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Contribution of 3D visualization and printing in teaching lung segments anatomy

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Abstract

Background The knowledge and understanding of the anatomy of lung segments is of great importance while segmentectomies are increasingly performed. To introduce new technologies and tools in anatomy teaching could help students to improve their skills.

Methods Students participants ($n=16$) were divided into 3 groups: traditional ($n=5$), 3D visualization ($n=5$) and 3D printing group ($n=6$). Each student took a pre- and post-test exam. The traditional teaching group had lessons using 2D anatomical drawings, the 3D visualization group had lessons using a dedicated software allowing anatomical 3D reconstructions and the 3D printing group had lessons using 3D printed anatomical models.

Results Students of the whole cohort had significant better scores at the post test (mean score = 14.2) compared to the pretest (mean score = 7.9) ($p=0.0011$). In the traditional and 3D printing groups, students had significant better scores in the post-test (mean scores = 17.7 and 14.2 respectively) than in the pre-test (mean scores = 8.2 and 7.5; $p=0.0247$ and $p=0.0003$ respectively). There was no significant difference between the pre and post-test scores for the 3D visualization group (mean score = 8.2 and 11.7 respectively) ($p=0.4347$).

Conclusions The knowledge of lung segment anatomy is poor among our medical students. Both traditional and 3D-printed teaching was shown effective. The contribution of 3D printed models would probably improve anatomy teaching among medical students. The introduction of this technology is instinctive and easy to use for both students and teachers. Furthermore, this technique was not particularly expensive to set up.

Keywords Lung segments, 3D visualization, 3D printing, Anatomical education

Background

The nomenclature used to describe lung segments dates back to 1950 and is still used today [1]. Given the complex anatomy, it was created to comply to the usual terms of descriptive anatomy and to be easily understood by all, even by the non-specialists. This nomenclature was inspired by several writings available at the time and reflects what was observed in most of cases. Over the years, many studies reported numerous anatomical variations, whether bronchial, arterial or venous [2–4], which can be confusing for medical students.

In France, anatomy is taught during the first two years of medical studies. In Lyon, these lessons are performed

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using traditional anatomical charts on a power point support or on a blackboard. Following these theoretical courses, the students participate to a 3 h-session of dissection on cadavers, in which they review the anatomy of the musculoskeletal system, head / neck, and thorax / abdomen. Later, according to their specialty, students must learn the specific anatomy of their field. However, there is no anatomy course in the third cycle of medical studies, so they have to find tools by themselves.

The anatomy of lung segments is mentioned during the second cycle of medical studies, but only briefly, although the knowledge and understanding of their anatomy is of great importance. A large Japanese randomized trial (JCOG0802) studied different surgical treatments in early-stage lung cancer (stage IA); lobectomy (current standard) was compared to segmentectomy (usually used in patients with limited lung function) [5]. Overall survival and progression-free survival were not worse in the segmentectomy group, leading the authors to propose this treatment to all patients with stage IA lung cancer. This study has had a major impact on the indications for segmentectomy, as oncological outcome appears to be identical while preserving respiratory function. Segmentectomies are no longer proposed for patients with limited respiratory function, but for all patients with early-stage tumors. As a result, segmentectomy is becoming increasingly performed, and learning lung segment anatomy has become essential for students of pulmonology and thoracic surgery.

Many tools are already available to help the students, from descriptive anatomy articles to 3D e-atlases [6–9] but anatomy remains a difficult discipline for almost half of the students [10] and efforts should be made to ease the learning of pulmonary segment anatomy. Many techniques have been developed such as virtual reality, 3D modelling and 3D printing [11–13]. Learning anatomy with 3D printed models is an emerging technique that has already been used in various fields as it became more affordable, accessible, and relevant in healthcare [14]. Regarding the learning of pulmonary segment anatomy, there is little data on the use of 3D printed models, but first experiences showed that this technology improved teaching effectiveness and was worth adopting [15]. 3D printed models have also been used to teach hepatic segment anatomy, which allowed students to have a better overview of complex anatomical relationships [16]. In this context, learning anatomy by using 3D printed models should play a crucial role in the future, due to the spatial context related to the learning of anatomy.

Study goals: The aim of the present study was to use 3D visualization methods in the learning of pulmonary segment anatomy. For this purpose, the effectiveness of traditional 2D atlas teaching was compared to that of teaching using a 3D visualization model and teaching using a 3D printed model. Given the current difficulties of our students in learning pulmonary segment anatomy, the hypothesis was that learning will be more effective by using 3D techniques.

Methods

Study population and teaching process

Participation in this study was proposed to all medical students (second and third cycle of medical studies) present in pulmonology and thoracic surgery departments at the Louis Pradel Hospital (GHE - Lyon) between May and July 2022. The teaching took place during the first two weeks of July 2022 and was delivered by two senior thoracic surgeons in the department, each of whom has been practicing thoracic surgery for over a decade. Both teachers are experienced in teaching and working with 3D reconstruction software. According to the cycle of medical studies, students were randomly assigned to each group: traditional teaching group (TRAD), 3D visualization teaching group (VIS3D) and 3D printing teaching group (PRINT3D). Details of how resources were created for the different groups are described later. Once the groups were formed and the lessons planned, the students took a “pre-test” exam. For the pre-test, students were exposed to anatomical drawings, CT scan images and an intraoperative view. Students also completed an information sheet to collect their age, level of education, medical specialty and whether they had previously participated to thoracic surgeries. The students were then given a one-hour teaching session, according to the group they had been allocated to. Five days after the teaching session, the students took a “post-test” exam. During the 5-day period, none of the students had access to the resources so as not to give anyone an advantage. For the post-test, students were exposed to anatomical drawings, CT scan images, 3D reconstructions and an intraoperative view (Fig. 5, supplementary material). The maximum score was 20 points. The scores obtained in the pre- and post-test exam were recorded and analyzed to compare the differences between each group. At the end of the post-test exam, students also completed a satisfaction questionnaire.

Traditional teaching group (TRAD group)

Traditional teaching was conducted using Power Point (Microsoft, Washington, USA). The slides were created inspired by Nomori’s book on lung segmentation [9], images from *imaios* (www.imaios.com/fr/e-Anatomy/Thorax/Poumons-Illustrations) and CT scan images of several patients. Examples of anatomical variations were given [3, 4]. The teaching session was not only theoretical, but also included exercises with a radiological part in which students had to identify the segmental structures on CT scan images, helped by what was seen on the 2D anatomical drawings. The teaching ended with a video sequence commented by the teacher of a segmentectomy of the right basal pyramid performed by videothoracoscopy.

3D visualization teaching group (VIS3D group)

Two patients that had an available 3D reconstruction performed using Visible Patient™ laboratory (Strasbourg, France, Fig. 1), were selected. They both underwent segmentectomy in the thoracic surgery department of Louis Pradel Hospital. One patient was selected for the right side and one patient for the left side due to an anatomy considered standard, i.e. without anatomical variations and whose anatomy is closest to theoretical knowledge. The 3D reconstruction was performed by the Visible Patient™ laboratory (https://www.visiblepatient.com/en/professionnals/access-solution/). The surgeon sent CT scan images to the platform and Visible Patient™ laboratory send back the 3D reconstruction that the physician can manipulate via the Virtual Planning™ software. The teachers extracted images of interest and annotated the segmental structures. The teaching session was an anatomy course using some 2D anatomical drawings and images extracted from the 3D reconstruction. Then the students were invited to manipulate the Virtual Planning™ software and find different segmental structures helped by annotated slides as a support.

3D printing teaching group (PRINT3D group)

The 3D printed model was performed by using the. stl files of the 3D reconstruction of the two previous patients, generously provided by the Visible Patient™ laboratory (Strasbourg, France). These files were processed at the CO'Lab 3D Platform (Lyon, France) using Meshmixer software (Autodesk, Inc, USA) in order to remove the lung parenchyma and all sub-segmental structures, allowing to only keep a segmental partition of the bronchovascular tree. Then, the model was 3D printed using material extrusion technology at the CO'Lab 3D platform with a Tiertime UP300 printer (Beijing, China). The material used for the printing was TPU (or thermoplastic polyurethane) from Polymaker (Utrecht, Netherlands), whose particularities are its resistance and flexibility. After printing, the bronchial, arterial and venous reconstructions were nested and glued together to obtain a complete model (Fig. 2). The teaching session was an anatomy course using some 2D anatomical drawings and images extracted from the 3D reconstruction, annotated with the names of the segmental structures. Then, the students were divided in groups and the 3D printed models were provided. Each group had to find each segmental structure by manipulating the 3D printed model, helped by the annotated 3D reconstruction images as a support. The teacher answered questions and assisted students whether necessary.

Student satisfaction survey

At the end of the post-test exam, students completed a satisfaction questionnaire. The survey consisted of the following 3 questions: rate on a scale of 1 to 10 the training you have received on lung segment anatomy, Did you find this course useful and why?, What would you change?.

Statistical analysis

Categorical data were expressed as numbers and percentages and continuous variables were expressed as mean and standard deviation (SD). Shapiro-Wilk test was used to determine the potential normal distribution of the data. The Shapiro-Wilk test did not show a significant departure from normality for the data set. Comparisons of quantitative data between the three groups were then made using the One-way ANOVA test. A threshold of $\alpha = 0.05$ was considered for statistical significance. Data were exported to GraphPad Prism Version 7.01 for Windows (GraphPad Software, La Jolla, CA, USA, www.graphpad.com).

Ethics

All students signed an informed consent before enrollment. The study was approved by the ethics committee of the French Society of Thoracic and CardioVascular Surgery (SFCTCV, IRB00012919), and was conducted in accordance with the Declaration of Helsinki.

Results

Student characteristics

Out of 27 students in the pulmonary and thoracic surgery departments, 16 (59.3%) participated in the study. There were seven women (43.7%) and nine men (56.3%), the mean (SD) age was 26 (3.3) years. Most students (11, 68.7%) were in the third cycle of medical studies; the remaining students (five, 31.3%) were in the second cycle of medical studies, one was in his second year, three were on their third year and one was on his last year of the second cycle of medical studies. Regarding the students of the third cycle of medical studies, two were on their first year, three were on their second year, two were on their third year and four were on their last year. These 16 students were divided into three groups: the traditional teaching group (TRAD, five, 31.2%), the 3D visualization group (VIS3D, five, 31.2%) and the 3D printing group (PRINT3D, six, 37.5%). In the TRAD group, there were 2 students in the second cycle and 3 students in the third cycle. The same distribution was observed in the VIS3D group. In the 3DPRINT group, there were 1 student in the second cycle and 5 students in the third cycle.

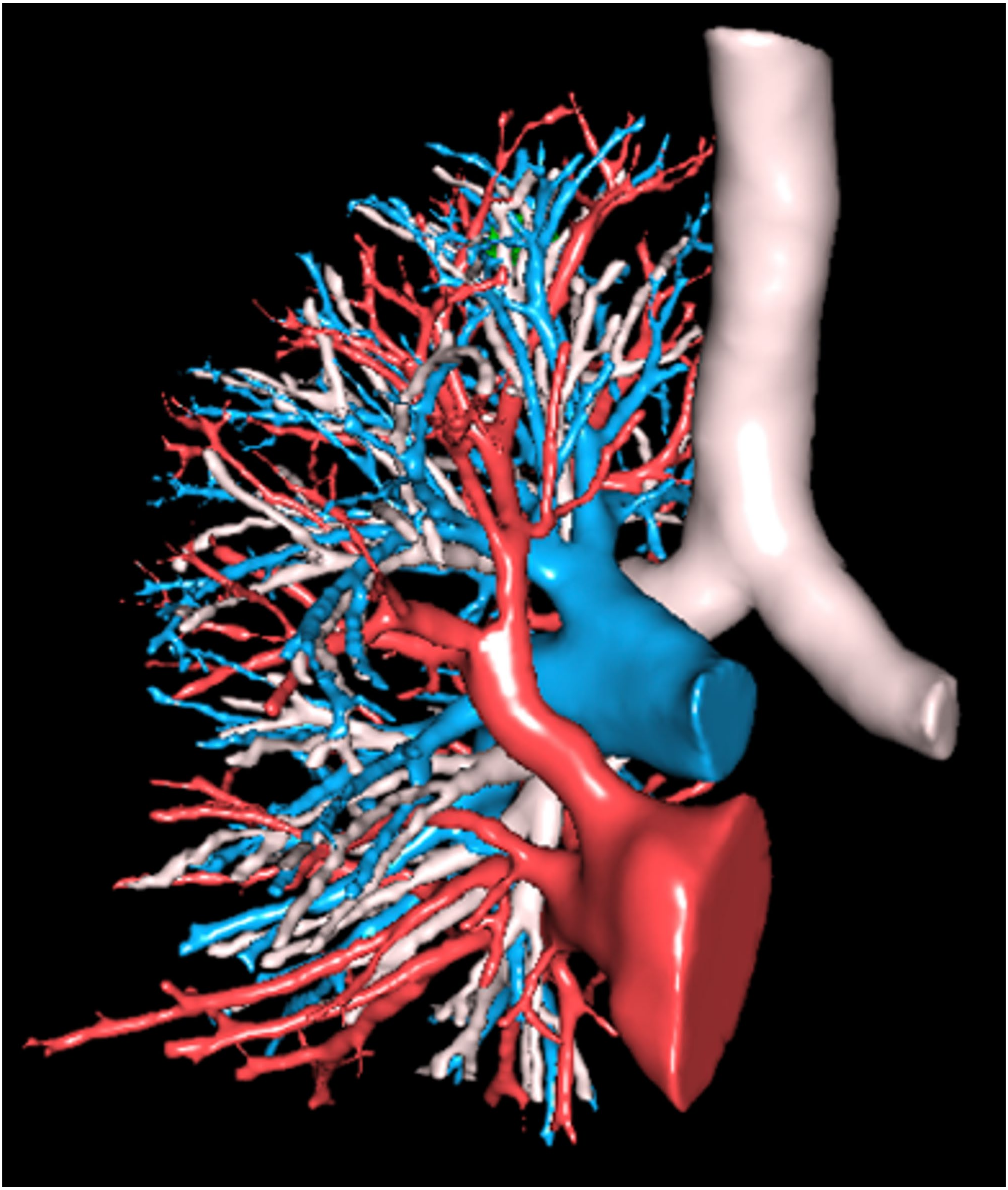

Fig. 1 Example of 3D modelling of the right bronchial and vascular tree, without the lung parenchyma. Thanks to the Visible Patient™ laboratory (Strasbourg, France). The bronchial tree is in white, the arterial tree is in blue and the venous tree is in red

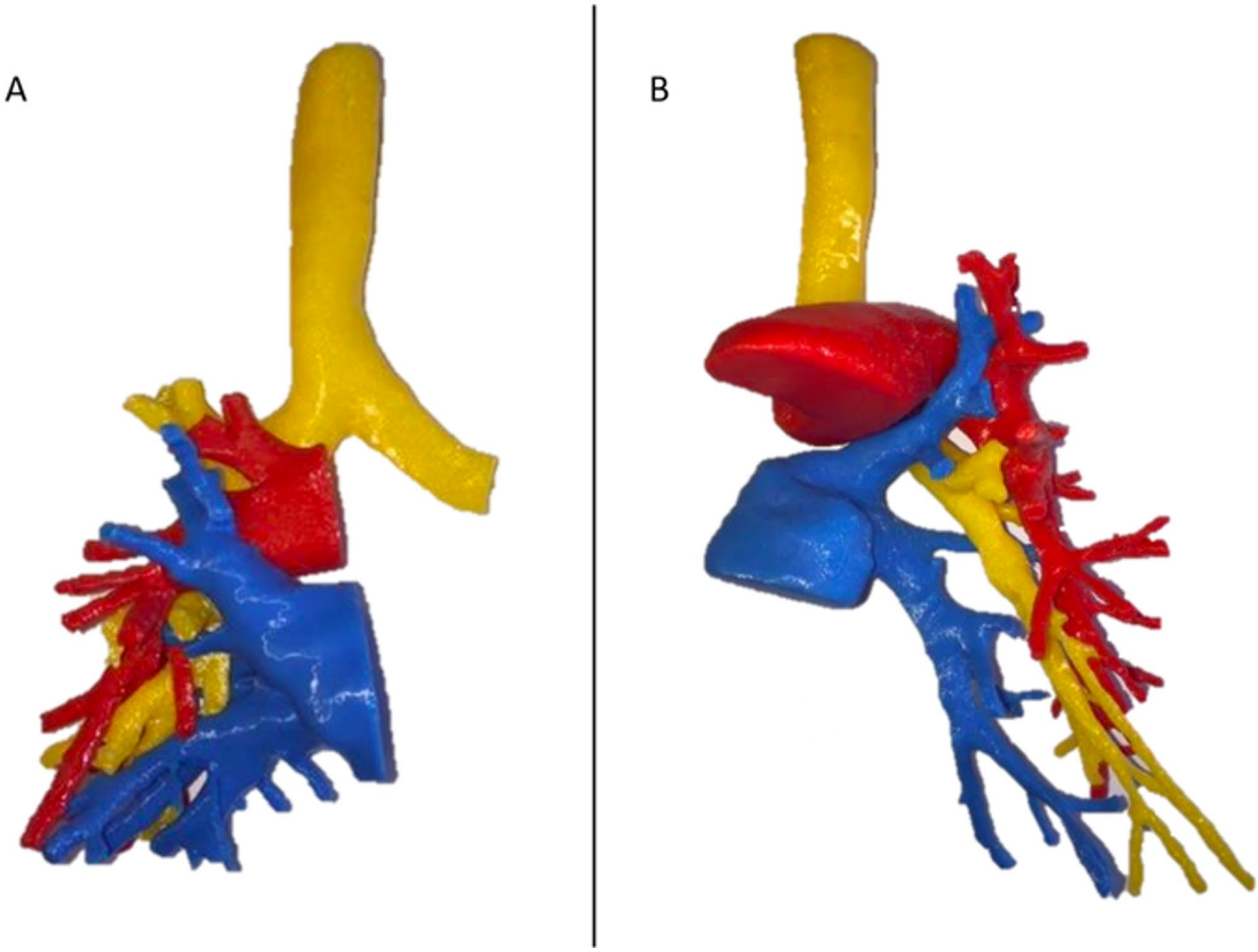

Fig. 2 Photographs of 3D printing models of the right (**A**) and left (**B**) bronchial and vascular tree, without the lung parenchyma, using the Hospices Civils de Lyon 3D printing platform: CO'Lab 3D. The bronchial tree is in yellow, the arterial tree in red and the venous tree in blue

Table 1 Characteristics of the student population and mean scores obtained in pre- and post-tests evaluations

	Mean age	Women *n*(%)	Men *n*(%)	2nd cycle *n*(%)	3rd cycle *n*(%)	Mean score for pre-test (SD)	Mean score for post-test (SD)
Whole cohort*n* = 16	26	7 (43.7%)	9(56.3%)	5 (31.3%)	11 (68.7%)	7.9 (4.33)	14.2 (4.59)
TRAD group*n* = 5	25	2 (40%)	3 (60%)	2 (40%)	3 (60%)	8.2 (4.32)	17.7 (0.47)
VIS3D group*n* = 5	26	2 (40%)	3 (60%)	2 (40%)	3 (60%)	8.2 (5.74)	11.7 (5.49)
PRINT3D group*n* = 6	27	3 (50%)	3 (50%)	1 (16.7%)	5 (83.3%)	7.5 (1.89)	14.2 (3.93)

Pre and post test scores

The mean (SD) score obtained by all students for the pre-test evaluation was 7.90/20 (4.33), with 8.2/20 (4.32) for the TRAD group, 8.2/20 (5.74) for the VID3D group, and 7.5/20 (1.89) for the PRINT3D group. The mean (SD) score obtained by all students in the post-test evaluation was 14.2 (4.59); 17.7 (0.47) in the TRAD group, 11.7 (5.49) in the VIS3D group and 14.2 (3.93) in the PRINT3D group (Table 1).

There was no significant difference in pre-test scores ($p = 0.9578$) and in post-test scores ($p = 0.2907$, Fig. 3) between the three groups.

In the overall student population, there was a significant difference between the pre- and post-test scores ($p = 0.0011$, Fig. 4). Post-test scores were significantly higher in the TRAD ($p = 0.0247$) and PRINT3D ($p = 0.0003$) groups compared to pre-test scores. The results were not significantly different between the pre- and post-test scores in the VIS3D group ($p = 0.4347$).

Second cycle students tended to perform less well on the pre-test than third cycle students (Table 2). There were less differences between third and second cycle medical students regarding the post test results.

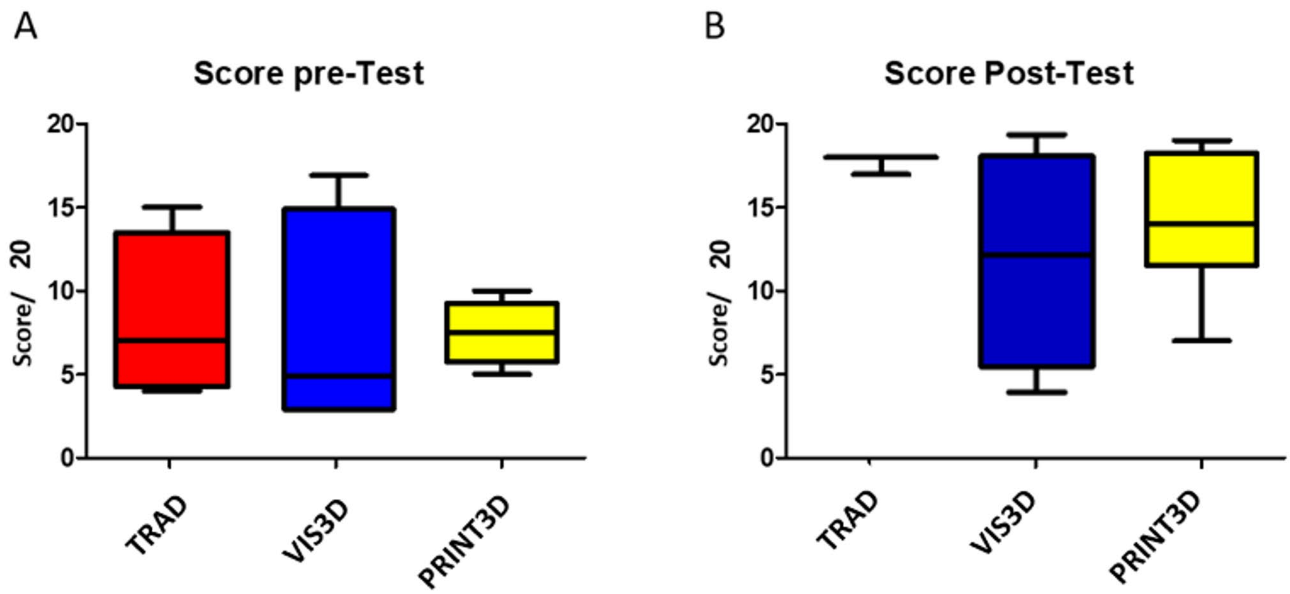

Fig. 3 (**A**) Comparison of pre-tests scores. (**B**) Comparison of post-tests scores

Students' evaluation of the teaching content

The students seemed satisfied of the course they received, as the evaluation mean (SD) score was 8/10 (1.30). The traditional teaching received a mean (SD) score of 7.5/10 (0.47) while the 3D visualization and 3D printing groups had a slightly higher mean (SD) score: 7.7 (2.05) and 8 (0.82), respectively. All students found this teaching useful. The student of the pulmonology department replied that the course helped them in the practice of bronchoscopy, and the students of the thoracic surgery department replied that it helped them to better understand the surgical anatomy. When asked what they would change, the students said they would like more reminders of the traditional anatomy, more exercises as used in the tests and more correspondence between anatomy and radiology.

Discussion

Knowledge of lung segment anatomy is generally poor among medical students, with pre-test scores in our study being quite low. Strengthening anatomy courses in this field is therefore essential. Our aim was to introduce new pedagogical tools to our students to facilitate the learning of lung segment anatomy. Courses were then conducted using anatomical drawings, 3D reconstructions and 3D printed models as support. The present study showed a significant difference in the overall population regarding pre- and post-test scores, suggesting that suggesting that the teaching, whatever its form, has been useful for the students. A significant difference between pre- and post-test scores was found in the traditional (TRAD) and the 3D printed model (3DPRINT) groups. Nonetheless, there was no significant difference between the pre- and post-test scores for the 3D visualization group.

Students in the VIS3D group did not perform any better on their post-test, which can be, in part, explained by the difficulty they faced understanding the modeling software; the time dedicated to the course was probably too short to understand the anatomy in addition to the software. In the VIS3D group, there were two undergraduate students and one resident of pulmonology that had never used this software before. This modelling software can be difficult to apprehend at first, but when the software is mastered, 3D modeling can be useful to learn anatomy. A 2014 Chinese study showed the beneficial contribution of 3D reconstruction images on the learning of surgical anatomy in a population of undergraduate students [22] that were used to manipulate this type of software. Students in the study group scored better in post-class exams and were better in "spatial thinking". Other studies confirmed the better understanding of anatomical relationships in students working on 3D reconstruction images. Authors also found that students learnt anatomy more quickly than in conventional anatomy lessons [19–21].

Students in the 3DPRINT group had significant better scores in the post-test (mean score = 14.2) than in the pre-test (mean score = 7.5; $p = 0.0003$) and the evaluation of the course by the students was slightly higher compared to the other groups. These observations, consistent with the literature [15], made teachers want to start using this type of pedagogical tool routinely. Before starting, the teacher must be aware of the following point: getting the most appropriate model, according to the anatomical region and its complexity [26–28]. The anatomy of the lung segments is complex to learn, but the use of 3D models could make it easier and faster. Liver anatomy

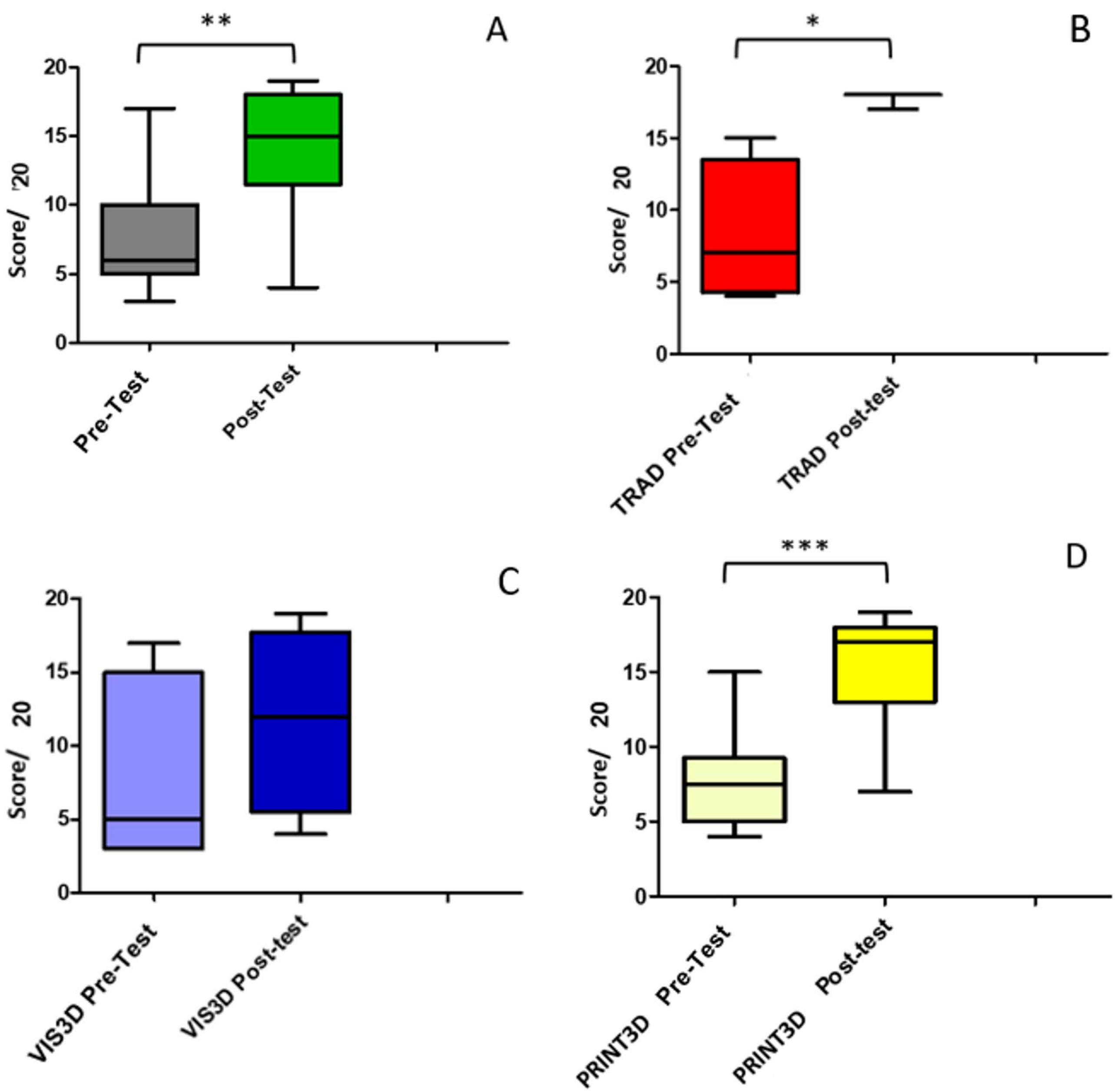

Fig. 4 Comparison of pre- and post-test scores. (**A**) Comparison within the whole cohort of students. (**B**) Comparison of students in the TRAD group. (**C**) Comparison of students in the VIS3D group. (**D**) Comparison of students in the PRINT3D group. *$p < 0.05$. **$p < 0.005$. ***$p < 0.0005$. The statistical test used was the one way test - ANOVA. The data were exported to GraphPad Prism Version 7.01 for Windows

Table 2 Mean scores at pre- and post-test by level of medical education

	TRAD group		VIS3D group		3DPRINT group	
	Mean score pre-test	**Mean score post-test**	**Mean score pre-test**	**Mean score post-test**	**Mean score pre-test**	**Mean score post-test**
2nd Cycle ***n*** **= 5**	4.5	17	4	10	5	15
3rd Cycle ***n*** **= 11**	12	18	11	12.5	8	14

is also a complex one with numerous ramifications and Kong et al., who succeeded in developing a 3D printed hepatic segment model, demonstrated that students enrolled in 3D visualization and 3D printed models had a better overall view of anatomical relationships [16]. Furthermore, learning anatomy with 3D-printed models would also help retain the information longer in time [28]– [29].

The aim here was not to replace existing methods, but rather to combine them in order to give students everything they might need to understand complex anatomy [23]– [24]. And this is, by the bye, what the satisfaction questionnaires showed. Students in the 3D groups wanted more traditional anatomical drawings. All students wanted more CT scan images and per operative views in addition to pure anatomical resources. This has led the teaching staff to think about a more comprehensive training programs combining 3D manipulation, traditional anatomy and radiological anatomy lessons.

Our study has several limitations. This study was conducted among students at all levels of study (second and third cycle of medical studies) and in different specialties (pulmonology and thoracic surgery) which may have biased our results. The sample size was very low, so the statistical power was weak, and the conclusions were hard to perform. Another larger-scale study is needed to confirm our preliminary results.

Conclusion

The knowledge of pulmonary segment anatomy among our medical students is poor. In the present study, both traditional and 3D-printed teaching have been effective to improve this knowledge and must be used in a complementary way, as students suggested. The use of 3D printed models is instinctive and easy to use for both students and teachers. In the literature, these models have been found to make learning easier, faster and longer. In the future, we plan to develop a comprehensive training program including 3D model manipulation associated with traditional anatomy reminders and radiological anatomy lessons.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s41205-025-00272-z.

Supplementary Material 1: **Figure 5**: Examples of questions asked in the pre-test (questions 2 and 6) and in the post-test (questions 2, 4 and 6).

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Author contributions

G.D.: writing manuscript, data interpretation. G.D. and V.S.: collection and assembly of data; S.G. and M.V.: provision of study materials: J-M.M.: data analysis; F.T.: conception and design. All authors read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The study was approved by the ethics committee of the French Society of Thoracic and CardioVascular Surgery (SFCTCV), (IRB00012919), and it was conducted in accordance with the Declaration of Helsinki. All students signed an informed consent form before participating in the study.

Competing interests

The authors declare no competing interests.

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