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A Novel Competency-Based Simulation Model for Thoracoscopic Lung Resection

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Abstract

Background Simulation-based thoracic surgery training is increasingly incorporating physical models to enhance traditional learning methods. Conventional box trainers, though useful for basic skills, often lack anatomical accuracy and tactile feedback, limiting their relevance for complex procedures like thoracoscopic lung resection. High-fidelity 3D-printed lung models offer realistic anatomy and procedural flow, but their educational impact remains underexplored.

Methods Fifty-two surgical residents without prior thoracoscopic experience were randomly assigned to a high-fidelity lung model group or a conventional Fundamentals of Laparoscopic Surgery (FLS) box trainer group. All participants completed a baseline thoracic anatomy test and received standardized educational materials. The lung model group received structured simulation training on procedural anatomy and operative steps, while the FLS group practiced fundamental laparoscopic tasks. After training, participants repeated the anatomy test and performed a thoracoscopic lung wedge resection in a live animal model. Performance was assessed using the Objective Structured Assessment of Technical Skill (OSATS) and a 5-point confidence scale.

Results A total of 52 surgical residents participated in the study, with 26 assigned to the high-fidelity lung model group and 26 to the FLS trainer group. Baseline anatomy scores were similar between groups (65.42 ± 6.10 vs. 66.12 ± 5.92; $p = 0.710$). Posttraining, the lung model group showed greater gains in anatomy comprehension (87.60 ± 4.75 vs. 78.19 ± 5.54; $p < 0.001$), higher OSATS scores (19.18 ± 2.43 vs. 15.41 ± 2.41; $p < 0.001$), and increased confidence (3.13 ± 0.61 vs. 2.27 ± 0.68; $p = 0.002$).

Conclusion High-fidelity 3D-printed lung models significantly enhance anatomical understanding, thoracoscopic skills, and confidence compared with conventional box trainers. These results support integrating anatomically accurate simulation into thoracic surgical education to improve both cognitive and psychomotor outcomes.

Keywords
- high-fidelity simulation
- thoracoscopic wedge resection
- surgical education
- technical skill acquisition
- trainee confidence

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Introduction

Video-assisted thoracic surgery (VATS) has become a standard approach for the management of pulmonary diseases, offering advantages over open thoracotomy such as reduced postoperative pain, shorter hospital stays, and fewer complications.[1] Despite these benefits, VATS remains technically demanding, requiring advanced hand–eye coordination, spatial orientation, and procedural expertise. These challenges highlight the need for structured and evidence-based training programs to ensure safe and competent surgical performance.

Simulation-based education is now an essential component of surgical training, enabling trainees to develop skills in a controlled, risk-free environment prior to entering the operating room. The Fundamentals of Laparoscopic Surgery (FLS) box trainer is widely adopted for teaching core laparoscopic skills, including tissue handling and instrument navigation.[2] However, its lack of anatomical fidelity and tactile realism limits its applicability to complex thoracic procedures such as lung resection. Alternative simulation modalities, including bench-top models and virtual reality systems, have been introduced to address these gaps.[3–11] While they offer benefits such as accessibility and programmable feedback, most fail to replicate the anatomical complexity and haptic feedback needed for advanced thoracic procedures.

Recent advances in 3D printing have enabled the development of anatomically accurate, high-fidelity models for surgical simulation across several specialties.[12–17] Such models may bridge the gap between generic skills training and procedure-specific performance by providing realistic and reproducible platforms for deliberate practice. However, despite their promise, few studies have rigorously evaluated the educational value of 3D-printed models in thoracic surgery training, particularly their impact on anatomical comprehension, technical skill acquisition, and learner confidence.

To address this gap, we developed a high-fidelity 3D-printed lung model designed specifically for thoracoscopic lung resection.[18] We conducted a comparative study to evaluate its effectiveness against the conventional FLS box trainer. Surgical residents were assigned to either modality, completed a standardized curriculum, and were subsequently assessed on anatomical knowledge, technical performance in live animal surgery, and self-reported confidence. Our goal was to generate quantitative evidence supporting the integration of anatomically realistic simulation models into thoracic surgical education.

Methods

Participants and Course Design

This randomized controlled study was conducted at Peking University People's Hospital. Fifty-two surgical residents without prior thoracoscopic experience were included and randomly assigned in a 1:1 ratio to either the high-fidelity 3D-printed lung model group ($n = 26$) or the FLS box trainer group ($n = 26$) using a computer-generated randomization list. Ethical approval was obtained from the institutional review board at Peking University People's Hospital (Approval No. 2024PHE081), and the study adhered to the Declaration of Helsinki. As this was a retrospective analysis of routine simulation training without additional intervention, the requirement for written informed consent was waived.

3D-Printed Lung Model

The model was reconstructed from anonymized high-resolution chest CT datasets and manufactured using a stereolithography-based 3D-printing system. Polymer-based composite materials were selected to mimic the compliance and handling characteristics of native lung tissue. To further enhance realism, a layered casting technique was applied so that vessels and bronchi offered distinct tactile feedback during dissection and stapling. Within the simulator, the lung itself was interchangeable to allow repeated practice, while the external thoracic housing, trocar ports, and illumination system were standardized across all training sessions to ensure consistency. The final construct reproduced anatomically accurate lobes, bronchial branches, and hilar vessels, enabling trainees to practice thoracoscopic orientation, scope handling, stapling, and specimen retrieval. By design, however, adjacent mediastinal structures such as the heart, great vessels (including the superior vena cava and aorta), and vertebral bodies were not replicated. This selective simplification emphasized thoracoscopic lung resection as the training objective rather than comprehensive replication of the entire thoracic cavity.

Course Preparation and Grouping

Before simulation training, all the participants completed a baseline anatomy test focused on thoracoscopic lung structures and key anatomical landmarks. To ensure consistent foundational knowledge, residents then received standardized preparatory materials, including a step-by-step procedural manual and a training video comparing real and simulated thoracoscopic wedge resections (►**Fig. 1** and ►**Video 1**, available in the online version only).

Video 1

Thoracoscopic wedge resection procedure showing parallel demonstration of clinical and simulation settings. The left panel illustrates the operative scene with lung grasping using a curved clamp, delineation of the resection margin, and division with an endoscopic linear stapler; the right panel presents the corresponding simulation on a training model. Online content including video sequences viewable at: https://www.thieme-connect.com/products/ejournals/html/10.1055/a-2702-2239.

Following preparation, residents participated in a structured, 2-day simulation training program. The lung model group was trained in a dedicated simulation laboratory using a high-fidelity, anatomically accurate 3D-printed lung model

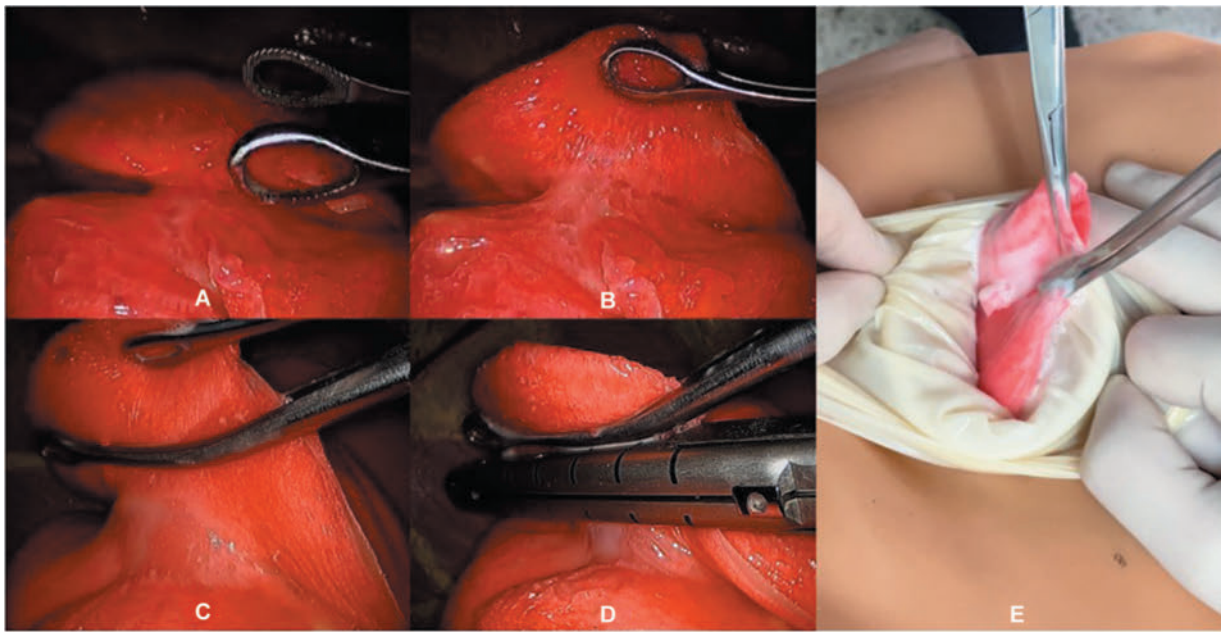

Fig. 1 Standardized procedure for thoracoscopic lung wedge resection in the 3D training model. (**A**) The thoracoscope was correctly inserted to facilitate the identification of lobe anatomy, ensuring a clear view of the target area. (**B**) Instruments were carefully used to handle the lung tissue, minimizing trauma and avoiding unnecessary damage to surrounding structures. (**C**) The lung was properly oriented and positioned for resection. (**D**) The stapling device was applied correctly to secure the resection area. (**E**) The resected lung tissue was placed into a retrieval bag and carefully extracted.

(►**Fig. 2**). Each session included a brief anatomy review, technical demonstrations by senior surgeons, and approximately 30 minutes of supervised, hands-on practice per trainee. Emphasis was placed on anatomical recognition, thoracoscopic orientation, stapling technique, and safe specimen retrieval.

In contrast, residents in the FLS group trained via a standard laparoscopic box trainer (►**Fig. 3**), with a curriculum focused on core laparoscopic skills such as hand–eye coordination, depth perception, and instrument handling. This training did not replicate full procedural steps but provided general psychomotor preparation. Both groups were trained in small teams (trainee-to-instructor ratio of 5:1) with real-time faculty feedback and peer observation to reinforce skill development.

Assessment

To assess learning outcomes, all participants repeated the anatomy test after simulation training. All residents subsequently underwent thoracoscopic lung wedge resection in a live animal model one week after training, which served as a test of skill transfer.

Surgical performance was evaluated using a modified Objective Structured Assessment of Technical Skills (OSATS)

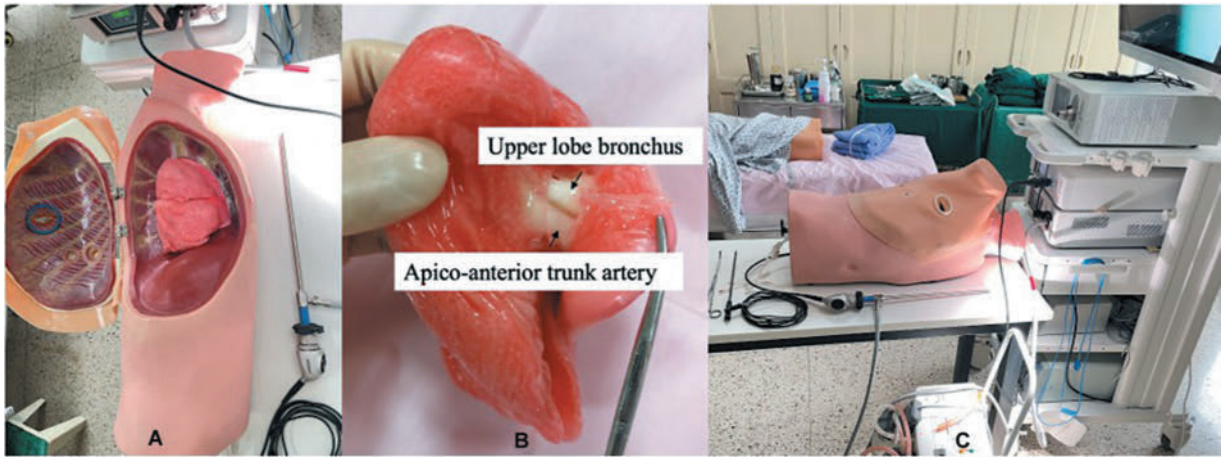

Fig. 2 High-fidelity 3D-printed lung model for thoracoscopic training. (**A**) External thoracic trainer housing with trocar ports and an interchangeable lung model positioned inside the cavity. (**B**) Magnified view of the lung hilum showing labeled anatomical structures, including the upper lobe bronchus and the apico-anterior trunk artery. (**C**) Complete training setup with the thoracic trainer connected to standard thoracoscopic instruments and a video display system.

Fig. 3 Conventional Fundamentals of Laparoscopic Surgery (FLS) box trainer used in the control group. The main image shows the external appearance of the trainer with trocar ports and a video display system. The inset demonstrates the endoscopic view inside the box during a suturing task, illustrating the limited spatial orientation and psychomotor focus of this training platform.

scoring system, adapted from prior thoracoscopic training literature.[19] Five domains were assessed: Thoracoscope handling, tissue handling, orientation, stapling, and specimen extraction. Each domain was scored from 1 (poor) to 5 (excellent), with a total maximum score of 25. Three OSATS domains (port placement, closure, and pneumostasis) were excluded due to the standardization of port placement by senior surgeons and the inability of the lung model to simulate air leaks.

In addition to technical proficiency, participants' self-reported confidence was measured immediately after the live animal procedure using a 5-point Likert scale (1 = not confident at all, 5 = very confident).

Statistical Analysis

Data are expressed as the mean ± standard deviation (SD). The analysis was performed using IBM SPSS Statistics (version 26.0, Armonk, NY). Normality of continuous variables was assessed using the Shapiro–Wilk test. Between-group comparisons were performed using the independent-samples *t*-test for normally distributed data and the Mann–Whitney U test for non-normally distributed data. Categorical variables were compared using the chi-square test. Graphs were plotted using GraphPad Prism version 8.4.3 (GraphPad Software, La Jolla, CA). A two-tailed p-value <0.05 was considered statistically significant.

Results

Baseline Characteristics

A total of 52 surgical residents participated in the study. Among them, 26 were assigned to the high-fidelity lung model group and 26 to the FLS trainer group. All participants had no prior experience in thoracoscopic surgery. The mean age was 24.90 ± 0.82 years in the lung model group and 25.10 ± 0.51 years in the FLS trainer group. Male participants accounted for 57.69% of the lung model group and 61.54% of the FLS group. Baseline demographic characteristics are presented in ►**Table 1**.

Comparison of Anatomical Knowledge before and after Training

In the baseline anatomy test, there were no statistically significant differences between the lung model and FLS groups (65.42 ± 6.10 vs. 66.12 ± 5.92; $p = 0.710$; ►**Table 1**). After completing the respective training programs, the lung model group demonstrated significantly greater improvement in anatomical understanding, scoring higher in the posttraining test compared with the FLS group (87.60 ± 4.75 vs. 78.19 ± 5.54; $p < 0.001$; ►**Table 2**),

Table 1 Participant characteristics at baseline

Characteristics	Lung model group ($n = 26$)	FLS trainer group ($n = 26$)	p-Value
Age (years), mean ± SD	24.90 ± 0.82	25.10 ± 0.51	0.480
Male, *n* (%)	15 (57.69%)	16 (61.54%)	0.722
Pretraining anatomy score	65.42 ± 6.10	66.12 ± 5.92	0.710

Abbreviations: FLS, Fundamentals of Laparoscopic Surgery; SD, standard deviation.

Table 2 Post-training outcomes

Outcome Variable	Lung model group ($n = 26$)	FLS trainer group ($n = 26$)	p-Value
Posttraining anatomy score	87.60 ± 4.75	78.19 ± 5.54	<0.001
OSATS total score	19.18 ± 2.43	15.41 ± 2.41	<0.001
Confidence score (1–5 Likert)	3.13 ± 0.61	2.27 ± 0.68	0.002

Abbreviation: OSATS, Objective Structured Assessment of Technical Skill.

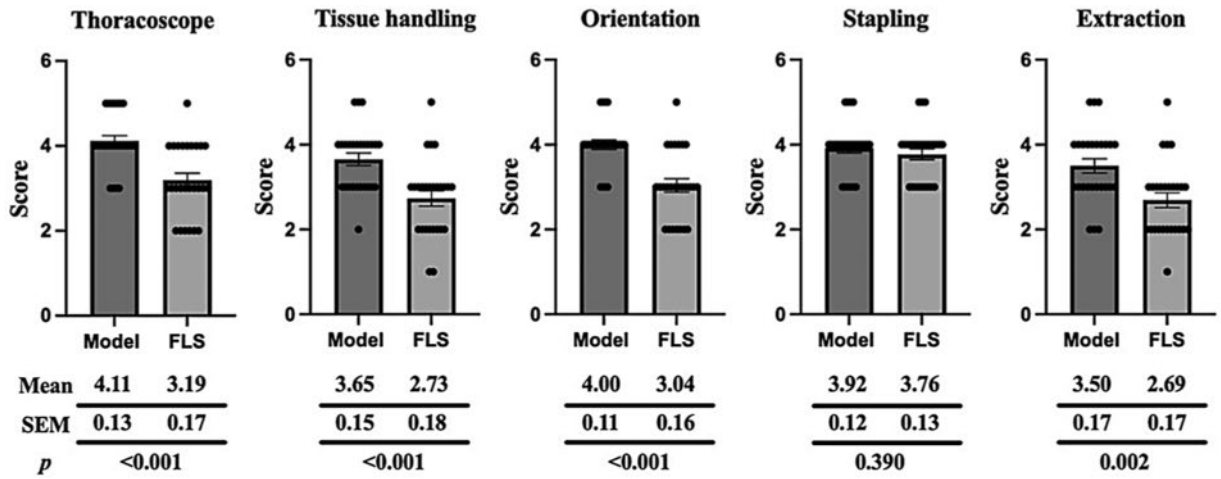

Fig. 4 Bar chart representing a comparison of mean OSATS scores between the high-fidelity lung model group and the FLS trainer group across five thoracoscopic skill domains, including the standard error of the mean (SEM) and *p*-values, during wedge resection training. FLS, Fundamentals of Laparoscopic Surgery; OSATS, Objective Structured Assessment of Technical Skill.

indicating superior spatial and procedural anatomical learning.

Technical Performance during Live Animal Surgery

During the live animal thoracoscopic wedge resection assessment, residents in the lung model group outperformed the FLS group in overall technical skill. The mean OSATS score for the lung model group was significantly higher than that for the FLS group (19.18 ± 2.43 vs. 15.41 ± 2.41; $p < 0.001$; ►**Table 2**). Specifically, higher scores were observed in four of the five OSATS domains, including thoracoscope handling (4.11 ± 0.65 vs. 3.19 ± 0.85; $p < 0.001$), tissue handling (3.65 ± 0.74 vs. 2.73 ± 0.91; $p < 0.001$), orientation (4.00 ± 0.56 vs. 3.04 ± 0.82; $p < 0.001$), and specimen extraction (3.50 ± 0.86 vs. 2.69 ± 0.88; $p = 0.002$), whereas stapling scores were comparable between groups (3.92 ± 0.62 vs. 3.76 ± 0.65; $p = 0.390$; ►**Fig. 4**).

Self-Reported Confidence Levels

Consistent with the performance outcomes, residents in the lung model group reported significantly greater confidence in performing thoracoscopic wedge resection compared with those in the FLS group (3.13 ± 0.61 vs. 2.27 ± 0.68; $p = 0.002$; ►**Table 2**).

Discussion

This study evaluated the effectiveness of a high-fidelity 3D-printed lung model compared with a conventional box trainer in enhancing anatomical understanding, technical skill acquisition, and trainee confidence during thoracoscopic wedge resection training. By employing a pretest–posttest design with standardized instructional materials and live animal surgery as assessment, we sought to rigorously examine both cognitive and psychomotor domains.

Our findings demonstrate that the high-fidelity lung model provided significant advantages over the FLS box trainer. Residents trained on the model group achieved higher posttraining anatomy scores and superior OSATS performance across most domains, particularly in spatial orientation, tissue handling, and thoracoscope manipulation. These results highlight the value of anatomical fidelity and tactile realism in simulation-based training. Given the spatial constraints and two-dimensional visual field inherent to thoracoscopic surgery, accurate anatomic modeling appears to facilitate more intuitive development of spatial reasoning and surgical procedures.

Equally noteworthy was the observed improvement in trainee confidence. Although self-reported, confidence represents a critical dimension of clinical readiness. Participants trained with the lung model consistently reported higher confidence levels, likely attributable to realistic haptic feedback, increased procedural familiarity, and greater engagement with the simulator. These findings align with psychological learning theories, in which mastery experiences are recognized as a key driver of competence development.[20]

The broader educational implications are substantial. Thoracic surgery, particularly video-assisted procedures, is characterized by a steep and unforgiving learning curve.[21] This challenge is compounded by the increasing volume of anatomical and technical knowledge required, the rapid pace of surgical innovation, and heightened expectations for patient outcomes.[22] In China, many surgical residents do not perform thoracoscopic procedures independently during training and often remain in assistant roles, limiting their operative exposure and delaying clinical autonomy.

In this context, simulation should not be considered an optional adjunct but rather a core element of surgical education. High-fidelity models allow repeated practice of essential skills, such as dissection, stapling, and spatial navigation, in a risk-free environment. Yet, the true educational value of simulation lies in its instructional design. Ericsson's framework of deliberate practice underscores that expertise emerges from structured, goal-directed,

and effortful repetition accompanied by timely feedback and self-reflection.[23,24] In our study, a stepwise simulation protocol combined with structured feedback appeared to promote not only technical performance but also psychological preparedness. These findings suggest that when grounded in sound pedagogical principles, high-fidelity simulation can accelerate the acquisition of thoracoscopic skills and facilitate the transition from passive observer to active operator.

Nonetheless, simulation alone cannot replace clinical experience. Although our results indicate successful skill transfer to live animal surgery, application in real patients remains subject to additional variables, including patient-specific anatomy, intraoperative bleeding, and the complexity of real-time surgical decision-making.[25] Moreover, non-technical competencies, such as situational awareness, communication, and teamwork, remain indispensable for safe operative practice.[26] As such, simulation should be integrated within a longitudinal training framework that combines deliberate practice with supervised operative experience, mentorship, and reflective learning.

Several limitations of this study must be acknowledged. First, it was conducted at a single institution with a relatively small sample size, which may limit generalizability. Second, the short follow-up period prevented evaluation of long-term skill retention and transfer to clinical performance. Third, although live animal models provide a more realistic operative environment than synthetic simulators, they still differ from human anatomy and cannot fully capture intraoperative variability. Future research should include multicenter studies, longer follow-up periods, and evaluation of real-world patient outcomes. Additionally, the cost-effectiveness and logistical feasibility of implementing such simulation programs across training institutions warrant further exploration.

Conclusion

This study provides quantitative evidence that high-fidelity lung simulation enhances anatomical understanding, surgical performance, and trainee confidence in thoracoscopic wedge resection. As surgical education continues to prioritize safety and efficiency, anatomically precise simulation should be recognized as a cornerstone of resident training. Future studies should focus on optimizing curriculum integration and clarifying how simulation-based learning translates into improved clinical outcomes.

Data Availability Statement

All original data are available upon reasonable request to the corresponding author.

Ethical Approval Statement

The project was reviewed and approved by the Institutional Review Board (IRB) of Peking University People's Hospital, Beijing, China.

Authors' Contribution

G.L. and F.Y. designed this study. G.L., F.Y., and Z.Z. collected the data. G.L. and Z.Z. analyzed and interpreted the data. G.L. and F.Y. wrote the manuscript. G.J. revised the manuscript. All authors have provided final approval for the version of the manuscript.

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Conflict of Interest

None declared.

References

1 Mahtabifard A, DeArmond DT, Fuller CB, McKenna RJ Jr. Video-assisted thoracoscopic surgery lobectomy for stage I lung cancer. Thorac Surg Clin 2007;17(02):223–231
2 Lazar A, Sroka G, Laufer S. Automatic assessment of performance in the FLS trainer using computer vision. Surg Endosc 2023;37 (08):6476–6482
3 Solomon B, Bizekis C, Dellis SL, et al. Simulating video-assisted thoracoscopic lobectomy: a virtual reality cognitive task simulation. J Thorac Cardiovasc Surg 2011;141(01):249–255
4 Iwasaki A, Moriyama S, Shirakusa T. New trainer for video-assisted thoracic surgery lobectomy. Thorac Cardiovasc Surg 2008;56(01):32–36
5 Meyerson SL, LoCascio F, Balderson SS, D'Amico TA. An inexpensive, reproducible tissue simulator for teaching thoracoscopic lobectomy. Ann Thorac Surg 2010;89(02):594–597
6 Tong BC, Gustafson MR, Balderson SS, D'Amico TA, Meyerson SL. Validation of a thoracoscopic lobectomy simulator. Eur J Cardiothorac Surg 2012;42(02):364–369, discussion 369
7 Jensen K, Ringsted C, Hansen HJ, Petersen RH, Konge L. Simulation-based training for thoracoscopic lobectomy: A randomized controlled trial: virtual-reality versus black-box simulation. Surg Endosc 2014;28(06):1821–1829
8 Jensen K, Bjerrum F, Hansen HJ, Petersen RH, Pedersen JH, Konge L. A new possibility in thoracoscopic virtual reality simulation training: Development and testing of a novel virtual reality simulator for video-assisted thoracoscopic surgery lobectomy. Interact Cardiovasc Thorac Surg 2015;21(04):420–426
9 Morikawa T, Yamashita M, Odaka M, et al. A step-by-step development of real-size chest model for simulation of thoracoscopic surgery. Interact Cardiovasc Thorac Surg 2017;25(02): 173–176
10 Sato T, Morikawa T. Video-assisted thoracoscopic surgery training with a polyvinyl-alcohol hydrogel model mimicking real tissue. J Vis Surg 2017;3:65
11 Martins Neto F, Moura Júnior LG, Rocha HAL, et al. Development and validation of a simulator for teaching minimally invasive thoracic surgery in Brazil. Acta Cir Bras 2021;36(05):e360508
12 Pietrabissa A, Marconi S, Negrello E, et al. An overview on 3D printing for abdominal surgery. Surg Endosc 2020;34(01):1–13
13 John J, Bosch J, Adam A, Fieggen G, Lazarus J, Kaestner L. Design and validation of a novel 3D-printed retrograde intrarenal surgery trainer. Urology 2024;191:171–176
14 Chen Y, Li M, Wu Y, Wang L, Cui Q. Design and fabrication of silicone cleft lip simulation model for personalized surgical training. J Plast Reconstr Aesthet Surg 2024;93:254–260
15 Ponzoni M, Alamri R, Peel B, et al. Longitudinal evaluation of congenital cardiovascular surgical performance and skills

retention using silicone-molded heart models. World J Pediatr Congenit Heart Surg 2024;15(03):332–339
16 Lähde S, Hirsi Y, Salmi M, Mäkitie A, Sinkkonen ST. Integration of 3D-printed middle ear models and middle ear prostheses in otosurgical training. BMC Med Educ 2024;24(01):451
17 Meglioli M, Naveau A, Macaluso GM, Catros S. 3D printed bone models in oral and cranio-maxillofacial surgery: a systematic review. 3D Print Med 2020;6(01):30
18 Liu G, Bian W, Zu G, et al. Development of a 3D printed lung model made of synthetic materials for simulation. Thorac Cardiovasc Surg 2022;70(04):355–360
19 Kenny L, Booth K, Freystaetter K, et al. Training cardiothoracic surgeons of the future: The UK experience. J Thorac Cardiovasc Surg 2018;155(06):2526–2538.e2
20 Babenko O, Oswald A. The roles of basic psychological needs, self-compassion, and self-efficacy in the development of mastery goals among medical students. Med Teach 2019;41(04): 478–481
21 Grossi S, Cattoni M, Rotolo N, Imperatori A. Video-assisted thoracoscopic surgery simulation and training: a comprehensive literature review. BMC Med Educ 2023;23(01):535
22 Lin J. Evolution of the thoracic surgeon educator: Incorporating education science into our DNA. J Thorac Cardiovasc Surg 2021; 162(02):503–509
23 Ericsson KA. Acquisition and maintenance of medical expertise: a perspective from the expert-performance approach with deliberate practice. Acad Med 2015;90(11):1471–1486
24 Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. Acad Med 2004;79(10 Suppl):S70–S81
25 Kowalczyk KA, Majewski A. Analysis of surgical errors associated with anatomical variations clinically relevant in general surgery. Review of the literature. Transl Res Anat 2021;23:100107
26 Taylor LJ, Nabozny MJ, Steffens NM, et al. A framework to improve surgeon communication in high-stakes surgical decisions: Best case/worst case. JAMA Surg 2017;152(06):531–538

