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Mediastinum & Esophagus: Short Report

Three-Dimensional Printed Model of the Mediastinum for Cardiothoracic Surgery Resident Education

Catherine T. Byrd, MD,[1] Winston L. Trope, BE,[1] H. Henry Guo, MD, PhD,[2] Kyle Gifford, BA,[2] Prasha Bhandari, MPH,[1] Jalen Benson, AB,[1] Douglas Z. Liou, MD,[1] Leah M. Backhus, MD, MPH,[1] Mark F. Berry, MD,[1] Joseph B. Shrager, MD,[1] and Natalie S. Lui, MD, MAS[1]

ABSTRACT

BACKGROUND Mediastinoscopy remains an important component of lung cancer staging. The development of endobronchial ultrasonography has meant residents perform fewer mediastinoscopies. We hypothesized that a 3-dimensional printed model of the mediastinum would be an effective tool for teaching residents the anatomy and techniques for mediastinoscopy.

METHODS A color model of the mediastinum was 3-dimensionally printed based on segmented computed tomographic images. For 2 years, residents and attendings were asked to provide a skills assessment after every mediastinoscopy. During the second year, all residents received standardized instruction for mediastinoscopy using the 3-dimensional model. Skills assessments were compared between the residents taught with and without the 3-dimensional model.

RESULTS There were 49 resident and 65 attending surveys completed. Residents taught with the 3-dimensional model were more likely to answer that they could identify normal anatomy "well"/"very well" compared with residents taught without the model (86% vs 52%, $P = .015$). Residents taught with the 3-dimensional model more frequently answered they were able to perform an uncomplicated mediastinoscopy "well"/ "very well" (59% vs 31%, $P = .079$) compared with residents taught without the 3-dimensional model, although this was not significant. Attendings were equally likely to answer "well"/"very well" that residents taught with the 3-dimensional model could identify normal anatomy (52% vs 55%, $P > .99$) and perform an uncomplicated mediastinoscopy (48% vs 43%, $P = .79$) compared with those taught without the model.

CONCLUSIONS A 3-dimensional printed model of the mediastinum may be an effective tool for teaching mediastinoscopy.

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Mediastinal staging in non-small cell lung cancer guides treatment. Those with resectable N2 disease may undergo induction therapy preoperatively, whereas those with N3 disease undergo definitive chemoradiation.[1] Endobronchial ultrasound with transbronchial needle aspiration and endoscopic ultrasound with needle aspiration to stage the mediastinum have decreased mediastinoscopy frequency.[2,3] Many surgeons agree that

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[1]Department of Cardiothoracic Surgery, Stanford University School of Medicine, Stanford, California; and [2]Department of Radiology, Stanford University School of Medicine, Stanford, California
Address correspondence to Dr Lui, Stanford Hospital, Falk Building, 300 Pasteur Dr, Stanford, CA 94305-5407; email: natalielui@stanford.edu.

mediastinoscopy is required when there is concern for positive nodes despite a negative endobronchial ultrasound with transbronchial needle aspiration result.[4] Experience is also needed to address the most serious intraoperative complication, hemorrhage, occurring in ~0.25% of cases.[5,6] There is concern that institutions lack the volume of mediastinoscopy to adequately teach it.[7]

Simulation is a resource for teaching difficult procedures. Customizable simulation models can be designed using three-dimensional (3D) printing.[8] Previous 3D printed models used in cardiothoracic training have demonstrated improvement in resident operative skills.[9] Given that success, we created a 3D printed model of the mediastinum and hypothesized that it may be a useful training tool.

MATERIAL AND METHODS

The Stanford University Institutional Review Board provided a notice of exempt review for this study.

A color model of the mediastinum was 3D printed based on computed tomographic (CT) images (Figure panel A). The CT image had normal anatomy aside from large lymph nodes. CT images were segmented using Materialise Mimics (Materialise, Leuven, Belgium) and exported as mesh (.stl) files. The files were assembled in Maya for repair and rendering (Autodesk, San Rafael, CA). Three manipulations were made:

1. The sternum was detachable from the model, increasing visibility of anterior mediastinal structures.
2. A pretracheal space was engineered to accommodate a video mediastinoscope (Figure panel B).
3. The left recurrent laryngeal nerve was drawn.

The files were printed on a Stratasys J735 (Stratasys, Eden Prairie, MN) industrial-level printer. The bones were printed using VeroPure-White and VeroYellow. Other structures were printed with various colors and blended with Agilus30 Clear material for flexibility.

During the first year of the study, residents prepared as they would for any procedure. During the second year, all residents on the service attended a monthly teaching session. They received standardized instruction using the 3D model, which included review of the anatomy, technical aspects mediastinoscopy, practice with the video mediastinoscope, and actions to take in the event of a complication, with specific instruction on hemorrhage (Figure panels C-E). Residents practiced the technique with corrective attending instruction.

During the second year the model was available before each mediastinoscopy for review with the attending and for self-study. Throughout the first year of the study, residents and attendings were asked to complete an anonymous online skills assessment after every mediastinoscopy. In the second year of the study, after the introduction of teaching using the mediastinoscopy model, residents and attendings were again asked to complete the anonymous assessment after every mediastinoscopy.

Baseline resident characteristics were assessed using the Pearson χ^2 test or Wilcoxon rank sum test. Skills assessment scores were based on a Likert scale. For resident self-assessments and attending assessments, the Likert scores were converted into a binary variable—those with an above-average score (scored as a 4 [“well”] or 5 [“very well”]) and those with an average or below-average score, scored as a 1 (“not at all”), 2 (“below average”), or 3 (“average”). The binary proportions were then compared between the groups with and without the 3D model using the Fisher exact test. We performed the same examination for senior residents, those greater than postgraduate year 3. A P of $<.05$ was significant. Analyses were completed using SAS 9.4.1 (SAS Institute, Inc, Cary, NC), SPSS Statistics 26 (IBM), and R (R Core Team, 2020) software.

IN SHORT

- Our group created a 3-dimensional printed mediastinal model to help teach surgical residents mediastinoscopy.
- Residents taught with the mediastinal model were more confident in their ability to identify normal anatomy and perform uncomplicated mediastinoscopy.

RESULTS

RESIDENT SELF-ASSESSMENT. There were 49 resident surveys completed, including 27 without the 3D model and 22 with the 3D model over 2 years (Table 1). They ranged from postgraduate year 1 to 8. The median number of mediastinoscopies participated in was 10 (interquartile range, 11), demonstrating wide range in experience. There was no difference in the median number of

FIGURE (A) Anteroposterior view of the mediastinal model with the sternum removed and (B) right lateral view of the model with the mediastinoscope in place. (C) Instruction using the mediastinal model. (D) A view into the printed mediastinum using the mediastinoscope shows the pink innominate artery, blue pulmonary arteries, white trachea, and green lymph nodes. (E) Preoperative review with the attending.

TABLE 1 Resident Characteristics

Characteristics	Total (N = 49)	Without 3D Model (n = 27)	With 3D Model (n = 22)	*P* Value
Type of training program				.17
General surgery residency	4 (8)	3 (11)	1 (5)	
Integrated cardiothoracic residency	18 (37)	12 (44)	6 (27)	
Cardiac track fellowship	6 (12)	1 (4)	5 (23)	
Thoracic track fellowship	21 (43)	11 (41)	10 (45)	
Postgraduate training stage				.76
Junior resident (postgraduate year 1-3)	15 (31)	9 (33)	6 (27)	
Senior resident (postgraduate year >3)	34 (69)	18 (67)	16 (73)	
Estimated number of mediastinoscopies				
Performed before the survey date	10.00 (5.00-16.00)	14.00 (3.50-16.50)	7.50 (5.00-10.75)	.31
Performed in the last 6 months, mean (SD)	4.35 (3.43)	4.33 (3.83)	4.36 (3.02)	.98

Data are presented as n (%) or median (interquartile range), unless indicated otherwise.

mediastinoscopies performed by those who did and did not receive model training (P = .31, Wilcoxon rank sum test).

In comparing the 22 residents taught with the model and the 27 taught without the model, residents taught with the 3D model were more likely

TABLE 2 Resident Skills Self-Assessment

Characteristics	Total (N = 49)	Without 3D Model (n = 27)	With 3D Model (n = 22)
How well prepared were you for the mediastinoscopy?			
1 Not at all	0 (0)	0 (0)	0 (0)
2	3 (6)	2 (7)	1 (5)
3	18 (37)	15 (56)	3 (14)
4	16 (33)	4 (15)	12 (55)
5 Very well	12 (24)	6 (22)	6 (27)
How well could you identify normal anatomy?			
1 Not at all	0 (0)	0 (0)	0 (0)
2	1 (2)	1 (4)	0 (0)
3	15 (31)	12 (44)	3 (14)
4	18 (37)	10 (37)	8 (36)
5 Very well	15 (31)	4 (15)	11 (50)
How well could you perform an uncomplicated mediastinoscopy? (n = 48)			
1 Not at all	5 (10)	3 (12)	2 (9)
2	8 (17)	4 (15)	4 (18)
3	14 (29)	11 (42)	3 (14)
4	8 (17)	4 (15)	4 (18)
5 Very well	13 (27)	4 (15)	9 (41)
How well could you handle an intraoperative complication during mediastinoscopy? (n= 46)			
1 Not at all	(13)	6 (25)	0 (0)
2	11 (24)	6 (25)	5 (23)
3	19 (41)	7 (29)	12 (5)
4	10 (22)	5 (21)	5 (23)
5 Very well	0 (0)	0 (0)	0 (0)

Data are presented as n (%).

TABLE 3 Attending Assessment of Residents

Characteristics	Total (N = 65)	Without 3D Model (n = 44)	With 3D Model (n = 21)
How well prepared was the resident for the mediastinoscopy? (n = 63)			
1 Not at all	3 (5)	3 (7)	0 (0)
2	7 (11)	5 (12)	2 (10)
3	13 (21)	7 (17)	6 (29)
4	20 (32)	14 (33)	6 (29)
5 Very well	20 (32)	13 (31)	7 (33)
How well could the resident identify normal anatomy? (n = 61)			
1 Not at all	3 (5)	3 (8)	0 (0)
2	8 (13)	8 (20)	0 (0)
3	17 (28)	7 (18)	10 (48)
4	22 (36)	19 (48)	3 (14)
5 Very well	11 (18)	3 (8)	8 (38)
How well could the resident perform an uncomplicated mediastinoscopy? (n = 65)			
1 Not at all	11 (17)	10 (23)	1 (5)
2	14 (22)	6 (14)	8 (38)
3	11 (17)	9 (20)	2 (10)
4	20 (31)	16 (36)	4 (19)
5 Very well	9 (14)	3 (7)	6 (29)
How well could the resident handle an intraoperative complication during mediastinoscopy? (n= 58)			
1 Not at all	13 (22)	10 (27)	3 (14)
2	11 (19)	7 (19)	4 (19)
3	15 (26)	7 (19)	8 (38)
4	17 (29)	12 (32)	5 (24)
5 Very well	2 (3)	1 (3)	1 (5)

Data are presented as n (%).

to answer "well"/"very well" for how prepared they were (82% vs 37%, $P = .003$) and their ability to identify normal anatomy (86% vs 52%, $P = .015$) (Table 2). More residents taught with the model (n = 22) also answered "well"/"very well" for their ability to perform an uncomplicated mediastinoscopy (59% vs 31%, $P = .079$) compared with those taught without the model (n = 26). This was not statistically significant. There was no difference in residents' assessment of their ability to manage intraoperative complications "well"/"very well" (23% vs 21%, $P > .99$) between those taught with the model (n = 22) and those taught without it (n = 24). Only 1 intraoperative complication (bleeding) occurred during the 2-year time frame of the study.

SENIOR RESIDENT SELF-ASSESSMENT. Senior residents taught with the model (n = 16) were also more likely to answer "well"/"very well" compared with those taught without the model (n = 18) for how prepared they were (94% vs 50%, $P = .008$) and their ability to identify normal anatomy (94% vs 61%, $P = .043$) (Supplemental Table). Senior residents taught with the model (n = 16) were also more likely to answer "well"/"very well" compared with those taught without the model (n = 17) for how well they could perform an uncomplicated mediastinoscopy (81% vs 47%, $P = .071$), although this trend did not reach statistical significance. There was no statistical difference in the senior residents' assessment of their ability to manage intraoperative complications "well"/"very well" (25% vs 29%, $P > .99$) between those taught with the model (n = 16) and those taught without it (n = 17).

ATTENDING ASSESSMENT OF RESIDENTS. The attendings completed 65 surveys, including 44 before the introduction to the 3D model and 21 after the introduction of the model (Table 3). Attendings were equally likely to answer "well"/"very well" that residents taught with the 3D model (compared with those taught without the model) were prepared for the mediastinoscopy (62% vs 64%, $P > .99$), could identify normal anatomy (52% vs 55%, $P > .99$), and could perform an uncomplicated mediastinoscopy (48% vs 43%, $P = .79$). Interestingly, there were significant differences when a different binary category of 1 to 4 ("not at all" to "well") and 5 ("very well") was used. Attendings were more likely to answer, "very well" that residents taught with the 3D model (compared with those taught without the model) could identify normal anatomy (38% vs 8%, $P = .005$) and could perform an uncomplicated mediastinoscopy "very well" (29% vs 7%, $P = .048$).

COMMENT

This study establishes that our 3D mediastinoscopy model is a useful tool to facilitate formal instruction for mediastinoscopy. 3D printed surgical models allow tactile interaction with complex anatomy.[8,10] This is especially important for procedures, such as mediastinoscopy, whose case numbers are dwindling.[2,3] High technical skill is vital to obtain adequate nodal samples, improve diagnostic accuracy, and to respond to the low but present risk of life-threatening hemorrhage during mediastinoscopy.[5,6]

The model was associated with improved confidence in preparedness, anatomic knowledge, and ability to perform uncomplicated mediastinoscopy, but the model did not improve confidence in ability to handle a complication. It is possible that residents provided an appropriately cautious answer, because only 1 complication occurred during the study period. This intraoperative bleeding complication occurred before the introduction of the model. Additionally, the attendings did not note a significant change in resident's knowledge or ability with the introduction of the model.

There were some limitations. First, we were unable to account for correlation within the data. Some of the residents performed several mediastinoscopies and were surveyed after each procedure. Additionally, a few senior residents did have multiple rounds of exposure to the model and mediastinoscopy, so there may be experience bias. However, most residents rotated on the thoracic surgery service only once over the 2-year study period. Thus, a paired analysis comparing survey results from the same person without and with the model was impossible.

Second, we lacked objective measures. We attempted to account for this by using both self-reporting and attending evaluations. Attending and resident evaluations were not linked, however, making it difficult to draw specific conclusions.

Third, there was a difference in how attendings rated the residents and how the residents rated themselves. The attendings rated the residents much lower. We did not provide specific descriptions about what would correspond to each component of the Likert scale. Thus, the residents and attendings could be judging from different mind-sets. This difference in rating may also signify that attendings generally would like for the residents to have more experience with mediastinoscopy.

Despite these limitations, our data suggest that the 3D printed mediastinoscopy model is a beneficial teaching tool to improve self-efficacy in learning mediastinoscopy. 3D printing has great potential for cardiothoracic training.

The Supplemental Table can be viewed in the online version of this article [https://doi.org/10.1016/j.atssr.2024.07.031] on https://www.annalsthoracicsurgery.org.

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DISCLOSURES

The authors have no conflicts of interest to disclose.

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