Enhancing surgical expertise: 3D anatomy's role in residency programs

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SUMMARY

Current virtual reality (VR) technology allows for the creation of instructional video formats that incorporate three-dimensional (3D) stereoscopic footage. Combined with 3D anatomic dissection, any surgical procedure or pathology can be represented virtually to supplement anatomical learning and surgical preoperative planning. The aim of this study was to evaluate the impact of virtual reality anatomical teaching. A prospective case-control study was performed. After a prerequisite anatomical knowledge assessment, participants were randomized in two groups: stereoscopic anatomical teaching program versus classic teaching with anatomical and surgical books of thoracic brachial outlet syndrome, and its related anatomy. Then, students completed a written anatomical test to assess their basic knowledge in vascular anatomy. Pre- and post-test performances were analyzed with independent t-tests for total score assessing basic anatomical knowledge, anatomical relationships and clinical inference.

Before performing the teaching, the 20 students included were homogenous in term of total exam mark in abdominal aorta (mean 78,78% vs 76,34%) and carotid artery evaluations (mean 78,57% vs 74,76%). After the course, there statistical differences (p<0,05) between the stereoscopic-3D.video group (n= 10, 90%) and classical-teaching group concerning the total exam mark, descriptive anatomy, anatomical relationships and clinical inference skills. All the students thought this method seemed indispensable to their anatomical training course (100%). The teaching video with 3D stereoscopy seems to be a useful and complementary teaching tool that is approved by the residents themselves. In a future study, it will be necessary to evaluate the contribution of this teaching in the long term.

Key words: Pedagogy – Vascular Surgery – Anatomy – 3D – Simulation

INTRODUCTION

Human anatomy is one of the fundamental disciplines of the medical curriculum. Its teaching combines lectures, dissections and commented illustrations and texts since the sixteenth centu-

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ry and the work of Andreas Vesalius (Cobolet et al., 2014). 500 years later, teaching this specialty is a delicate undertaking. Almost all the anatomical learning is provided in the early stage of the medical curriculum (Bernard et al., 2020a). The students learn the basics without any clinical and surgical experience. At the beginning of residency, a second anatomical course is required to learn and practice surgery, such as vascular surgery. This includes a refresher course on surgical and clinical based-anatomy.

The recent growth of digital technologies offers new perspectives for medicine and the clinical follow-up of patients (Bernard et al., 2021; Satava et al., 1995), surgeries and surgical anatomical teaching (Bernard et al., 2019; Bernard et al., 2020b). Students can now view videos in 3D with their smartphones. The use of 3D stereoscopy is better than 2D to stimulate the student's visuospatial cognition (Bernard et al., 2018b; 2020b) and to learn anatomy (Bogomolova et al., 2020). We have shown in a previous study that this technology helps medical students to better understand anatomical relationships and clinical inference (Bernard et al., 2020a). The ability for students to visualize in 3D anywhere enables us to offer digital anatomo-surgical course tutorials on the go and challenge previous ways of accessing anatomical knowledge. In order to obtain certified anatomy videos, we undertook their production with residents, as well as anatomical and vascular teachers. These videos have been added as an extra tool to traditional teaching methods since 2016 at the University of Angers. The objective of this study is to evaluate the pedagogical value of 3D stereoscopic video compared to the traditional study method during residency.

In order to learn surgical anatomy, residents need to assist senior surgeons as often as possible. The repetition allows him/her to increase his/her mental representation of the surgery (Gimm et al., 2019; Sosa et al., 2007). Then, he/she can learn in the anatomical and/or simulation centre and perform surgeries step-by-step with the help of a mentor over a period of time (Scott et al., 2008). This teaching method is good, and many surgeons have been successfully trained this way. However, it has its limits, such as the need to find a "mentor" (Solorzano et al., 2010), to be in a reference university centre or to attend conferences with hidden costs (Miahi et al., 2019; Palazzo et al., 2016). Moreover, the increase of the number of residents accepted in the vascular surgery residency program raises the training issue, particularly as surgeries are scarce (too many residents for few surgeries). As a result, we have developed an anatomo-surgical 3D teaching program that can be displayed in a virtual-reality, mobile and web application. This application can be used in a pre-operative context. The aim of this study was to compare this approach to a traditional teaching method.

MATERIAL AND METHODS

Study design and population

This study is a prospective study conducted between September 2020 and June 2021. The study population is composed of surgical residents from the Faculty of Medicine in Angers and Nantes (France). All participating residents received anatomical instruction and dissection study during their medical curriculum.

3D stereoscopic clinical based anatomical video

A 3D video with French commentaries was developed to teach the anatomy of the thoracic brachial outlet, explaining its syndrome and its surgical treatment (available at https://youtu.be/UdmakWf7us4, supplemental video material 1). It could be watched via a 3D television, smartphone or virtual reality headsets in a VR, mobile and web app (AKIVI, Anatomical Knowledge in Virtual Immersion, www.AKIVI.fr). We set up a pedagogical committee to provide anatomical content that met the requirements of the first years of vascular surgery training. A resident (AD, first author) was also involved in the creation of this pedagogical resource at each step to meet students' and teachers' requirements.

Study protocol

Before the beginning of the session, the residents were divided into 2 main groups by randomization in order to minimize selection bias (Fig. 1). All the students in the study had previously completed cadaver dissection over a period of two weeks. The "video group" learnt from a 3D stereoscopic video and the "traditional methods group" or "book group" studied a selection of reference books. Before the teaching session, both groups completed an anatomical quiz to evaluate their knowledge of vascular surgical anatomy (Supplemental Materials 1 through 8). Two groups were subjected to different learning methods for a duration of 3 hours each. The first group, referred to as the "Video Group", engaged in learning through a 3D stereoscopic video, offering a potentially more immersive educational experience. Conversely, the "Traditional Methods Group (Book Group)", utilized a selection of reference books, adhering to conventional text-based learning approaches (*Atlas d'anatomie humaine*, Elsevier-Masson, 2021; Chaikof and Cambria, 2014; *Gray's Atlas d'anatomie humaine*, Elsevier-Masson, 2021). Both groups received an equal amount of study time, facilitating a comparative analysis of the effectiveness of immersive versus traditional

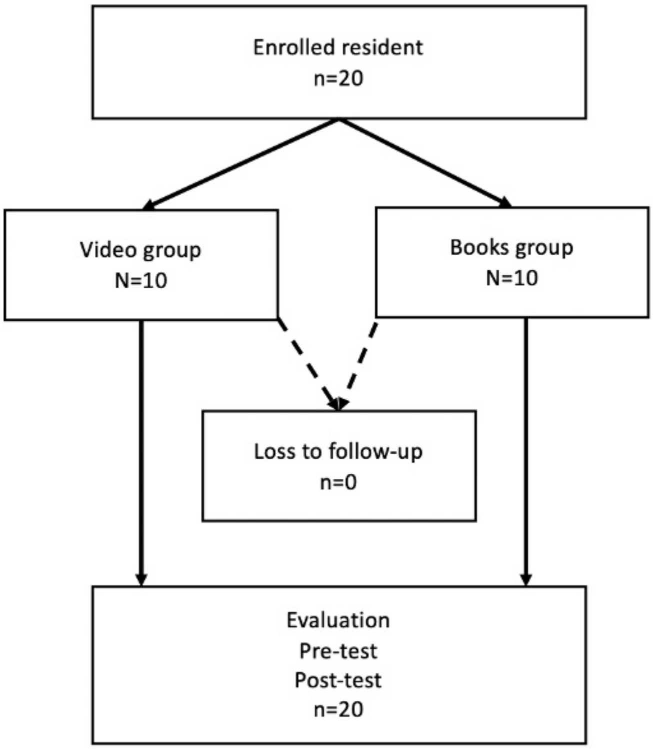


Fig. 1.- Cohort recruitment flowchart.

Table 1. Evaluation criteria for the video by residents using a Likert scale.

Q1	Do you find this teaching method easy to use
Q2	Does this teaching method seem similar to practicing it according to you
Q3	The possibility of reviewing the videos is a positive aspect of this method
Q4	The possibility of seeing dissections outside an anatomy laboratory is a positive point of this method
Q5	The possibility to see 3-dimensional dissections and to see the relationships and depth between organs is a positive aspecy of this method
Q6	The ability to see the surgery with commentary from the surgeon's point of view is a positive aspect of this method
Q7	Does this method (visible on mobile, computer, virtual reality glasses) seem indispensable to you in your anatomical training course
Q8	"I learned more with the help of the 3D video than during the practical dissection work dissection".
Q9	"I preferred virtual visualizations to cadaver dissections".

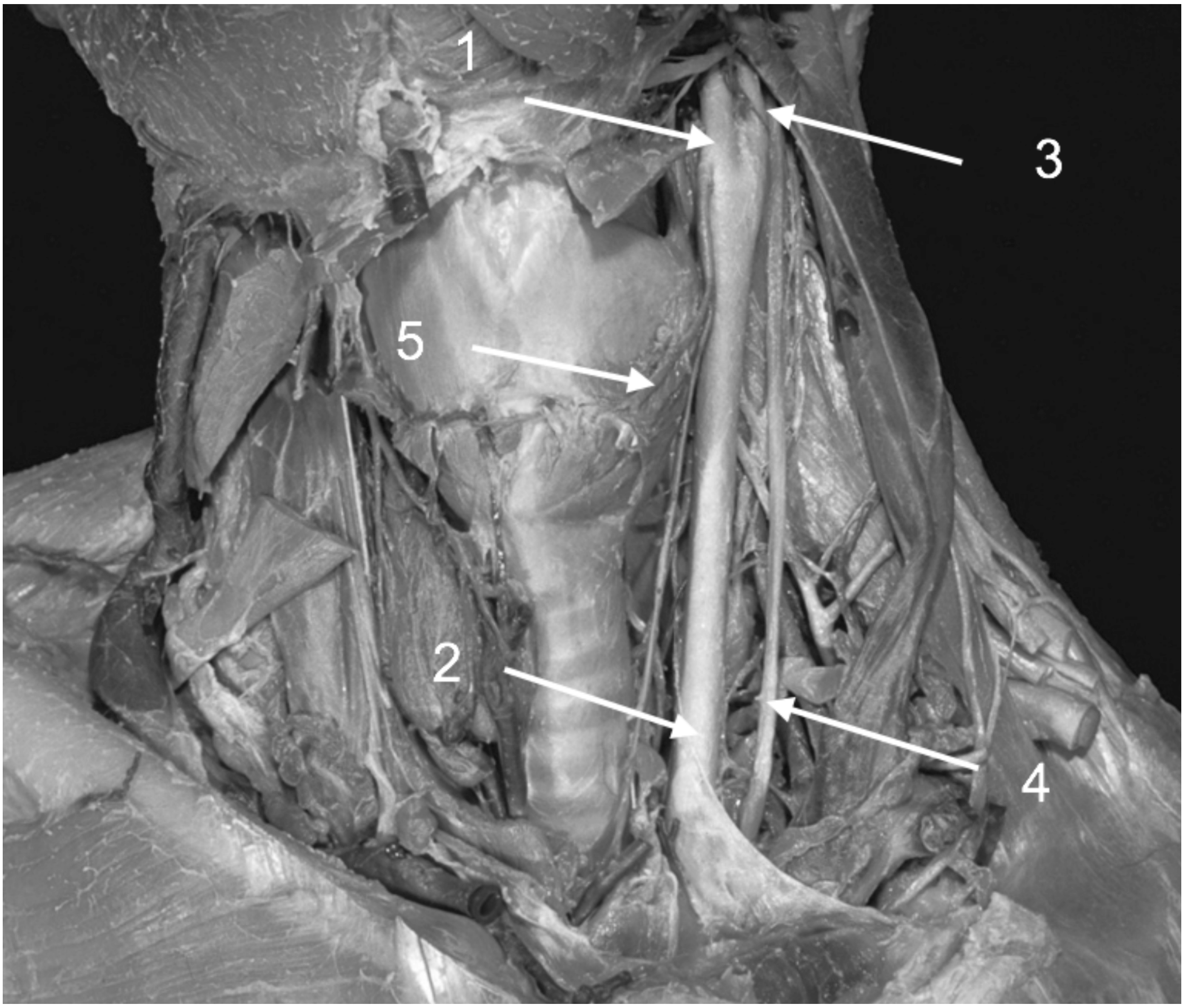
learning methods. Then, the students answered questions about the thoracic brachial outlet one month later. The video group also completed a satisfaction questionnaire about the 3D experience (Table 1). This quiz was not mandatory for the students. By agreeing to take it, the students agreed to participate in the study. Each student was evaluated individually.

3D students feedback

After watching the video, the students in the video group completed a 5-point Likert scale evaluation form ("strongly disagree", "somewhat agree", "don't know", "somewhat agree" and "strongly agree"). They also had the opportunity to select positive and negative aspects of the video.

Knowledge evaluated	Questions	Type
Descriptive anatomy	Q1 – Legend 1 = Internal carotid artery	R/W
	Q2 – Legend 2 = Common carotid artery	R/W
	Q3 – Legend 3 = External carotid artery	R/W
	Q4 – Legend 4 = Vagus nerve	R/W
	Q5 – Legend 5 = Inferior thyroid artery	R/W
	Q6 - Legend 1 = Internal carotid artery	R/W
	Q7 - Legend 2 = Sternocleidomastoid muscle	R/W
	Q8 - Legend 3 = Homohyoid muscle	R/W
	Q9 - Legend 4 = External carotid artery	R/W
	Q10 - Legend 5 = Common Carotid artery	R/W
Anatomical relationships	Q11 - The carotid bifurcation corresponds to the division of the common carotid artery into the internal and external carotid arteries.	R/W
	Q12 - The carotid bifurcation is located above the sternocleidomastoid muscle.	R/W
	Q13 - The sternocleidomastoid muscle divides the cervical region into an anterior and a lateral region.	R/W
	Q14 - The carotid bifurcation is located at the level of the 3rd cervical vertebra.	R/W
	Q15 - The right and left carotid bifurcations are similar.	R/W
	Q16 - The carotid bifurcation is located in a triangular muscle space.	R/W
	Q17 - The sternocleidomastoid, homohyoid and digastric muscles help to identify the carotid bifurcation.	R/W
	Q18 - The external carotid artery is anteromedial to the carotid bulb.	R/W
	Q19 - The internal carotid artery is posterolateral to the carotid bulb.	R/W
	Q20 - The four previous propositions are correct.	R/W
	Q21 - The internal carotid artery has an extracranial and intracranial course.	R/W
	Q22 - The internal carotid does not have any collaterals in its cervical portion.	R/W
	Q23 - The internal carotid artery vascularises the cervico-facial region.	R/W
	Q24 - The superior thyroid artery is a collateral branch of the internal carotid.	R/W
	Q25 - The internal carotid artery arises from the carotid bulb.	R/W
	Q26 - The internal jugular vein is located laterally to the carotid axis.	R/W
	Q27 - The thyro-lingual-facial venous trunk is a branch of the external jugular vein.	R/W
	Q28 - The X nerve or vagus nerve is anterior to the vascular axis of the neck.	R/W
	Q29 - The XII nerve or hypoglossal nerve may cross anteriorly to the carotid bifurcation.	R/W
	Q30 - The carotid glomus is dissected to release the origin of the internal carotid artery.	R/W
Reasoning, physiopathology, clinical outcomes	Q31 - Carotid massage can lead to syncope.	R/W
	Q32 - The carotid bifurcation is an area of curage in cancers of the cervical region.	R/W
	Q33 - A carotid murmur may be related to carotid stenosis.	R/W
	Q34 - Internal carotid surgery is indicated for internal carotid stenosis greater than 70%.	R/W
	Q35 - Angioscanner and echodoppler are examinations to assess carotid stenosis.	R/W
	Q36 - Carotid clamping during endarterectomy may damage the vagus nerve.	R/W
	Q37 - Carotid dissection above the bifurcation may damage the hypoglossal nerve.	R/W
	Q38 - As the hypoglossal nerve passes posteriorly and medially, it may be injured in the event of carotid clamping.	R/W
	Q39 - The presence of intracranial collaterals of the internal carotid artery allows carotid clamping to be performed with clinical or paraclinical monitoring of cerebral perfusion.	R/W
	Q40 - Postoperative haematoma after endarterectomy may be due to the presence of small perforating branches emerging from the common carotid artery	R/W
	Q41 - Preoperatively for an endarteriectomy, it is necessary to ensure that the patient is on antiplatelet therapy, that he has had two paraclinical imaging examinations (ultrasound, CT and/or MRI), as well as an ENT examination to look for vocal cord paralysis.	R/W
	Q42 - Surgically the posterior belly of the digastric muscle borders the carotid region above.	R/W

Supplemental material 1. Anatomical evaluation of carotid artery. R/W: right/wrong items.



Supplemental material 2. Anatomical view of carotid artery (Q1-Q5) from David Lee Basset stereoscopic Atlas. Creative Commons Attribution-Noncommercial-Share Alike 3.0 United States License.

Pre- and post-course testing

This pedagogical approach aims to help students achieve the acquisition of anatomical knowledge and understanding of vascular anatomy and its surrounding structures. The quiz consisted of several multiple-choice questions (MCQs). The post-test in this study took place one month after the participants studied the material using the video or the book. This timing was chosen to evaluate the long-term retention of knowledge gained through the different learning methods. According to the pedagogical committee, three key skills had to be evaluated: fundamental knowledge, structural relationships in space, and clinical and surgical relevance (Table 2). The same quiz on the above topics was given to both groups. For each group, an average score out of 100 was calculated for each question, as well as the percentage of correct answers.

Several precautions were taken to minimize possible biases in the analysis: (A) all data were collected using designated serial numbering without any identifying information; (B) all exams were analysed by an anatomist who was not involved in the teaching phase of the study, did not know the students and was blind to the students' designated group; (C) the resident who contributed to the design of the pedagogical videos did not participate in the delivery of the instructional sessions or the evaluation process, to prevent any potential influence on the study outcomes or the opinions of other participants. Data analysis was performed in SPSS (version 17.0). Paired t-tests were used to compare pre- and post-test perfor-

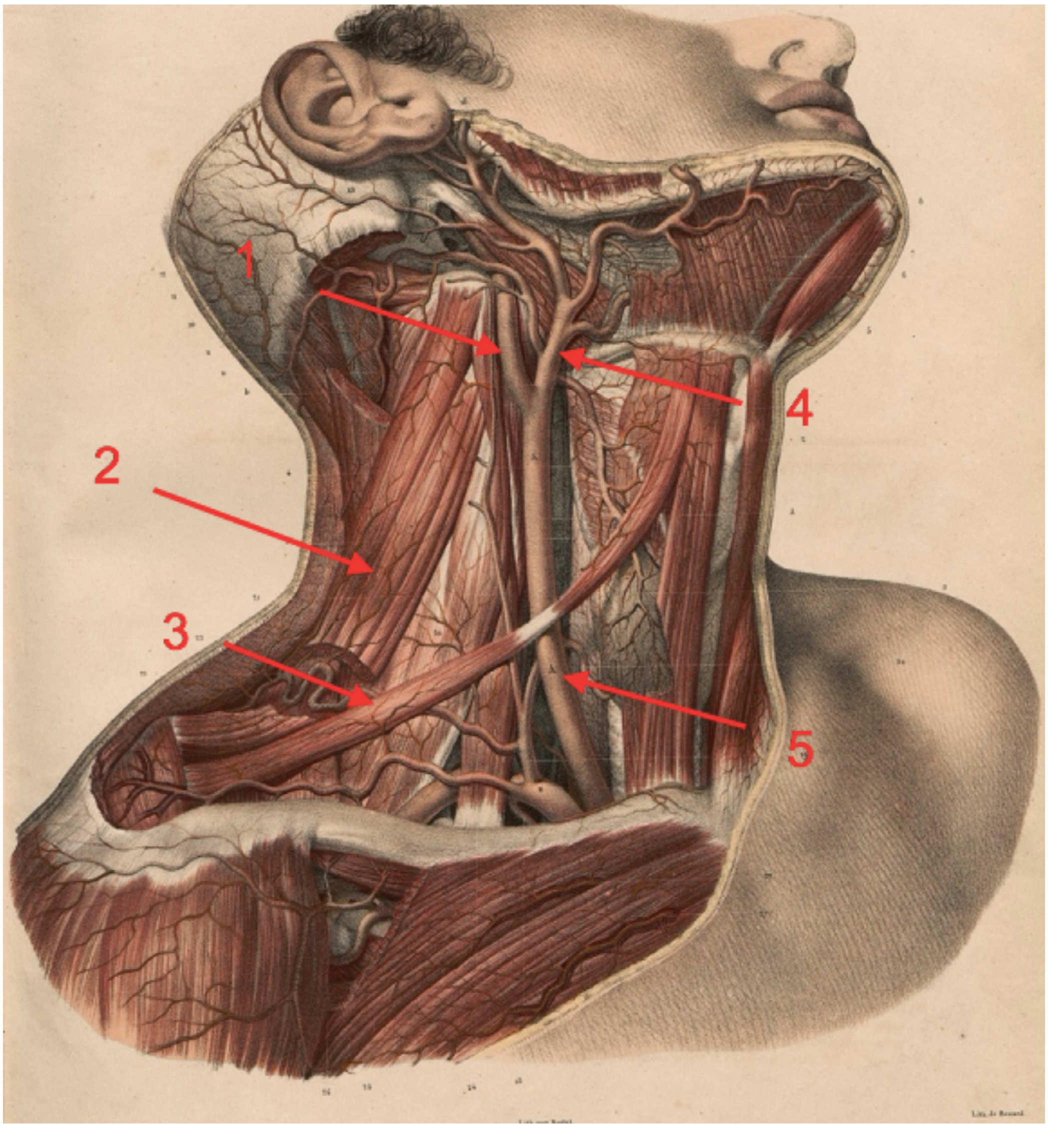
Table 2. Anatomical evaluation of thoracic brachial outlet. R/W right / wrong items.

Knowledge evaluated	Questions	Type
Descriptive anatomy	Q1 - Legend 1 = Clavicle	R/W
	Q2 - Legend 2 = Subclavian muscle	R/W
	Q3 - Legend 3 = Subclavian vein	R/W
	Q4 - Legend 4 = Axillary artery	R/W
	Q5 - Legend 5 = Brachial plexus	R/W
	Q6 - Legend 1 = Right common carotid artery	R/W
	Q7 - Legend 2 = Subclavian artery	R/W
	Q8 - Legend 3 = Pectoralis major muscle	R/W
	Q9 - The clavicle is severed.	R/W
	Q10 - The first rib is not visible on this view.	R/W
	Q11 - The cervical thoracic brachial outlet is defined by 4 successive spaces.	R/W
	Q12 - The scalene pathway is part of the cervical thoracic brachial pathway.	R/W
	Q13 - The costo-clavicular canal is part of the thoracic brachial outlet.	R/W
	Q14 - The supra pectoral tunnel is part of the thoracic brachial parade.	R/W
	Q15 - The humeral neck is part of the thoracic brachial outlet.	R/W
Anatomical relationships	Q16 - The costoclavicular canal is located between the distal part of the clavicle and the first rib.	R/W
	Q17 - The anterior and middle scalene muscles are elements of the costoclavicular canal.	R/W
	Q18 - The subclavian vein is medial to the subclavian artery.	R/W
	Q19 - The subclavian artery lies outside the C8T1 nerve roots.	R/W
	Q20 - The subclavian muscle passes in front of the lower surface of the clavicle.	R/W
Reasoning, physiopathology, clinical outcomes	Q21 - Thoracic brachial outlet syndrome is a chronic pain syndrome.	R/W
	Q22 - The thoracic outlet syndrome has a dynamic component.	R/W
	Q23 - The thoracic brachial outlet syndrome is caused by compression of the vascular and nervous structures.	R/W
	Q24 - The costo clavicular canal is part of the thoracic brachial outlet.	R/W
	Q25 - Resection of the clavicle is one of the treatments for thoracic brachial outlet syndrome.	R/W
	Q26 - Resection of the first rib is the gold standard surgical treatment for thoracic brachial outlet syndrome.	R/W
	Q27 - The section of the pectoralis minor muscle can be associated with the resection of the first rib.	R/W
	Q28 The Roos axillary approach allows for resection of the first rib.	R/W
	Q29 The Roos axillary approach passes in front of the pectoralis minor muscle.	R/W
	Q30 None of the four previous proposals is correct.	R/W

mance. Between-group performance and demographic comparisons at baseline were analysed using independent t-tests. A p-value of less than 0.05 was considered significant. The data analysis was conducted in SPSS (version 17.0). Descriptive statistics were presented in the form of frequencies and percentages.

Role of funding source

The AKIVI project was supported by University of Angers' Health Department and its 3D-lab, the Pays de la Loire Department Council and SATT oust valorisation. This funding made possible the production of the videos and the creation of the application.



Supplemental material 3. Anatomical view of the carotid artery (Q6-Q10) Illustration for Traité complet de l'anatomie de l'homme comprenant la médecine opératoire (1831-1854) by Jean-Baptiste Marc Bourgery. Public domain.

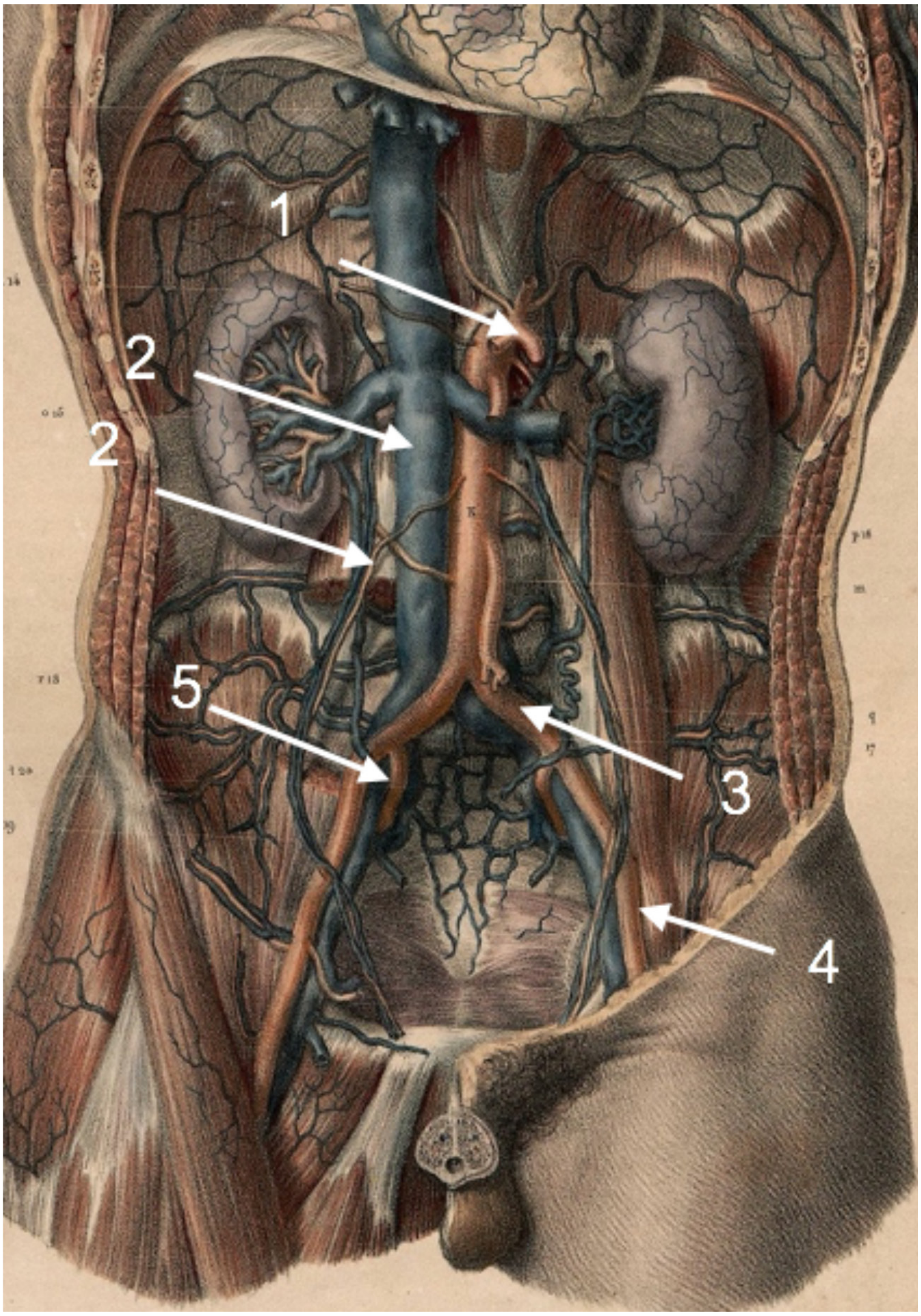
RESULTS

Population

A total of 20 residents were enrolled in the study and successfully completed the course in the laboratory of Angers, France. All participants were surgical residents. All completed the study and followed up. The video group and books group were each composed of 10 residents who completed the first cycle of medical studies in different French universities. They were residents in different surgical specialties. Among the residents in the video group, there were 6 males and 4 females from Angers (n=3), Nantes (n=1), Marseille (n=1), Paris, (n=1), Caen (n=1), Toulouse (n=1), Amiens (n=1) and Reims (n=1). In this group, there were two vascular surgery residents (2nd and 3rd year), two visceral surgery residents (2nd and 3rd year), one maxillofacial surgery resident (1st year), one ophthalmology resident (1st year), two orthopedics surgery residents (1st and 5th year), one ENT surgery resident (4th year) and one urological surgery resident (1st year). Among the book group, there were 5 males and 5 females from Angers (n=2), Nantes (n=1), Paris (n=2), Rennes (n=1), Poitiers (n=1), Caen (n=1), Toulouse (n=1) and Bordeaux (n=1). In this group, there were two vascular surgery residents (two in 1st year), two thoracic and cardiovascular surgery residents (1st and 3rd year), two visceral surgery residents (2nd and 3rd year), one neurosurgery resident (1st year), one gynaecology-obstetrics resident (4th year), one ENT surgery resident (2nd year), and one urological surgery resident (2nd year).

Knowledge evaluated	Questions	Type
Descriptive anatomy	Q1 – Legend 1 = Celiac trunk	R/W
	Q2 – Legend 2 = Inferior vena cava	R/W
	Q3 – Legend 3 = Left Primitive Iliac Artery	R/W
	Q4 – Legend 4 = Left internal iliac artery	R/W
	Q5 – Legend 5 = Right external iliac artery	R/W
	Q6 - Legend 1 = Sub-renal aorta	R/W
	Q7 - Legend 2 = Urethra	R/W
	Q8 - Legend 3 = Iliac muscle	R/W
	Q9 - Legend 4 = Left renal artery	R/W
	Q10 Legend 5 = Inferior mesenteric artery	R/W
	Q11 - The abdominal aorta gives rise to parietal, visceral and urogenital collaterals.	R/W
	Q12 - The subrenal abdominal aorta gives rise to the lumbar arteries.	R/W
	Q13 - Each common iliac artery divides into an internal iliac artery and an external iliac artery.	R/W
	Q14 - The external iliac artery vascularises the pelvic viscera.	R/W
	Q15 - The inferior phrenic arteries are collaterals of the subrenal abdominal aorta.	R/W
Anatomical relationships	Q16 - The aorta enters the abdomen at the level of the T12 vertebra.	R/W
	Q17 - The abdominal aorta is retroperitoneal and follows the right edge of the vertebral bodies.	R/W
	Q18 - The abdominal aorta divides, at the level of the L4 vertebra, into the common iliac arteries.	R/W
	Q19 - The median sacral artery arises at the level of the subrenal abdominal aorta termination.	R/W
	Q20 - The celiac trunk arises at the anterior aspect of the abdominal aorta above the superior mesenteric artery.	R/W
	Q21 - The celiac trunk gives three branches: hepatic artery, splenic artery and left gastric artery.	R/W
	Q22 - The superior mesenteric artery arises at the posterior aspect of the abdominal aorta.	R/W
	Q23 - The inferior mesenteric artery arises from the anterior aspect of the abdominal aorta at the level of the L5 vertebra.	R/W
	Q24 - The arcade of Riolan is an anastomotic network between the superior mesenteric artery and the inferior mesenteric artery.	R/W
	Q25 - The renal arteries arise on the lateral aspect of the abdominal aorta on either side in L1.	R/W
	Q26 - They have a generally horizontal course, slightly oblique downwards and outwards.	R/W
	Q27 - The gonadal arteries arise on the anterolateral aspect of the abdominal aorta above the renal arteries.	R/W
	Q28 - The sub-renal abdominal aorta passes in front of the anterior common vertebral ligament.	R/W
	Q29 - Both the kidneys and the subrenal abdominal aorta are in a retroperitoneal position.	R/W
Reasoning, physiopathology, clinical outcomes	Q30 - Surgery on the subrenal abdominal aorta requires opening the root of the mesentery to mobilise the intraperitoneal contents	R/W
	Q31 - The suprarenal aorta approach is more complex as it requires approaching the duodenopancreatic block via the retroperitoneal route	R/W
	Q32 - Aortic prosthesis in the management of a subrenal aneurysm can lead to phrenic artery ischaemia resulting in ventilatory failure	R/W
	Q33 - The approach to the sub-renal aorta is easier on the right side	R/W
	Q34 - Aortic prosthesis in the management of a sub-renal aneurysm can lead to ischaemia of the superior mesenteric arteries resulting in mesenteric ischaemia	R/W
	Q35 - Ischaemia of the lumbar arteries can lead to necrosis of the surrounding skin	R/W
	Q36 - Ischaemia of the lumbar arteries can lead to paraplegia	R/W
	Q37 - The superior mesenteric artery passes in front of the right renal vein which explains the risk of varicocele	R/W
	Q38 - Superior mesenteric artery syndrome can result in renal failure	R/W
	Q39 - Compression of the left common iliac vein by the right common iliac artery is possible due to the anatomy of the aortic bifurcation: this is Cockett's syndrome (or May-Thurner syndrome)	R/W
	Q40 - Surgery on the aortic bifurcation may result in retrograde ejaculation due to damage to the superior hypogastric plexus	R/W
	Q41 - The left genital vein may be ligated and then cut during a retroperitoneal approach	R/W

Supplemental material 4. Anatomical evaluation of abdominal aorta. R/W: right/wrong items.



Supplemental material 5. Anatomical view of abdominal aorta (Q1-Q5). Illustration for Traité complet de l'anatomie de l'homme comprenant la médecine opératoire (1831-1854) by Jean-Baptiste Marc Bourgery. Public domain.

Pedagogical evaluation

Before taking the course, there were no statistical differences in abdominal aorta knowledge in terms of total score (78,8% vs 76,3%, p=0,162), descriptive anatomy (mean 81,3% vs 71,3%, p=0,293), anatomical relationships (mean 82,9% vs 74,3%, p=0,112), or clinical reasoning (mean 63,3% vs 61,7%, p=0,41) between the video and book group. Before taking the course, there were no statistical difference in carotid artery knowledge in terms of total score (78,6% vs 74,8%, p=0,162), anatomical relationships (mean 77,0% vs 78,0%, p=0,569), or clinical reasoning (mean 74,2% vs 70,0%, p=0,298) between the video and book group (Table 3).

After taking the course, there were statistical differences (p<0,05) between the video group and books group in terms of the total score (mean 90% vs 70,67%), descriptive anatomy (mean 90% vs 69,33%), anatomical relationships (mean 74% vs 54%), and clinical reasoning (mean 98% vs 81%) of thoracic brachial outlet (Fig. 2).

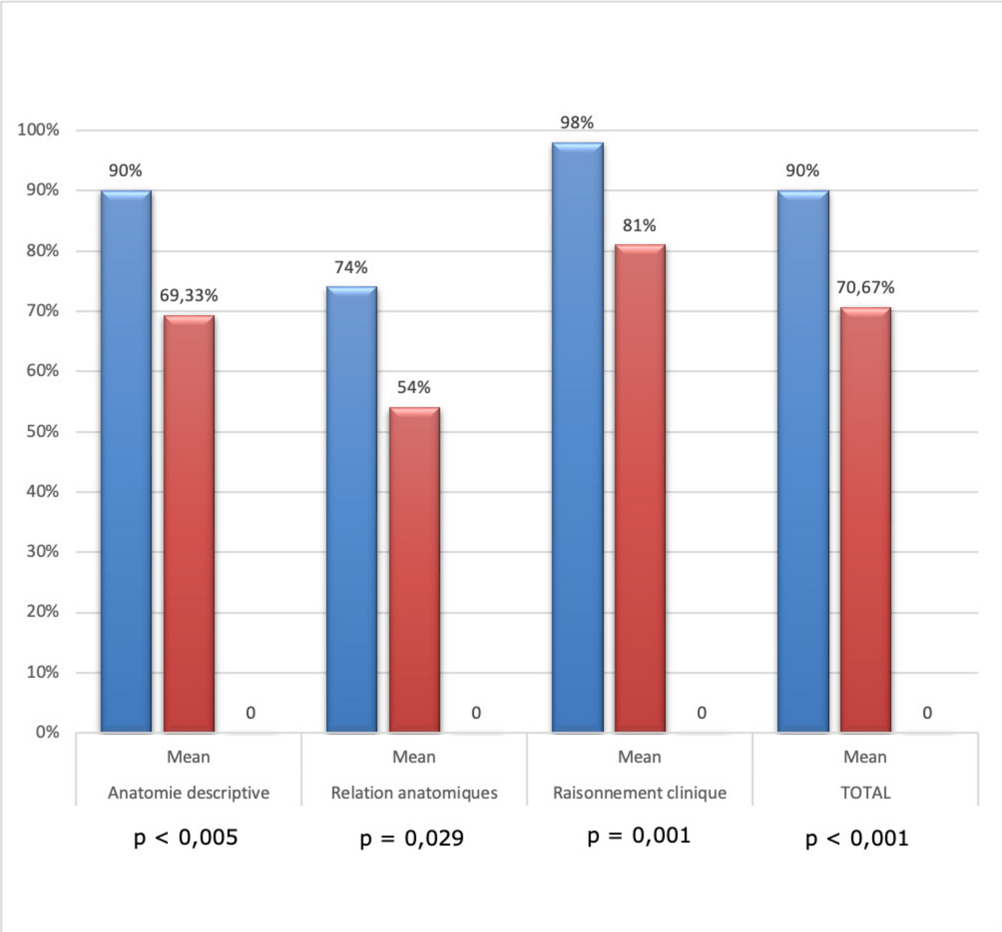


Fig. 2.- Post-test groups performances concerning Abdominal Aorta anatomy before the courses. Blue, video group; Orange, books group.

Satisfaction questionnaire (Table 1 and 4)

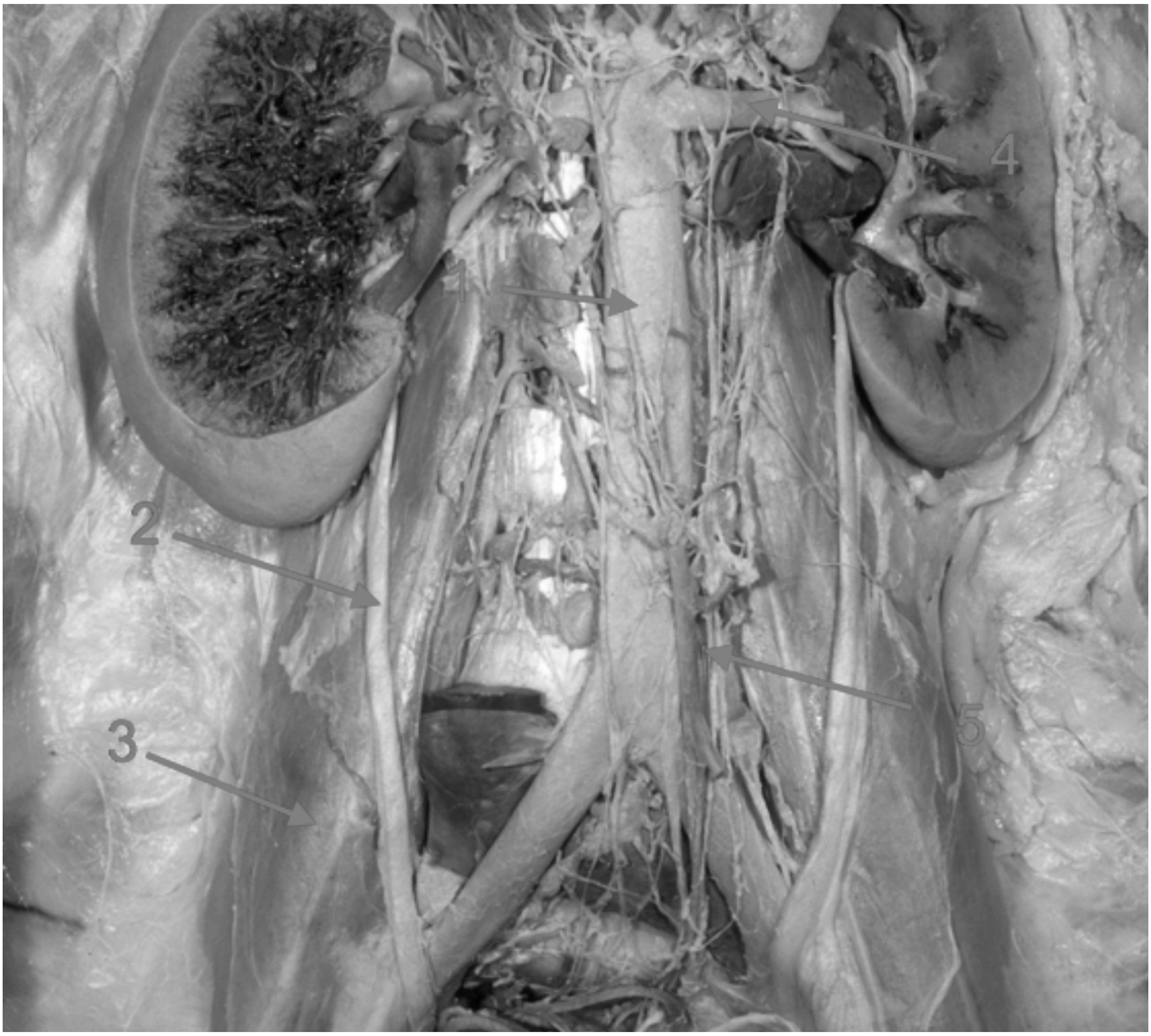
Regarding the residents who viewed the video of the thoracic brachial outlet and who answered the satisfaction questionnaire (n=10), results are summarized in Table 4. According to the Q1-Q2 responses, all of the residents thought that the video was an easy method to use (100%, Table 4) and close to practice. According to all residents, the possibility of reviewing the videos (100%, Q3, Table 4) and seeing dissections outside the anatomical laboratory (100%, Q4, Table 4), especially in 3-dimensional stereoscopy, was useful. Observing the relationships and depth between organs was positive (100%, Q5, Table 4). Moreover, stu-

Table 3. Group performance concerning abdominal aorta and carotid artery before instructional video or books. For each group, expression of the average score out of 100 then the average of the correct answers in percentage. This table demonstrates the group test performances before their exposure to the instructional video or books.

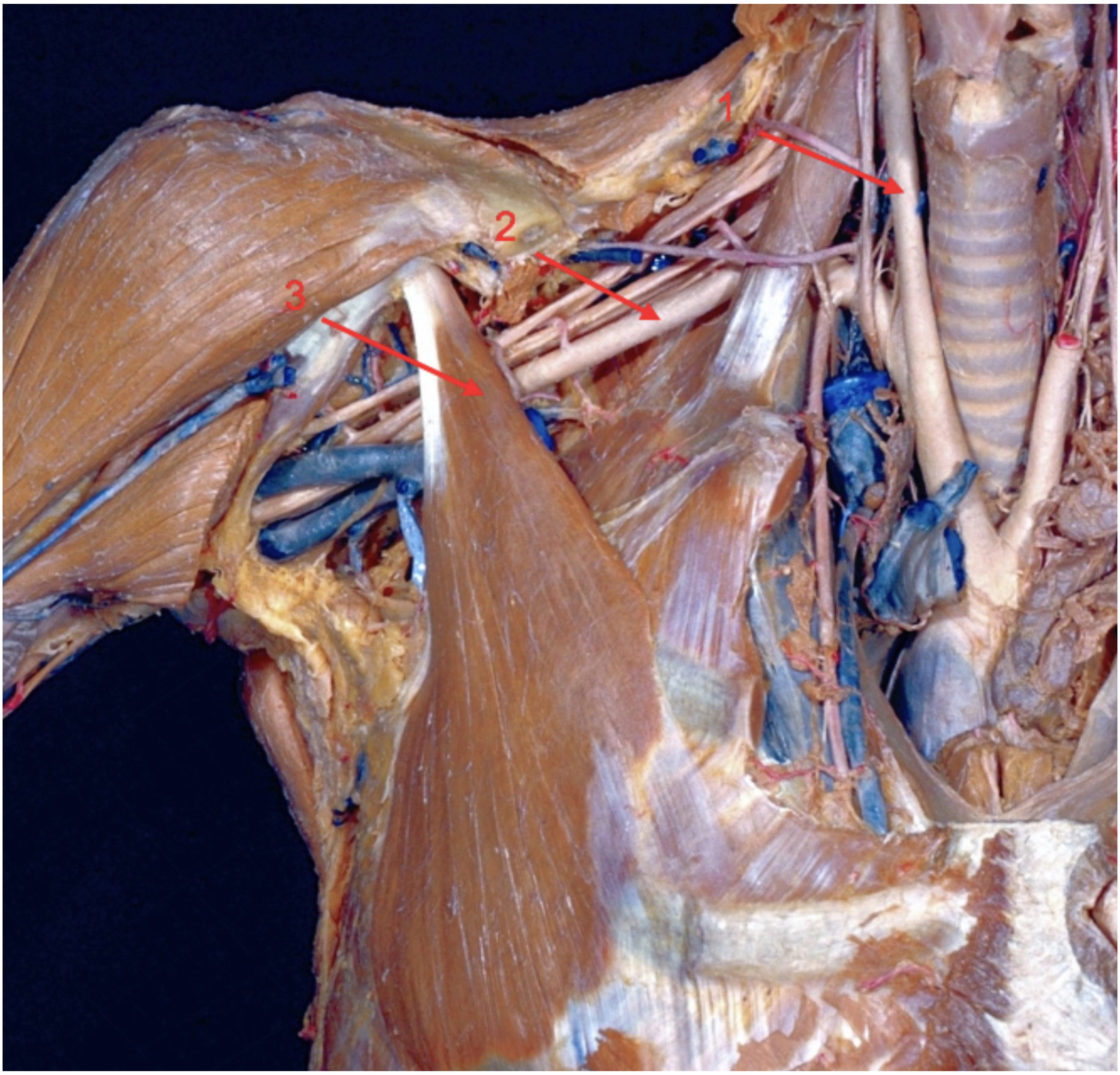
SUBJECT	KNOWLEDGE EVALUATED (MEAN OF GOOD RESPONSES)	PRE TEST VIDEO GROUP	PRE TEST BOOKS GROUP	P-VALUE
CAROTID ARTERY SUPPLEMENTAL MATERIAL 1-3	**Descriptive anatomy (Q1-Q10)**	**87,0%**	**74,0%**	**p = 0,028**
	Anatomical relationships(Q11-Q30)	**77,0%**	**78,0%**	**p = 0,569**
	Reasoning, physiopathology, clinical outcomes (Q31-Q42)	**74,2%**	**70,0%**	**p = 0,298**
	TOTAL	**78,8%**	**74,8%**	**p = 0,162**
ABDOMINAL AORTA SUPPLEMENTAL MATERIAL 4-6	**Descriptive anatomy (Q1-Q15)**	**81,3%**	**71,3%**	**p = 0,293**
	Anatomical relationships(Q16-Q29)	**82,9%**	**74,3%**	**p = 0,112**
	Reasoning, physiopathology, clinical outcomes (Q30-Q41)	**63,3%**	**61,7%**	**p = 0,412**
	TOTAL	**78,8%**	**76,3%**	**p = 0,162**

Table 4. Evaluation of the 3D stereoscopic video by the residents (n=10).

	Not agree at all	Rather disagree	Do not know	Agree	Totally agree	Positive reviews
Q1	0%	0%	0%	0%	100%	100%
Q2	0%	0%	0%	50%	50%	100%
Q3	0%	0%	0%	0%	100%	100%
Q4	0%	0%	0%	0%	100%	100%
Q5	0%	0%	0%	0%	100%	100%
Q6	0%	0%	0%	30%	70%	100%
Q7	0%	0%	0%	40%	100%	100%
Q8	0%	0%	0%	60%	40%	100%
Q9	10%	30%	10%	50%	0%	50%



Supplemental material 6. Anatomical view of abdominal aorta (Q6-Q10) from David Lee Basset stereoscopic Atlas. Creative Commons Attribution-Noncommercial-Share Alike 3.0 United States License.



Supplemental material 7. Anatomical view of thoracic brachial outlet with section of the clavicle (Q6-Q10) from David Lee Basset stereoscopic Atlas. Creative Commons Attribution-Noncommercial-Share Alike 3.0 United States License.

dents enjoyed the ability to watch the surgery with commentary from the surgeon's point of view (100%, Q6, Table 4). Students did not give negative feedback after watching this tutorial course.

All the students thought that providing digital certified course using currently available devices (smartphone, computer and virtual reality glasses) seem indispensable to their anatomical training course (100%, Q7, Table 4). They thought they learned more with the help of the 3D video than during previous practical dissection work (100%, Q8, Table 4). However, almost half of the residents thought that this kind of video could not replace cadaver dissection (40%, Q9, Table 4).

DISCUSSION

We have shown that residents are in favour of a virtual clinical-based anatomical teaching program and that they would find it useful.

In our study, before the course (video or books) there were no statistical differences ($p>0,05$) between the groups performances in basic vascular anatomy. It is noteworthy that in the video group they had better performance in the pretest in total score knowledge and clinical reasoning (although it was not significant). After watching the tutorial, we have seen that the video group scored higher than conventionally taught residents in descrip-

Supplemental material 8. Anatomical view of thoracic brachial outlet with section of the pectoralis minor muscle (Q1-Q5) from David Lee Basset stereoscopic Atlas. Creative Commons Attribution-Noncommercial-Share Alike 3.0 United States License.

tive anatomy, anatomical relationships and even clinical inference. These results are similar to another study conducted on a different population (Deng et al., 2018). Understanding anatomy means to be able to master visual-spatial skills. However, these skills are not necessarily mastered or understood by the students' pre-specialisation, especially for specific topics such as the thoracic brachial outlet that include three anatomical regions (interscalenic triangle, costoclavicular space, pectoralis minor space) (Connolly et al., 2021; Illig et al., 2016; Jones et al., 2019; Masson, 2021), to which we can add the humeral block (Brunet, 1999).

Over the years the anatomical and surgical knowledge of the thoracic outlet has evolved. Therefore, it is necessary to provide an updated anatomical and surgical description of each area. As an example, we will discuss thoracic outlet syndrome (TOS). TOS is a disease that requires a good anatomical knowledge to understand its diagnosis and its surgical treatment. This syndrome is a good example of the implication of anatomical knowledge in relation to surgical technique.

In the clinical-based anatomical videos, the addition of a surgical section showing the view of the main surgeon during the operation allowed for a better understanding of the surgical relevance of such anatomy. Our results showed that the instructional video with stereoscopic 3D views is an effective tool for learning surgical anatomy and the steps of a surgical procedure. Although the acquisition of theoretical knowledge is essential, the mastery of surgical procedures is the cornerstone of clinical expertise (Alameddine et al., 2018). The teaching of surgical skills is one of the most important and exhilarating tasks for a university surgeon (Norman, 1985). All teaching programs are aiming at professional skills acquisition, which is the "individual's capacity to effectively resolve various problems met in his domain of practice" (Jean et al., 1993). Most of this surgical learning is done in the operative room on real surgeries during residency. It follows 3 stages: demonstration, repeated practice, and immediate feedback on the procedure (Reznick, 1993). The first stage (demonstration) is the main one and is progressively put aside in favour of the next ones (practice and feedback). This kind of teaching is obviously dependant on day-to-day mentoring. Students need to be taught by their mentors in order to develop and acquire the technical skills for surgical procedures. Furthermore, as the surgical disciplines tend to be over specialized and with numerous new technics and instruments that are complementary or alternative to conventional procedures, these multiply the ways of teaching surgery. This progressive direction towards poles of excellence or even hyper-specialization is a trend that is widespread among institutions. The specific care needs of local populations, and the frequent medical under-staffing of university teams accentuate the phenomenon.

As 50% of the residents argue, the training program using only educational videos with a 3D method cannot obviously replace the cadaver dissection course. As described previously (Bernard et al., 2020a,b), surgical anatomy training deserves further exploration of the role of synergistic multimodal teaching strategies, such as the combination of 3D anaglyphic stereoscopy with virtual reality simulations, augmented reality teaching and 3D printing. In our study, students supported the development of stereoscopic teaching as a complementary resource. Indeed, their enthusiasm for the 3D method was mitigated by the fact that they found that this approach did not exclude the traditional pedagogical method. These findings were in accordance with previous studies, where new digital tools and integrative teaching methods have been promoted to complement anatomical education and the lecture experience (Hattie, 2012; Louw et al., 2009). Modern digitalized methods of teaching anatomy are undoubtedly useful (Louw et al., 2009; Turney, 2007). However, body dissections can still benefit significantly the new medical students, and these procedures should be maintained as part of surgical training (Shiozawa et al., 2017). 3D-stereoscopic-based learning, and new techniques such as virtual reality and 3D printing can be used to enhance and support anatomical teaching and learning in medical education (Vaccarezza and Papa, 2015). According to Papa and Vaccarezza's review (Papa and Vaccarezza, 2013), we are confident that gross anatomy through dissection and mental visualization cannot be undermined in a modern medical curriculum, since it gives a 3D experience that cannot yet be reproduced by the most advanced digital anatomy programs available.

All the participants in the study had previously completed cadaver dissection over a period of two weeks. Cadaver dissections and virtual visualizations each have distinct advantages in anatomical education. Cadaver dissections offer unparalleled realism and tactile feedback, crucial for understanding human tissue characteristics, but require a specialized lab and come with higher costs (Bernard et al., 2019; Cobolet et al., 2014). Virtual tools, while lacking in tactile feedback, provide accessibility, convenience, and customization, allowing for repeated use and updates to illustrate various anatomical variations. They are cost-effective in the long run despite high initial setup costs, and remove ethical concerns associated with cadaver use. However, they may have a learning curve and often lack the detail and accuracy found in cadaver dissections (Bernard et al., 2019; Cobolet et al., 2014). Ultimately, these methods are complementary, with cadaver dissection providing depth and realism, and virtual visualization offering innovation and practicality in anatomical learning.

In our study, we evaluated the contribution of an educational video on an uncommon surgical approach (axillary removal of the first rib) performed in a tertiary centre. This surgery requires an excellent anatomical knowledge. The contribution of educational videos including 3D stereoscopic views at the beginning of the residency could help beginning residents to understand this surgical procedure. It could also allow residents who are not part of an expert centre to access training on specific surgical techniques. Scientific societies work hard to digitalize and promote such teaching. Vascular surgery training in France is delivered by the French College of Vascular Surgery on a national basis. During their four years of residency, vascular surgery residents must follow a national digital teaching programme. The SIDES NG platform is the result of work carried out in collaboration with all the national stakeholders concerned by the 3rd cycle of medical studies. This platform is supported by all French medical universities. This represents more than 40,000 residents, 44 postgraduate diplomas and 34 faculties of medicine (Vaccarezza and Papa, 2015). The postgraduate diploma in vascular surgery includes distance learning courses taught by different surgeon-teachers of the specialty in France. Slide shows are accessible to the residents and are divided into 3 parts (base phase, deepening phase and consolidation phase) in line with the new reform of the 3rd cycle of medical studies. The viewing of these videos could be part of the validation of the different phases of the postgraduate diploma in vascular surgery and amounts to several hours of viewing. Currently, the foundation phase includes a chapter on anatomy and surgical approaches in vascular surgery, and it should be noted that the anatomy of the thoracic brachial outlet and surgery for resection of the first rib are not included in this teaching. Moreover, it does not include 3D stereoscopic video or VR courses. In view of this new digital curriculum, the addition of educational videos of surgical anatomy could be a complement to the digital training of vascular surgery residents.

Limitations

Our study has several limitations. Our sample size was small, despite the recruitment of residents from several hospital sites and several surgical specialties. Surgical specialty is not a determining factor, as the answers to the MCQs were equivalent for both groups before viewing the video or the anatomy books. Descriptive results showed that the resident profile was heterogeneous in terms of surgical specialty, age, vascular surgery experience and university origin. Whatever the student profile, all students assume that a complementary anatomo-surgical program is needed. We can add to the limitations the fact that the students in the 3D group were probably more enthusiastic and motivated, leading to better results. Additional study time due to enthusiasm is a valid consideration; however, the study's design aimed to minimize its impact. Future research could track actual study time to further address this variable. Furthermore, the absence of a satisfaction survey for the book group precludes a comprehensive comparative analysis of students' satisfaction with the learning methods, which may have provided additional insights into the educational impact. The results of these studies should be confirmed by larger studies. Additionally, the timing of our evaluation poses a limitation: the long-term knowledge assessment was conducted only one-month post-intervention, which may not sufficiently capture the true extent of knowledge retention over a longer period. It is necessary to evaluate the impact of this teaching method on the students' long-term knowledge with assessments at multiple intervals post-intervention.

CONCLUSION

The teaching of vascular anatomy and surgical approaches in postgraduate vascular surgery studies is essential. The development of educational videos using 3D stereoscopy in particular could complement teaching in this field. This digital clinical-based method of anatomical teaching is particularly suited as a complement to traditional teaching methods.

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