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Novel Robotic Esophagogastric Anastomosis Simulation Model for Skill Development and Training

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ABSTRACT

BACKGROUND Esophagogastric anastomosis is a critical step of esophagectomy. We aimed to develop a novel robotic esophagectomy simulator with high rates of fidelity and educational value for trainee surgeons to advance these skills in a low-risk setting.

METHODS A porcine esophagus-stomach block was secured on a platform resembling the anatomy during an esophagectomy, and a da Vinci Xi (Intuitive Surgical) robotic system was docked above it. Participants completed 5 key steps (creating the gastric conduit, transecting the esophagus, making the gastrotomy and esophagotomy, creating the anastomosis, and sewing the common enterotomy). The model was assessed through surveys under domains of fidelity (surgical field, reality of materials, anatomy, and experience) and value as a training tool on a scale of 1 to 5 (strongly disagree to strongly agree).

RESULTS Of 14 participants, 8 (57.1%) were women, 9 (64.3%) were integrated cardiothoracic surgery residents, 1 (7.1%) was a thoracic-track resident, and 10 (71.4%) were in postgraduate year 4 or higher. Participants thought most aspects of the model had high fidelity, including the anatomy of conduit (4.8 ± 0.4) and proximal esophagus (4.9 ± 0.4), realism of the stomach (4.9 ± 0.4) and esophagus (4.9 ± 0.4), stapling (4.7 ± 0.6), suturing (4.8 ± 0.4), and tissue handling (4.4 ± 0.6). Participants rated the model highly overall (4.7 ± 0.5) and as a training tool (4.9 ± 0.4), with strong interrater reliability (0.69).

CONCLUSIONS The robotic esophagogastric simulation model demonstrated high fidelity and value as a training tool, suggesting its potential effectiveness for surgeons with limited experience. However, it warrants further refinement to address limitations and to optimize its value as a training tool.

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Although the concept of simulation in cardiothoracic surgery training has existed for some time, efforts until now have predominantly focused on creation of simple bench models that allow practice of only discrete tasks rather than of complete procedures.

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Moreover, a systematic review by Trehan and coworkers[1] showed that most of the procedural simulators in cardiothoracic surgery were created for cardiac procedures, such as bypass grafting, and pulmonary procedures, such as lobectomy, with a substantial gap in models dedicated for esophageal procedures. There are 2 known models for esophageal anastomosis, but neither of them incorporates the robotic system as part of the simulation.[2,3] Robot-assisted surgery lends itself to simulation because the system and instruments are the same as those used in a real-life setting.[4,5]

Despite the increasing adoption of the robotic approach for esophageal procedures,[6] no robotic simulation models or standardized curricula have been developed to facilitate the transition. We aimed to develop an innovative robotic esophagogastric anastomosis (EGA) simulation model with high rates of fidelity to the actual operating room experience. We hoped this would have educational value as a training tool for trainee surgeons to acquire or to advance their skills in preparing a gastric conduit and performing an EGA in a low-risk setting.

MATERIAL AND METHODS

ROBOTIC EGA SIMULATION MODEL. We developed a robotic EGA simulation model using a porcine esophagus-stomach block with a da Vinci Xi robotic system (Intuitive Surgical) docked above it (Figure 1). The porcine anatomic model was rinsed intraluminally with tap water. It was placed on a synthetic surgical drape secured with tacks at the upper end of the esophagus, gastroesophageal junction, and pylorus to a polystyrene foam board fixed to an immobile platform. The robotic system was first positioned over the stomach, akin to operating in the abdomen, then moved over the esophagus, akin to operating in the chest. The simulation model underwent in-person testing by the study team, which defined the key steps of an Ivor Lewis esophagectomy as the simulation curriculum (Figure 2). The 5 key steps were creating the gastric conduit, transecting the esophagus, making the gastrotomy and esophagotomy, creating the anastomosis, and suturing the common enterotomy. Skills involved included stapling (creating the gastric conduit, transecting the esophagus, and creating the anastomosis), bipolar cautery (making the gastrotomy and esophagotomy), and suturing (suturing the common enterotomy). The intent of this curriculum was to simulate performing an EGA after the perigastric and periesophageal dissection has been completed.

IN SHORT

- Robot-assisted surgery lends itself to simulation because the system and instruments are the same as those used in a real-life setting.
- However, current robotic simulation training allows practice of only discrete tasks, like maneuvering and suturing.
- We assembled a novel robotic esophagectomy simulator for trainees to practice the technical skills relevant to creation of esophagogastric anastomoses.

STUDY PARTICIPANTS AND WORKFLOW. We included general surgery residents, cardiothoracic surgery integrated residents, and traditional cardiothoracic surgery residents at our academic, tertiary care hospital. The study was reviewed and approved by our institutional review board. Beginning with a 10- to 15-minute introductory lecture by the senior author (N.S.L.) to all participants, using photographic and video aids to describe key steps and techniques, followed by a question and answer session, trainees proceeded to the simulation, where each trainee had an individual 30- to 60-minute session with the study team.

The participant completed the 5 key steps in the EGA as the console surgeon, guided by the senior author (N.S.L.), while a member of the study team served as the bedside assistant. The time for the completion of each task was recorded to assess the feasibility of completing the entire curriculum within the session. At the end of the session, participants completed an anonymous online survey, rating aspects of the simulation model and giving subjective opinions about the simulation session.

SURVEY TOOL. A 28-item survey was developed with consensus of the first (L.Y.W. and D.K.) and senior (N.S.L.) authors (Figure 3). Participants were asked to rate the EGA simulation model in domains of fidelity and value on a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

STATISTICAL ANALYSIS. Descriptive statistics were used to summarize participant characteristics and the time taken for each task of the study procedure. Continuous data were presented as mean (±SD) or median (interquartile range), and categorical data were presented as frequency

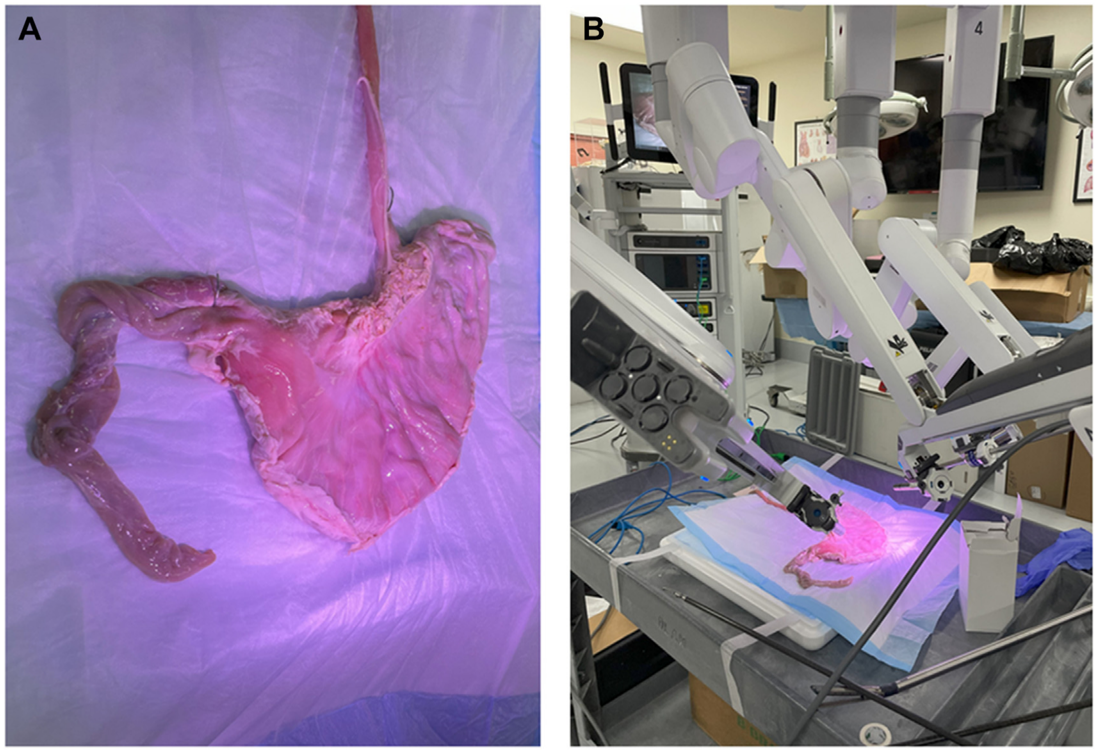


FIGURE 1 The porcine anatomic esophagogastric anastomosis simulation model (A) pinned to the table and (B) with the robotic system positioned above it.

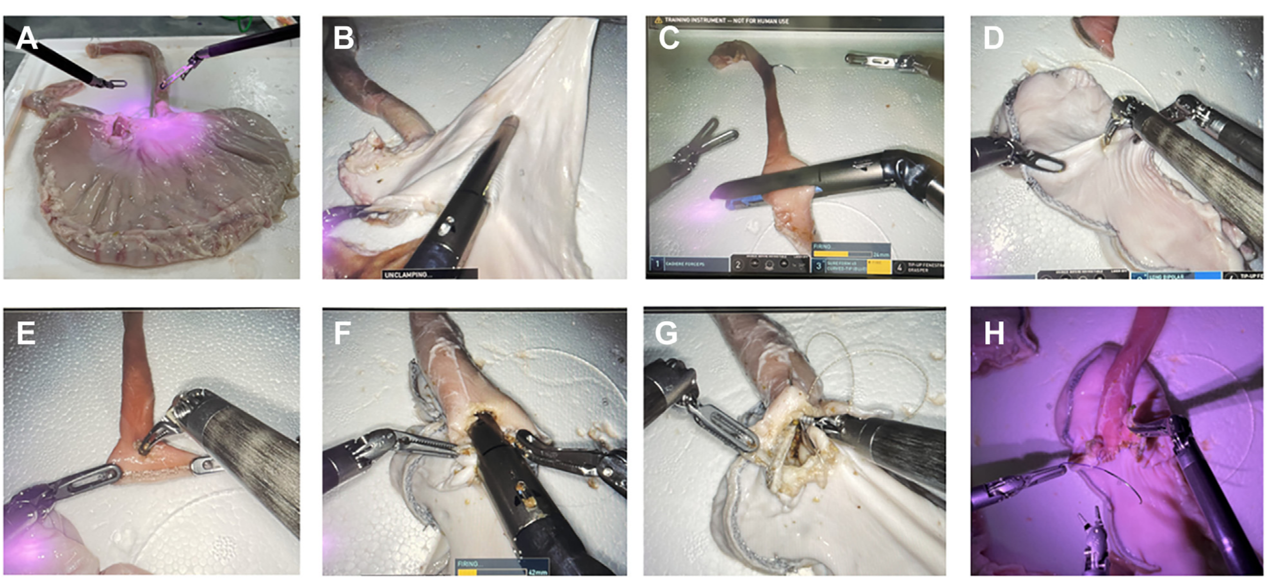
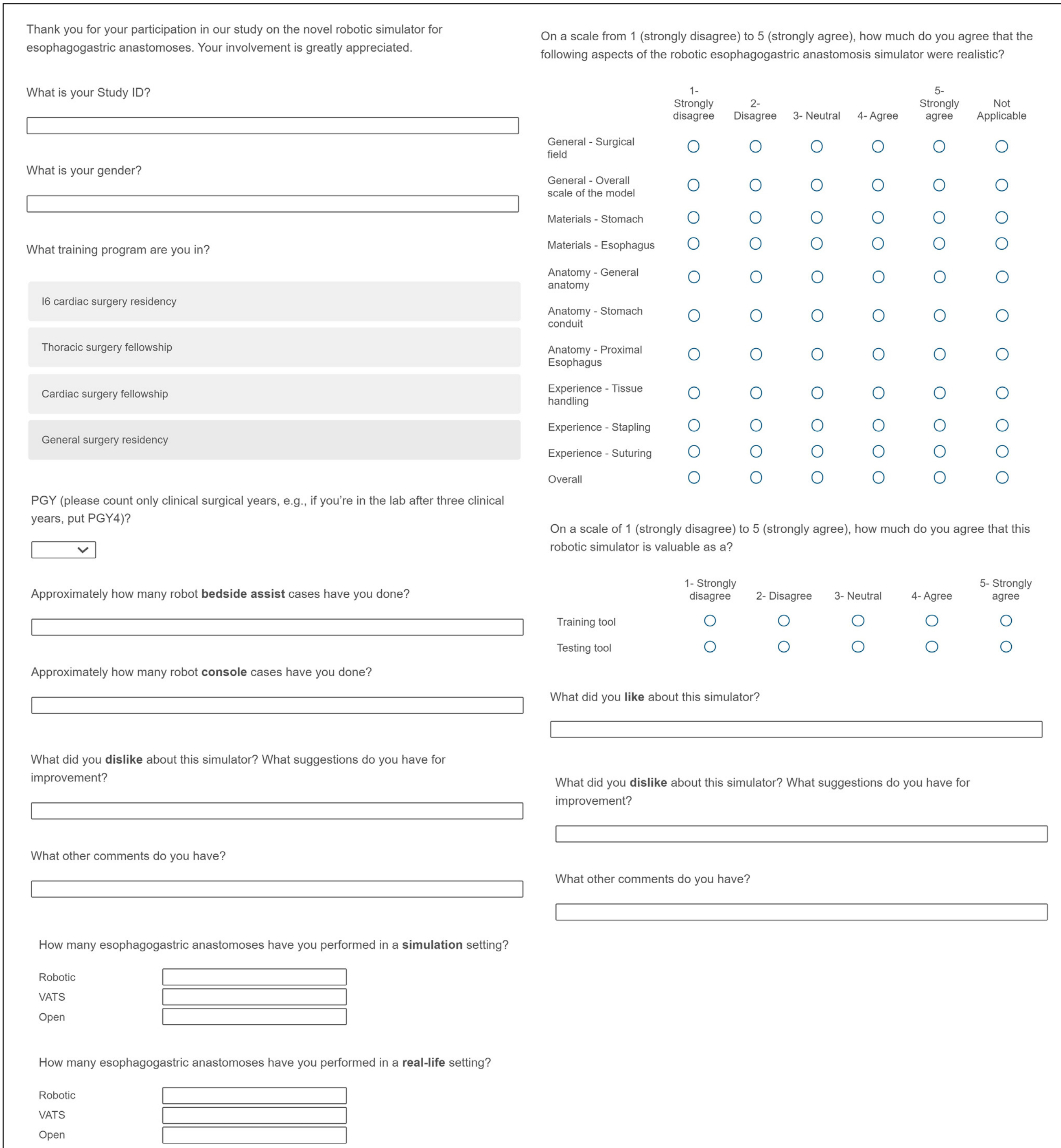


FIGURE 2 The robotic esophagogastric anastomosis simulation model, including (A) the porcine esophagus-stomach block with robot docked, (B) creating the gastric conduit with a linear stapler, (C) transecting the esophagus with a linear stapler, (D) making a gastrotomy with bipolar cautery, (E) making an esophagotomy with bipolar cautery, (F) creating the anastomosis with a linear stapler, (G) sewing the common enterotomy with needle driver and barbed suture (V-Loc; Medtronic), and (H) completed esophagogastric anastomosis.


Thank you for your participation in our study on the novel robotic simulator for esophagogastric anastomoses. Your involvement is greatly appreciated.

What is your Study ID?

What is your gender?

What training program are you in?

- I6 cardiac surgery residency
- Thoracic surgery fellowship
- Cardiac surgery fellowship
- General surgery residency

PGY (please count only clinical surgical years, e.g., if you're in the lab after three clinical years, put PGY4)?

Approximately how many robot **bedside assist** cases have you done?

Approximately how many robot **console** cases have you done?

What did you **dislike** about this simulator? What suggestions do you have for improvement?

What other comments do you have?

How many esophagogastric anastomoses have you performed in a **simulation** setting?

Robotic
VATS
Open

How many esophagogastric anastomoses have you performed in a **real-life** setting?

Robotic
VATS
Open

On a scale from 1 (strongly disagree) to 5 (strongly agree), how much do you agree that the following aspects of the robotic esophagogastric anastomosis simulator were realistic?

	1- Strongly disagree	2- Disagree	3- Neutral	4- Agree	5- Strongly agree	Not Applicable
General - Surgical field	○	○	○	○	○	○
General - Overall scale of the model	○	○	○	○	○	○
Materials - Stomach	○	○	○	○	○	○
Materials - Esophagus	○	○	○	○	○	○
Anatomy - General anatomy	○	○	○	○	○	○
Anatomy - Stomach conduit	○	○	○	○	○	○
Anatomy - Proximal Esophagus	○	○	○	○	○	○
Experience - Tissue handling	○	○	○	○	○	○
Experience - Stapling	○	○	○	○	○	○
Experience - Suturing	○	○	○	○	○	○
Overall	○	○	○	○	○	○

On a scale of 1 (strongly disagree) to 5 (strongly agree), how much do you agree that this robotic simulator is valuable as a?

	1- Strongly disagree	2- Disagree	3- Neutral	4- Agree	5- Strongly agree
Training tool	○	○	○	○	○
Testing tool	○	○	○	○	○

What did you **like** about this simulator?

What did you **dislike** about this simulator? What suggestions do you have for improvement?

What other comments do you have?

FIGURE 3 The complete Qualtrics survey administered to gather participants' perceptions of the simulation model, focusing on the domains of fidelity and its value as a training and testing tool (PGY, postgraduate year; VATS, video-assisted thoracoscopic surgery).

and proportions. To evaluate for evidence of validity pertaining to internal structure, inter-rater reliability between participant responses was estimated by a 2-way random effects model and reported as intraclass correlation with 95% CIs.

RESULTS

PARTICIPANT CHARACTERISTICS. Of 14 total participants, there were 9 (64.3%) cardiothoracic surgery integrated residents, 3 (21.4%) general surgery residents, 1 (7.1%) thoracic surgery fellow, and 1

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(7.1%) cardiac surgery fellow (Supplemental Table 1). All participants had some robotic experience, with a median of 7.5 (interquartile range, 0-18.5) cases as console surgeon and 20 (9.5-35) cases as bedside assistant.

SIMULATION MODEL RATINGS. Participants rated the fidelity of the simulation model very highly (Table). The highest ratings were for realism of the anatomy of the conduit (mean ± SD, 4.79 ± 0.42) and proximal esophagus (4.86 ± 0.36), the stomach (4.86 ± 0.36) and esophagus (4.86 ± 0.36), and the experience of stapling (4.71 ± 0.61) and suturing (4.85 ± 0.37). The lowest ratings were for realism of the surgical field (4.36 ± 0.74) and tissue handling (4.43 ± 0.64). The participants rated the simulation model highly on its value as a training tool (4.86 ± 0.36) but lower on its value as a testing tool (4.36 ± 0.74).

The median time taken to complete each of the tasks of the simulation curriculum is presented in Supplemental Table 2. Overall, most participants were able to complete the simulation curriculum in 33.9 (26.8-44.6) minutes, around the stipulated time of 30 to 60 minutes.

SUBJECTIVE RESPONSES TO OPEN-ENDED QUESTIONS. The responses to the open-ended questions were reviewed and categorized into themes (Supplemental Table 3). Participants responded that the advantages of the model included handling real tissue (75%) and receiving one-on-one instruction (25%), whereas limitations of the model included the lack of periesophageal dissection (37.5%) and excessively mobile tissue specimens (37.5%).

COMMENT

One of the major barriers to surgical education through simulation training has been the wide variety of models available, including 3-dimensional (3D) printed synthetic models, cadaver and animal tissue models, and virtual reality. Orringer and coworkers[2] devised and demonstrated the fidelity and value of a 3D printed model using silicone to facilitate practice of a cervical EGA. Despite the low cost, limitations remain with tissue realism and realism of suturing as the lowest ratings recorded for these measures. Tissue-based cadaver or animal models address these limitations effectively by offering realistic anatomic and tissue experience, as evidenced by the highest rating observed on these same measures. Moreover, there is also need for standardization of the measures used to validate these models, enabling the integration of these models into structured training programs.[7]

Given the recent rapid shift in trend toward the expansion of robot-assisted surgery across all subspecialties,[8] simulation training in robot-specific curricula is all the more relevant. Simulation training with robotic systems provides additional advantages, such as integrated software using artificial intelligence that can provide feedback and assessment of quality of surgical movements, force, and tension applied on tissue.[9] A study by Liddy and colleagues[10] on

TABLE Summary Data of Participant Feedback on Fidelity, Realism, and Value of the Robotic Esophagectomy Simulation Model

Variable	Scoring, No. (%) 1 (strongly disagree)	2 (disagree)	3 (neutral)	4 (agree)	5 (strongly agree)	Mean ± SD	Intraclass Correlation Coefficient (95% CI)
Overall scale of the model	0 (0)	0 (0)	1 (7.1)	1 (7.1)	11 (78.6)	4.77 ± 0.59	
Surgical field	0 (0)	0 (0)	2 (14.3)	5 (35.7)	7 (50.0)	4.36 ± 0.74	
Realism of anatomy							
General anatomy	0 (0)	0 (0)	0 (0)	4 (28.6)	10 (78.6)	4.71 ± 0.46	0.82 (0.56–0.94)
Stomach conduit	0 (0)	0 (0)	0 (0)	3 (21.4)	11 (78.6)	4.79 ± 0.42	
Proximal esophagus	0 (0)	0 (0)	0 (0)	2 (14.3)	12 (85.7)	4.86 ± 0.36	
Realism of materials							
Stomach	0 (0)	0 (0)	0 (0)	2 (14.3)	12 (85.7)	4.86 ± 0.36	0.61 (−0.31 to 0.88)
Esophagus	0 (0)	0 (0)	0 (0)	2 (14.3)	12 (85.7)	4.86 ± 0.36	
Realism of experience							
Tissue handling	0 (0)	0 (0)	1 (7.1)	6 (42.9)	7 (50.0)	4.43 ± 0.64	0.51 (−0.17 to 0.83)
Stapling	0 (0)	0 (0)	1 (7.1)	2 (14.3)	11 (78.6)	4.71 ± 0.61	
Suturing	0 (0)	0 (0)	0 (0)	2 (14.3)	11 (78.6)	4.85 ± 0.37	
Value							
As a training tool	0 (0)	0 (0)	0 (0)	2 (14.3)	12 (85.7)	4.86 ± 0.36	0.22 (−0.66 to 0.70)
As a testing tool	0 (0)	0 (0)	2 (14.3)	5 (35.7)	7 (50.0)	4.36 ± 0.74	
Overall	0 (0)	0 (0)	0 (0)	4 (28.6)	10 (78.6)	4.71 ± 0.47	

tracheoesophageal repair using a 3D simulator and physical force sensors to measure and compare surgical performance between novice and expert surgeons is one such example. Although the surgical robot lends itself to an effective simulation model for training purposes, challenges related to costs and logistics may not be feasible for most institutions, thus precluding its widespread adoption. In such a case, a more effective choice involves a centralized boot-camp session during conference meetings.

Future directions to more accurately assess the simulator include conducting a similar study with experienced surgeons currently performing robot-assisted esophagectomies in their clinical practice to evaluate the fidelity of this training tool. The potential of social desirability bias in our study is acknowledged, as trainees may be more likely to enjoy a simulator created by their attendings and may not be able to separate educational satisfaction and simulator fidelity. In addition, the time taken to perform each procedural step was evaluated to ascertain the feasibility of completing the study within 30- to 60-minute sessions rather than to assess skill levels. Incorporating additional metrics, such as tissue handling and movement efficacy, would likely offer a more comprehensive assessment of the participants' skills and the effectiveness of the training, beyond time alone. Regarding technical aspects, the inability to re-create the periesophageal field, the compact nature of the thoracic cavity, and the challenges with patient positioning and ventilatory changes common to esophageal procedures preclude practice of other crucial steps of a minimally invasive esophagectomy. However, some of these limitations can be overcome by using porcine organ blocks with attached periesophageal tissues enclosed in box trainers. Hence, with further refinements and a broader testing pool, we believe that this robotic EGA simulation model holds potential for use as a training tool to aid in skill transfer of this critical step of minimally invasive esophagectomy and to advance the training of residents, fellows, and early-career surgeons.

CONCLUSION

We developed a robotic EGA simulation model that facilitates practice through a structured curriculum with one-on-one instructorship, in accordance with several consensus recommendations for robotic esophagectomy training by expert robotic surgeons. The model could be a valuable training tool for trainees and early-career surgeons learning these key steps of an esophagectomy, with the goal of reducing the morbidity and mortality of this procedure and improving long-term patient outcomes.

The Supplemental Tables can be viewed in the online version of this article [https://doi.org/10.1016//j.atssr.2024.07.030] on http://www.annalsthoracicsurgery.org.

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DISCLOSURES

The authors have no conflicts of interest to disclose.

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