

Development of a median sternotomy simulation model for cardiac surgery training



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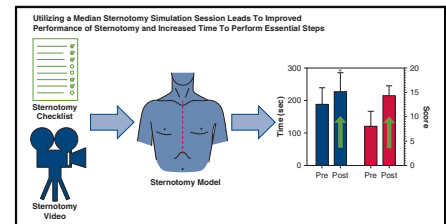
ABSTRACT

Objective: We sought to develop a simulation model to train resident physicians in the performance of a median sternotomy.

Methods: A modified Delphi consensus process was used with cardiac surgery staff to develop a 20-point checklist for the safe performance of a median sternotomy. Thirteen junior cardiac surgery trainees from across Canada participated in this study to assess the simulation model. Trainees performed the sternotomy before and after reviewing an instructional video. Two senior cardiac surgery resident physicians assessed the participants with the checklist during each session. An entry and exit questionnaire was given to the participants to evaluate the simulation model.

Results: Participants scored higher after the training (14.3 ± 2.0) compared with before training (8.0 ± 3.1) ($P < .001$). The mean duration of time for participants to complete the sternotomy was shorter before training (188 ± 52 seconds vs 228 ± 58 seconds; $P = .003$). The checklist interrater reliability was $\kappa = 0.47$ (moderate) for before training and $\kappa = 0.37$ (fair) for after training. All study participants rated the simulation sessions as very useful or extremely useful.

Conclusions: Using the simulation model, training video, and checklist, trainees were able to improve their skill in performing a median sternotomy. This improvement was associated with longer times to complete all procedure steps. Rater training may further improve interrater reliability. Our median sternotomy checklist and simulation model can be adopted for the technical skills training of future cardiac surgery trainees. (JTCVS Techniques 2020;2:109-16)



A sternotomy model, video, and checklist leads to performance improvement.

CENTRAL MESSAGE

An inexpensive simulation model and didactic video helps trainees improve their technical performance on the essential skill of median sternotomy.

PERSPECTIVE

Simulation affords trainees increased opportunities to develop their skills in a safe environment. Checklists allow trainees to be assessed in their skill performance while also providing a study aid. Our sternotomy model and checklist led to improved performance in this essential skillset. This inexpensive model and checklist can potentially be incorporated into other cardiothoracic training programs.

See Commentaries on pages 117 and 119.

Video clip is available online.

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Simulation-based training is being increasingly incorporated in cardiac surgery training programs across North America.¹⁻⁶ The simulation lab is an ideal arena for the acquisition of technical skills because it allows for deliberate practice in a low stakes, low stress, and safe environment.^{1,7,8} As more surgical residency programs transition from a time-based training model toward a competency-based medical education model, trainees will require more objective measures of performance and competency as well as validated assessment tools for these

measures.⁹ Task-specific checklists, global rating scales, and objective structured assessment of technical skills are some of the assessment tools being employed in the assessment of surgical trainees.^{9,10} In particular, task-specific checklists allow the trainee to be assessed throughout pivotal points of the procedure and also act as a study aid for reviewing the procedure.^{9,10}

Median sternotomy is an essential and foundational skill for cardiac surgery training. Although the median sternotomy is learned during the early stages of training; that is, postgraduate years 1 and 2,¹¹ it is an essential skill to master. A poorly performed sternotomy may have devastating consequences, including sternal dehiscence, deep sternal wound infection, and mediastinitis.¹²

Although many cardiac surgical training programs have focused on the development of skills such as vascular anastomosis, thoracotomy, internal thoracic artery harvest, initiation of cardiopulmonary bypass, and cannulation, there is a paucity of literature regarding the development of models for the simulation of and assessment of median sternotomy.^{1,5,6,13,14} Even high-fidelity models that mimic operating in the pericardial cavity have simulated the performance of a sternotomy.¹⁴

The objective of the current study was to develop an inexpensive simulation model for the practice of median sternotomy and gather preliminary validity evidence for its use in cardiac surgery technical skills training. The study was undertaken during an annual nationwide boot camp for junior trainees enrolled in cardiac surgery residency training programs across Canada.

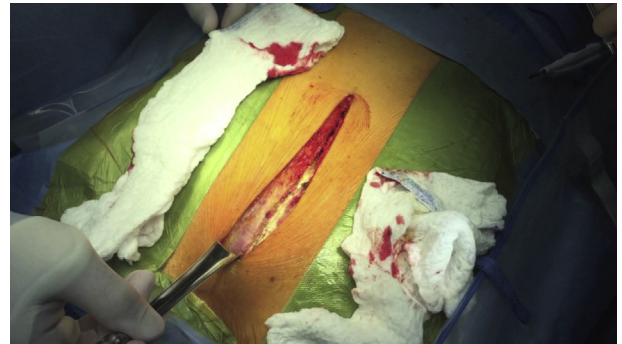
METHODS

Setting and Participants

The Canadian Cardiac Surgery Junior Resident Bootcamp is an annual training week outside of the formal residency curriculum for junior trainees enrolled in cardiac surgery training programs across Canada. The Bootcamp encompasses both simulation-based and didactic-based sessions in fundamental topics and skills related to cardiac surgery. As part of the Bootcamp, a sternotomy simulation session was conducted. The sternotomy session consisted of a sternotomy simulation with our developed median sternotomy model, a teaching video (Video 1), which highlighted and modeled our median sternotomy checklist, and repeat sternotomy simulation after viewing the video and review of the checklist (Video 2). Thirteen resident participants enrolled in this study in July 2017. The study was reviewed by the institutional ethics committee.

Development of Median Sternotomy Checklist

We used a modified Delphi consensus process¹⁵⁻¹⁷ to create a checklist. An initial checklist was created by 2 senior cardiac surgery resident physicians. The checklist was then distributed to an expert panel consisting of 4 staff cardiac surgeons for review. Changes were made in the checklist if at least 3 out of the 4 surgeons made similar recommendations. The revised checklist was re-presented to the faculty surgeons and a 75% panel agreement had to be obtained for every item on the checklist. After 2 rounds of review, a final checklist was created (Table 1). The final version of the checklist consisted of a total of 20 steps subcategorized into 4 sections.



VIDEO 1. An intraoperative instructional video demonstrating the steps of median sternotomy. This video was used as guide for the performance of median sternotomy for study participants and trainees. Video available at: [https://www.jtcvs.org/article/S2666-2507\(20\)30152-8/fulltext](https://www.jtcvs.org/article/S2666-2507(20)30152-8/fulltext).

Development of Video on Sternotomy

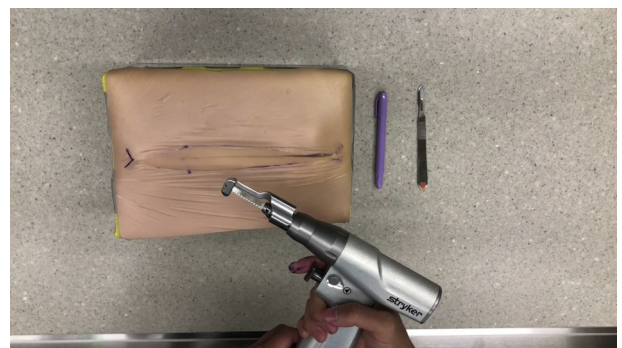
A 5-minute video prepared using intraoperative footage with a real patient was developed (Video 1). The video was edited to highlight each of the steps on the median sternotomy checklist. Verbal consent was obtained from the patient before the recording of the procedure.

Conduct of Participant Assessment

Participants were assessed during the sternotomy simulation before (Pre) and after viewing an instructional video (Post). Two senior residents independently observed each participant during the simulation, recording the time required to complete the task and the achieved score on the checklist. Duration of the task was defined as the time elapsed from incision to time of completion.

Entry and Exit Questionnaires

All candidates completed an entry questionnaire that included demographic information before the session. An exit questionnaire was given to the participants to assess their anxiety and preparedness regarding the performance of median sternotomy. Participants were also asked the following: feedback regarding the simulation model, usefulness of the simulation session (5-point Likert scale), perception of how realistic they found the model (5-point Likert scale), and individual feedback in terms of usefulness of the entire session. Finally, participants were given the



VIDEO 2. A video demonstrating the use of the sternotomy model. Video available at: [https://www.jtcvs.org/article/S2666-2507\(20\)30152-8/fulltext](https://www.jtcvs.org/article/S2666-2507(20)30152-8/fulltext).

TABLE 1. The median sternotomy checklist

Sternotomy Checklist Marking Scheme (Final Version)
<p>Skin & Subcutaneous Tissue</p> <ul style="list-style-type: none"> Palpate and identify surface anatomy Sternal notch Angle of Louis Xyphoid process Mark the midline with a marking pen (if using incise tape/drape such as Ioban [3M, St Paul, Minn] then please mark the skin before placement of the incise tape/drape) Surgical pause and verify administration of prophylactic antibiotic Incision extending approximately 1 cm above the angle of Louis to the tip of xyphoid process Extend incision to the anterior table of sternum
<p>Sternal Notch</p> <ul style="list-style-type: none"> Identify the middle of sternal notch – between the insertion of 2 sternocleidomastoid muscle heads Clear supra-sternal notch space with blunt finger dissection Divide interclavicular ligament
<p>Xyphoid Process</p> <ul style="list-style-type: none"> Identify xyphoid process and divide through the middle Clear the space underneath with blunt finger dissection
<p>Sternum</p> <ul style="list-style-type: none"> Check for the centre of the sternum; for example, using fingers or a hemostat to locate the lateral sternal margins as reference Score the periosteum of sternum to mark the midline Notify the anesthesiologist to turn off ventilator Test the sternal saw Saw through the sternum following the midline mark Re-engage the safety lock and hand it back to the scrub nurse/assistant Notify the anesthesiologist to resume ventilation Establish hemostasis

Total Duration: _____ Total Score: ____/20 points Comments: _____
 Proctor (please print): _____

opportunity to provide open-ended qualitative feedback as part of the exit questionnaire. Questionnaires are available in Tables 2 and 3.

Creating a Benchtop Sternotomy Model

The sternotomy model was created using an acrylic box measuring 20 cm long × 12 cm wide and 15 cm deep. A sternum model (Sternum with cartilage 20PCF Solid Foam; Sawbones, Vashon Island, Wash) was placed on a foam floor mat (3 mm thick) and the outline was cut out to encompass the sternal bone model into the foam sheet. A popsicle stick was placed on each side of the sternum approximately 0.5 to 1 cm lateral to the sternal edge and secured with duct tape. A small piece of artificial skin (Dragon Skin 10; Smooth-On, Macungie, Pa) outlining the sternal notch was stapled adjacent to the sternal notch to accentuate it for trainees to palpate. Another layer of artificial skin was then layered above the sternum. The layers were then secured together with brass split pins. The water-filled balloon was placed in the acrylic box and cling film was placed over the box to simulate the heart with pericardium above it. The artificial chest wall containing all pertinent layers and artificial sternum was then put on top of the acrylic box, which was secured tightly with tape. Images of the model are available in Figure 1, A-H.

The materials required to perform the sternotomy simulation are displayed in Figure 2. These materials include the sternotomy model, a marking pen (acting as both a marking pen and cautery tip), a 10-blade scalpel, and a sternal saw (Stryker, Kalamazoo, Mich).

Data Analysis and Interrater Reliability

Interrater reliability was assessed using the kappa statistic.¹⁸ Characterization of agreement for interrater reliability was based on

recommendations of Landis and colleagues¹⁹ as follows: values ≤0 as indicating no agreement, 0.01 to 0.20 as none to slight, 0.21 to 0.40 as fair, 0.41 to 0.60 as moderate, 0.61 to 0.80 as substantial, and 0.81 to 1.00 as almost perfect agreement.¹⁹

Normality of the data was tested using the Shappiro-Wilk test. The Student *t* test was used to analyze the continuous data. Analyses were performed using STATA version 14.2 (StataCorp, College Station, Tex).

RESULTS

Participants

Participant demographic data are noted in Table 4. All study participants were enrolled in Royal College of Physicians and Surgeons of Canada 6-year cardiac surgery training programs from across Canada.

Performance of Sternotomy and Checklist Reliability

Participants had a significantly higher mean score on the median sternotomy checklist Post compared with Pre (14.3 ± 2.0 vs 8.0 ± 3.1; *P* < .001) (Figure 3). The mean duration of time for participants to complete the sternotomy was lower Pre versus Post (188 ± 52 seconds vs 228 ± 58 seconds; *P* = .003) (Figure 3). All individual participants seemed to follow a similar pattern of increasing time and score from Pre to Post (Figure 3). The checklist interrater reliability was κ = 0.47 (moderate) for Pre and κ = 0.37 (fair) for Post.

TABLE 2. Pre video and sternotomy session questionnaire

Sternotomy Pre-session Questionnaire
1. Which training program stream are you currently enrolled in? <input type="checkbox"/> 6-y cardiac surgery residency <input type="checkbox"/> Cardiac surgery residency after general surgery training <input type="checkbox"/> Other (please specify: _____)
2. What is your current postgraduate year (PGY) level? 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 or above <input type="checkbox"/>
3. What is your gender? Male <input type="checkbox"/> Female <input type="checkbox"/>
4. During what year did you graduate from medical school? _____
5. Have you ever had any previous postgraduate training in cardiothoracic surgery? <input type="checkbox"/> Yes (please specify the duration of training: _____ years) <input type="checkbox"/> No
6. How many sternotomies have you performed before this session? None <input type="checkbox"/> 1 to 5 <input type="checkbox"/> 6 to 10 <input type="checkbox"/> More than 10 <input type="checkbox"/>
7. How would you rate your anxiety about performing a sternotomy? Not anxious <input type="checkbox"/> A little <input type="checkbox"/> Somewhat <input type="checkbox"/> Very <input type="checkbox"/> Extremely <input type="checkbox"/>
8. Please rank the following aspect of the sternotomy that makes you most anxious (1) to least anxious (5) <input type="checkbox"/> Risk of causing injury to the heart or other structures <input type="checkbox"/> Risk of going off midline <input type="checkbox"/> Risk of causing bleeding <input type="checkbox"/> Strength required <input type="checkbox"/> Control and handling of the sternal saw
9. How prepared do you feel to perform a sternotomy? Not prepared <input type="checkbox"/> A little <input type="checkbox"/> Somewhat <input type="checkbox"/> Very <input type="checkbox"/> Extremely prepared <input type="checkbox"/>

Entry and Exit Questionnaires

On the entry questionnaire, participants were surveyed regarding their anxiety toward the performance of median sternotomy. Fifty percent of participants ranked causing injury to the heart or other structures and 50% of participants ranked going off midline as the greatest sources of anxiety. Thirty-eight percent of participants rated their anxiety level for performing a median sternotomy as a little anxious on their entry questionnaire. Twenty-three percent of participants were equally somewhat anxious and very anxious. Only one participant was not anxious and only 1 participant was extremely anxious.

On the exit questionnaire, 100% of participants rated the simulation sessions as very useful or extremely useful. Even participants who had done 10 or more sternotomies before the session found that the session was either very useful or extremely useful. Eight participants (62%) described the median sternotomy simulation model as very realistic, four participants (31%) described it as somewhat realistic, and only 1 participant described it as a little realistic. Most

TABLE 3. Post video and sternotomy session questionnaire

Sternotomy Post-session Questionnaire
1. How useful did you find this training session? Not at all <input type="checkbox"/> A little <input type="checkbox"/> Somewhat <input type="checkbox"/> Very <input type="checkbox"/> Extremely <input type="checkbox"/>
2. How would you rate your anxiety about performing a sternotomy? Not anxious <input type="checkbox"/> A little <input type="checkbox"/> Somewhat <input type="checkbox"/> Very <input type="checkbox"/> Extremely <input type="checkbox"/>
3. How prepared do you feel to perform a sternotomy? Not prepared <input type="checkbox"/> A little <input type="checkbox"/> Somewhat <input type="checkbox"/> Very <input type="checkbox"/> Extremely prepared <input type="checkbox"/>
4. Please rank the following elements of the training session most useful (1) to least useful (3) <input type="checkbox"/> Didactic video/lecture <input type="checkbox"/> Practice on the sternotomy model <input type="checkbox"/> Debriefing by the evaluator
5. How realistic is the sternotomy simulation model? Not at all <input type="checkbox"/> A little <input type="checkbox"/> Somewhat <input type="checkbox"/> Very <input type="checkbox"/> Extremely <input type="checkbox"/>
6. Please provide comments/feedbacks/suggestions regarding the sternotomy session.

participants (70%) ranked the simulation model as the most useful element of the training session compared with the individual feedback and didactic video. Based on the commentary of the questionnaire and feedback of the participants, participants found the hands-on component of the session the most useful.

DISCUSSION

As surgical residency programs transition toward a competency-based paradigm, more learning will occur outside of the traditional clinical environment. Previous studies have demonstrated improvements in cardiac surgery-related technical and procedural skills after practice in the simulation laboratory.^{1,2,6} This study found that an inexpensive median sternotomy simulation model paired with an instructional video led to improvement in procedural performance reflected by improved scores on our checklist.

We found an increased duration of time to perform the median sternotomy during Post compared with Pre, after participants had an opportunity to review the checklist and see the instructional sternotomy video. This increased time may have been related to increased cognitive load as participants tried to recall and mentally process the newly learned steps. Dreyfus and Dreyfus²¹ support this with their theory of skill acquisition. Because participants in the simulation sternotomy session were likely in the Novice to Competent level of skill acquisition, a significant amount of cognitive processing, including effort and attention, is attributed to each detail and step of the skill.^{20,21} Furthermore, participants may have been spending more time performing previously missed steps.

The creation of a procedural checklist for training median sternotomy serves 2 purposes in this setting; first, the

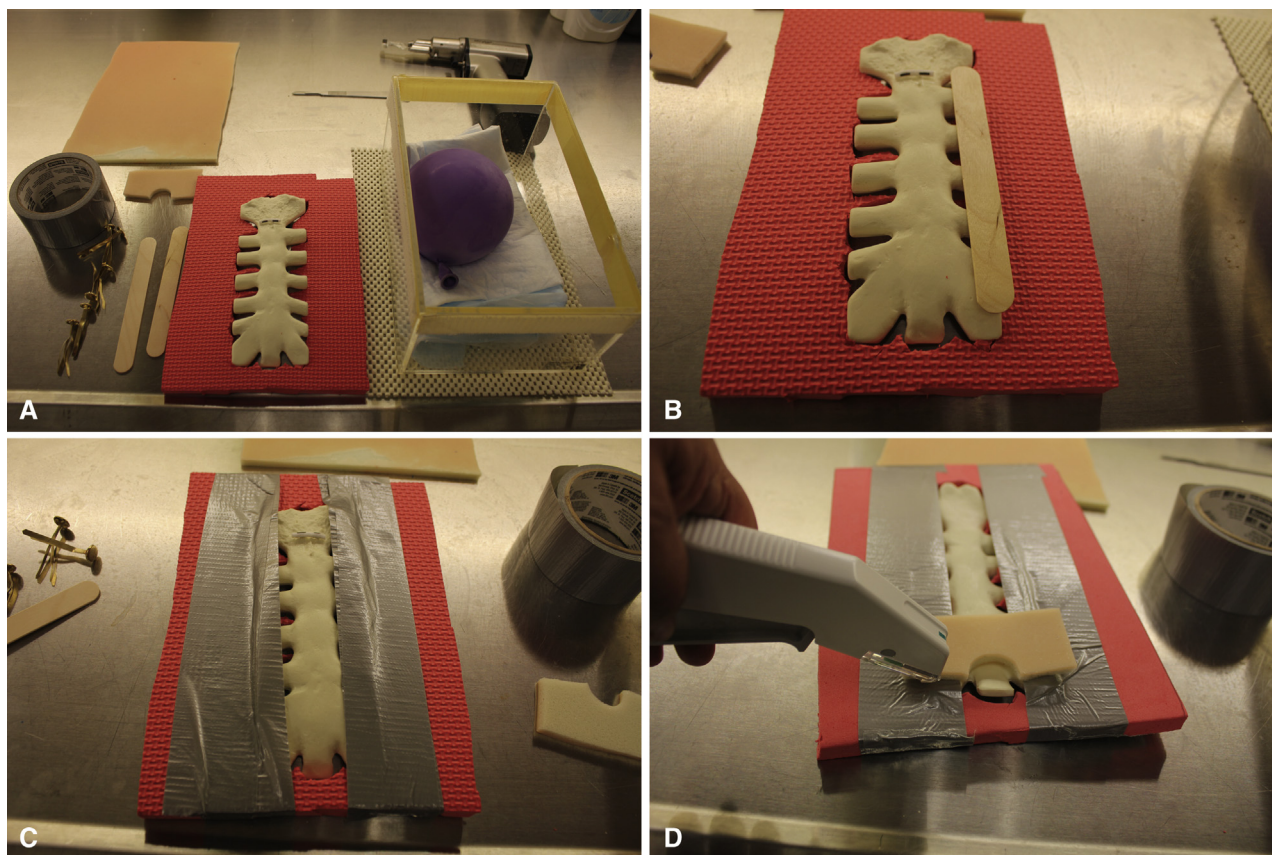


FIGURE 1. A, Materials required for the construction of the sternotomy model. B, The artificial sternal bone model (Sternum with cartilage 20PCF Solid Foam; Sawbones, Vashon Island, Wash) is encased in the red floor mat foam after cutting out the outline. The popsicle stick is placed approximately 0.5 to 1 cm lateral to the sternal edge. C, The popsicle sticks are secured to the foam with duct tape. D, An outline of the sternal notch using artificial skin (Dragon Skin 10; Smooth-On, Macungie, Pa) is stapled to the red foam. E, The water-filled balloon (to simulate a heart) is placed inside the acrylic box and a layer of cling wrap is sealed above the box (to simulate pericardium). F, All layers are secured together with the brass split pins. G, The sternum and all of the encompassing layers are secured to the box using tape and cling wrap. H, A profile view of all layers of the sternotomy model.

checklist provides a tool for assessment of trainee performance, and second, the checklist provides the trainee with a list of fundamental and salient steps to review. Checklists also allow trainees to mentally practice and review the steps of a procedure before performance of the skill. The ability to mentally practice a skill is paramount to the development of technical skills.²² For example, a randomized control trial by De La Garza and colleagues²³ found that providing trainees with a procedural checklist enhanced knowledge acquisition when learning a new technical skill. Petrik and colleagues²⁴ found that use of a checklist decreased the omission of critical steps of weaning from cardiopulmonary bypass.²⁴ With the transition to competency-based medical education, assessment tools are refocusing on the development of task-specific checklists because they act as study aids and allow learners to focus on specific and salient steps of a technical task.⁹ Using our checklist as a foundation, future iterations may also be developed for more complex variations such as redo sternotomy and ministernotomy.

The interrater reliability during checklist scoring was fair to moderate.¹⁹ There are multiple factors that may be responsible for this. First, rater training or piloting of the checklist was not done before assessment of participants. Previous studies have demonstrated the importance of rater training and experience with assessment tools in improving interrater reliability.²⁵⁻²⁷ Because future iterations of the Bootcamp employ the median sternotomy training model and procedure checklist, the interrater reliability can be improved with training of raters and improved iterations of the checklist. Additionally, analysis of checklist items with recurrent poor interrater reliability and discussion with raters to ascertain sources of discrepancy may help elucidate whether rater training is sufficient, or whether modifications to the checklist are needed.

Limitations

There were several limitations in the present study. The raters responsible for assessing the participants in the study were not blinded, thus increasing the risk of bias during the

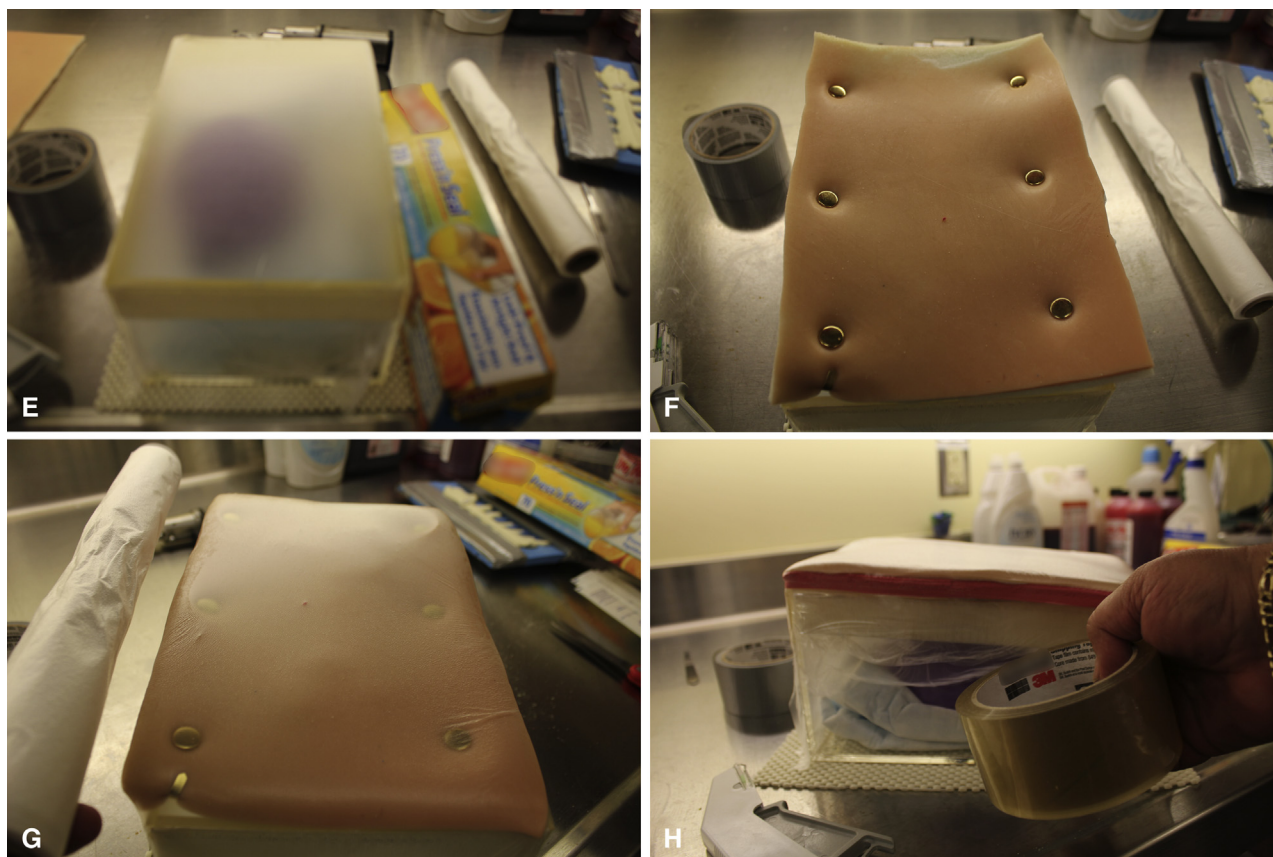


FIGURE 1. (Continued).

assessment of participants. Notably, there were no pre-existing relationships between the raters and participants and thus bias in assessment was expected to be low. Future studies may consider videorecording participants' performance and using blinded raters to assess the participants



FIGURE 2. Materials required to perform the median sternotomy simulation. From left to right, the sternotomy model, a marking pen, a 10-blade scalpel, and a sternal saw.

TABLE 4. Demographic characteristics of study participants (N = 13)

Characteristic	Result
Training program	
6-y Program	13 (100)
Postgeneral surgery	0
Postgraduate year	
1	10 (76.9)
2	2 (15.4)
≥3	1 (7.7)
Sex	
Male	10 (76.9)
Female	3 (23.1)
Years past completion of medical school	
≤1	8 (61.5)
1-2	1 (7.7)
≥2	4 (30.8)
Previous postgraduate training in cardiac surgery	
Yes	3 (23.1)
No	10 (76.9)
Previous performance of median sternotomy	
None	1 (7.7)
1-5	5 (38.5)
6-10	3 (23.1)
≥10	4 (30.8)

Values are presented as n (%).

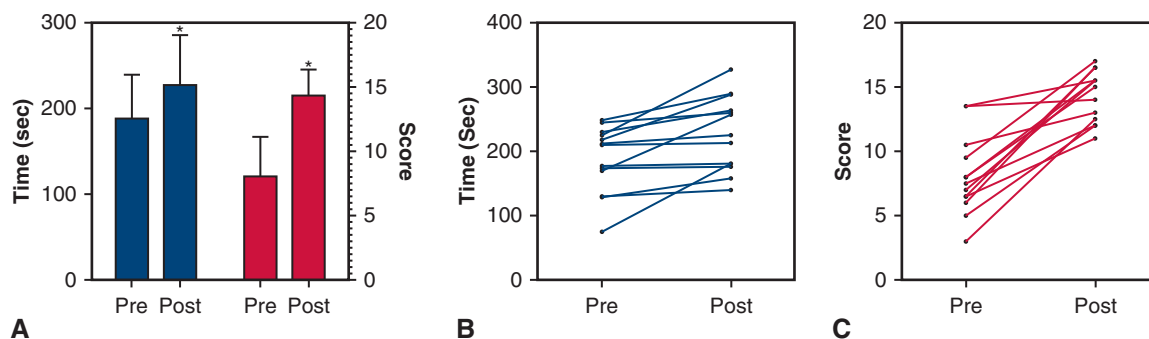


FIGURE 3. A, Time (in seconds) elapsed from the beginning to end of performance of simulated median sternotomy (*blue histograms*) and participant scores on the median sternotomy checklist (*red histograms*) before (Pre) and after (Post) viewing of the sternotomy video and reviewing of the sternotomy checklist. B, Individual performances for time required to perform the simulated sternotomy Pre and Post. C, Individual performances for checklist score Pre and Post. The error bars represent standard deviation. *Statistically significant at $P \leq .05$.

to reduce bias.²⁶ Secondly, although inexpensive models like ours are easily acquired, they lack the realistic nature of human tissue. The majority of participants, however, did believe that the model was very realistic. Finally, a limitation of our study is the use of only local institutional staff as experts for the modified Delphi consensus method. Although the median sternotomy is a fairly standardized technique, there are standards and preferences that vary between institutions and thus applicability of our checklist may not be universal. Other institutions that consider adopting the sternotomy checklist may consider modifying the checklist for their own trainees based on institutional preferences.

CONCLUSIONS

An inexpensive simulation model paired with an instructional video led to improvement in the performance of a safe simulated median sternotomy. A checklist was developed for the assessment of median sternotomy performance in addition to providing trainees with a stepwise approach for this important skill. Overall, participants were very satisfied with the simulation model and found it beneficial to their learning.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: surgical education, medical education, simulation, sternotomy