates (Nieder et al., 2005). These data suggest that small-group sessions provide crucial instruction for students benefit from additional learning beyond textbook readings and lectures (Nieder et al., 2005; Phillips et al., 2012b).

To address these issues, a novel program was developed (Talarico, 2010) that integrates the disciplines of human gross anatomy and radiology in the study of human structure. This program included small groups of individuals at various stages of medical education and different fields of medical

Fig 3. Small Team-Based medical imaging experience. (**A**) Radiography and non-radiography student use hands-on problem-solving and discussion to determine how to obtain the best x-ray image of a patient lower extremities. (**B**) A student doctor uses his knowledge of anatomy and radiology to discuss high-resolution medical images with non-medical students. Team members teach each other as they learn to interpret images. (**C**) Interdisciplinary team members work together to position their patient in the MRI scanner to obtain high-quality images using FLAIR and STIR techniques. (**D**) Group members discuss and interpret CT scans of their patient in real time, and problem-solve to obtain the best images of normal anatomy and anomalies discovered during this hands-on activity.

practice. In particular, premedical and medical students worked alongside student radiographers to learn from physicians, anatomists, professional radiographers, and other healthcare specialists as they obtained high-quality images of cadavers and discussed the findings. Additionally, students experienced firsthand the importance of positioning mechanics for obtaining radiographic images of the non-responsive patient – a scenario that is not uncommon in the clinical setting. Then, these small groups systematically discussed the radiographic images from their cadavers. This resulted in a comfortable environment for team-based collaboration. Radiography students were able to teach imaging techniques to medical students, and premedical and medical students were able to teach human anatomy under professional supervision.

Through the use of Likert-scale surveys, comprehensive feedback was obtained to assess multiple aspects of the program (Tables 1 and 2). Overall, these data suggest that participants found the experience beneficial and worth recommending to peers. Laboratory sessions were helpful in understanding radiographic position, technique and equipment, and these sessions enhanced knowledge of skeletal anatomy, visceral anatomy, anatomical relationships and sectional anatomy. One participant appreciated the small-group discussions in approaching anatomical dissection and imaging as a “multi-dimensional process”, requiring critical analysis of anatomy while simultaneously appreciating the pathological differences that made each cadaver unique from the others.” A student wrote that “experiencing human anatomy first-hand was unlike anything I’ve ever read in a book. Seeing, touching, and exploring helped me gain genuine insight into how the body functions and how well-constructed but delicate and fragile [the human body] is.” Radiography students commented on the benefits of working alongside medical professionals and medical students, stating that they were able to “obtain a breadth of knowledge that they may not have otherwise experienced in the professional world.” Additionally, the program helped expose students early in their medical career to the concepts of pathology, and they were able to observe the direct application to radiological techniques in capturing and interpreting radiological imaging. Another student described the radiological images as "roadmaps" during the dissection process; helping them look for key anatomical and pathological findings. The program provided quality images that the participants found to be helpful in the formal course work (i.e., didactic and laboratory sessions).

These data suggest that participants benefitted from the integration of cadavers with radiographic imaging in forming small-group discussions to create an excellent learning experience that provides a foundation for understanding the unique diagnostic tools available in healthcare. During small-group sessions, radiographers, anatomists and medical doctors provided professional discussion about significant pathology and anatomical relationships from the radiological images. It was noted that medical students expressed gratitude for the technical expertise of the student radiographers, and that radiography students expressed an appreciation of pathological explanation and clinical anatomy from student physicians during medical imaging review sessions. Radiography students instructed medical students in the principles of radiographic imaging that lead to greater understanding and appreciation for the quality of imaging. The medical students and professionals taught gross anatomy and image interpretation to the radiography students. This form of peer teaching provides instruction for learners, and data suggest that it strengthens the instructor’s understanding, competency and confidence in the given field (Krych et al., 2005; Rego et al., 2009; Burgess et al., 2014). For example, one orthopedic specialist commented: “I enjoyed reviewing the anatomy with students. In practice, I generally do not get the opportunity to see anatomy utilizing the entire body. This course is an excellent review!” These data support the hypothesis that interdisciplinary small-group curriculum creates a positive environment for medical student instruction and learning, and this creates an early appreciation for team-based approach commonly used in the healthcare field to deliver the most effective care for a patient (Hall and Weaver, 2001; Chen et al., 2010; Huitt et al., 2015).

Additionally, the data in the present study confirm that cadavers were treated with professionalism and respect, and participants appreciated the holistic approach of practicing the multiple layers of patient care. The medical student’s care for a cadaver has many parallels to the experience of a healthcare professional providing care for a clinical patient. The cadaveric laboratory dissection provides a unique opportunity for first-year medical students to understand and practice aspects of professionalism that are difficult to experience prior to clerkship rotations (Escobar-Poni and Poni, 2006). Multiple radiological and medical students commented on the unique perspective of working with cadavers and seeing them as a patient with a social and medical history that provided valuable context to the pathological conditions that they encountered during the medical imaging process and dissection.

There were several noteworthy strengths of this study. First, data were collected from a large cohort of study subjects (n=734). Additionally, data were collected over ten years from participants that came from a wide variety of backgrounds (Fig. 1). Third, the survey instrument was able to assess individual involvement and small-group interdisciplinary education, as well as the outcomes and impacts of this novel activity. Finally, this small-group program produced resources for use in anatomy lab, anatomy lecture and radiography courses while simulating a real clinical scenario of obtaining radiographic images of a non- responsive patient. With the data collected over ten years from participants that came from a variety of backgrounds, we were able to assess the involvement in a small-group integrated course focused on interdisciplinary education.

It must be noted that there is a limiting factor with this study. Although data were collected from a large cohort over the course of ten years, this program has only been introduced at the IUSM-NW location. It is possible that if this program were used at other schools and geographic locations that the results might vary from the present work. However, the make-up of the subjects in the present study was mixed – local, regional, national and international – suggesting that this might not be a factor influencing the results.

The present program here, as well as that previously outlined (Talarico, 2010), can serve as a novel model for interdisciplinary team-based learning of human anatomy and radiology. Future studies in anatomical education and sciences can build on the foundation of this study. For example, in addition to a multi- disciplinary approach to anatomical dissection, the study of gross anatomy has advanced to include technologies and programs (i.e., BodyViz, Anatomage, Sectra) that provide a precise focus on organ systems and structure. However, studies are lacking that compare the use of such technologies versus traditional dissection and imaging techniques and their effects on student learning (or outcomes). The protocol outlined within the present work can be utilized to compare the usefulness of these new technologies with traditional methods of instruction in human gross anatomy.

CONCLUSION

This study assesses a novel teaching method that uses the process of obtaining radiographic images of cadavers through the interaction of small interdisciplinary teams of student doctors and student radiographers to enhance learning of human gross anatomy and radiology. This program can serve as a model for other institutions to prepare healthcare students for the inter-professional clinical setting in the face of curricular changes in anatomical education.

ACKNOWLEDGEMENTS

The authors most gratefully acknowledge the contributions and gifts of the anatomical donors (i.e., first patients) and their families to medical education and scientific research, and the dedication and respect of the students toward their first patients and their patients' families, as well as this study. The authors also express sincere appreciation to Mary Ann Hansen and Luis O. Marquez, Current Director and former Director, respectively, of Imaging Service at Methodist Hospitals South Lake Campus (Merrillville, IN), and Rhonda C. During, CT Technologist at Methodist Hospitals South Lake Campus, for their assistance in this study. Finally, the authors are also grateful for the participation of faculty, namely, Robin J. Jones, Clinical Associate Professor, and Vesna Balac, Director and Clinical Assistant Professor, in the Department of Radiologic Sciences, of the Indiana University Northwest (Gary, IN).

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