Simulation in Cardiothoracic Surgery

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James I. Fann, Richard H. Feins, and George L. Hicks

Introduction

Changes to surgical training, patient safety concerns, and the emergence of complex procedures in high-risk patients have generated greater interest in simulation-based learning in cardiothoracic surgical education [1–16]. Surgical simulation, defined as any skills training or practice outside of the operating room, can provide practice in a less stressful environment and enable graduated training of technical skills and crisis management. Further, this modality may be one means by which proficiency can be assessed [2–6, 9, 13, 17–22]. In general, cardiothoracic surgery simulation has been directed at the technical aspects of procedures, with emphasis on unique requirements of this specialty, such as performing small vessel anastomosis in a moving environment with time constraints (i.e., off-pump coronary artery bypass grafting), or implanting a cardiac valve with limited exposure. For the simulation exercises, the trainee needs to understand and articulate the correct way to use instruments, how to handle tissue and suture, and the relevant surgical anatomy. Additionally, scenarios for crisis management in cardiothoracic surgery are being developed and employed in simulation training.

As evidenced by laboratories investigating surgical techniques and the use of explanted porcine hearts in "wet-lab" environments, simulation, while not originally termed as such, has been widely employed in the history of cardiothoracic surgery. For instance, the technique of cardiac transplantation was extensively evaluated in the animal laboratory prior to clinical application. In the 1990s, synthetic cardiac surgery simulators for training attracted attention in the educational arena [23–26]. Stanbridge et al. and Reuthebuch et al. described beating heart simulators intended for training residents and surgeons [23, 24]. Bashar Izzat et al. and Donias et al. developed plastic and tissue-based beating heart models and noted that trainees became more proficient in their ability to perform beating heart anastomoses [25, 26]. In general, the focus and educational goals of these models were limited, and these efforts did not result in widespread adoption. Reported in 2005, Ramphal and colleagues employed a high-technology, high-fidelity porcine heart model to address the shortage of cardiac surgery cases for training in Jamaica [7]. To enhance cardiac surgical education in Europe, an important simulation effort was initiated over 10 years ago using a tissue-based approach by the Wetlab Ltd facility in the United Kingdom [8, 27].

Along with local efforts, the leadership in cardiothoracic surgery has provided focused programs to advance and formalize simulation-based learning, including the Thoracic Surgery Foundation for Research and Education Visioning Conference and the "Boot Camp" and "Senior Tour" supported by the Thoracic Surgery Directors Association, American Board of Thoracic Surgery, and the Joint Council on Thoracic Surgery Education [1, 3–5, 14, 15]. These efforts have increased our understanding of the type of simulators required, led to the development of performance assessment, and provided a venue to address barriers to

J.I. Fann, MD (✉)
Department of Cardiothoracic Surgery, Stanford University, 300 Pasteur Drive, Stanford, CA 94305, USA
e-mail: jfann@stanford.edu

R.H. Feins, MD
Division of Thoracic Surgery, University of North Carolina, 3031 Burnett Womack Building, CB 7065, Chapel Hill, NC 27599, USA
e-mail: richard_feins@med.unc.edu

G.L. Hicks MD
Division of Cardiothoracic Surgery, University of Rochester Medical Center, 601 Elmwood Avenue, Rochester, NY 14642, USA
e-mail: george_hicks@urmc.rochester.edu

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adoption [3–5]. The emphasis at the Boot Camp has been on five basic aspects of training, including cardiopulmonary bypass and aortic cannulation, coronary anastomosis, aortic valve surgery, pulmonary resection, and bronchoscopy and mediastinoscopy. At the meeting of the Senior Tour, comprised of senior (retired or semiretired) cardiothoracic surgical educators, 12 cardiothoracic surgical simulators are employed along with proposed assessment tools [4]. Concurrent with these initiatives has been the development of cardiothoracic surgical simulators at many centers [2–4, 6, 7, 9–12, 28].

Simulator Development

Because procedures in surgery can be partitioned into components leading to the development of partial-task trainers, one emphasis in cardiothoracic surgery simulation has been to provide the trainee with models that can be used for deliberate and distributed practice [2, 4, 9]. Synthetic simulators, considered "low-tech and low to moderate fidelity," can be useful in developing basic surgical skills, whereas tissue-based simulators such as the "wet-lab" experience can be considered "low-tech, high fidelity", since they are readily available and provide good anatomic representation and appropriate tissue or haptic response.

Cardiac Surgery Simulators

Coronary Artery Bypass Surgery

The technical tasks and procedures include coronary artery anastomosis, proximal anastomosis, and beating heart coronary anastomosis [2–4, 9]. Generally, coronary artery anastomoses can be performed using synthetic or tissue-based vessels attached to an apparatus. Synthetic models and simulators in coronary artery and vascular anastomosis are commercially available, and simpler models can be constructed (e.g., anastomosis "block") (Fig. 19.1a). The HeartCase model (Chamberlain Group, Great Barrington, MA) has a vessel anastomosis attachment which permits sewing an end-to-side anastomosis at different angles using 3–4 mm synthetic target vessels (Fig. 19.1b) [4]. For the tissue-based or "wet-lab" component, porcine hearts are prepared and positioned so as to expose the left anterior descending artery in a container (Wetlab Ltd, Kenilworth, Warwickshire, England) (Fig. 19.1c) [8, 27]. Synthetic tissue grafts from the Chamberlain Group and LifeLike BioTissue (Toronto, Ontario) can be used as grafts for the anastomosis. These grafts and target vessel thus offers some degree of realism, but its importance is in teaching the mechanics of anastomosis [4].

Beating Heart Surgery

The technical challenge of off-pump coronary artery bypass grafting is to expeditiously perform accurate coronary anastomoses on constantly moving target vessels, typically 1–2 mm in diameter. Understanding the stabilization devices is critical as is the various methods of optimizing exposure of the target vessel [2]. Commercially available synthetic beating heart model includes a simulator from the Chamberlain Group, which includes a compressor and controller (Fig. 19.2a), and one developed by EBM, which is motor driven (EBM, Tokyo). Tissue-based models using explanted porcine hearts include the Ramphal simulator, which is a high-fidelity, computer-controlled simulator that can be employed in many aspects of training (Fig. 19.2b). This educational approach permits the surgeon to become familiar and achieve some degree of proficiency before attempting this technique in the clinical setting.

Aortic Cannulation

One part-task simulator for aortic cannulation is the HeartCase model with the synthetic thoracic aortic attachment. Using a syringe or a pressure bag, normal saline can be instilled into the synthetic aorta for pressurization. A tissue-based model used at the Boot Camp is a porcine heart in which the coronary sinus, coronary arteries, and aortic arch vessels are oversewn (Fig. 19.3a) [5, 28]. The ascending aorta with the arch and a portion of the descending aorta is pressurized with a bag of saline. Another model utilizes the porcine descending thoracic aorta, which is prepared by oversewing the intercostal vessels, securing it in a plastic container, and pressurizing it using saline (Fig. 19.3b) [4]. The tissue-based models are realistic, permitting multiple cannulations. Also, they can serve as thoracic aortic surgery anastomosis simulators [4].

Atrial Cannulation

Right atrial or bicaval cannulation for cardiopulmonary bypass is simulated using the porcine heart model placed in a container. Understanding the anatomy, suture placement, and cannulation are the primary objectives. Ideally, atrial cannulation is performed as part of other procedures, such as aortic cannulation. In order to simulate atrial cannulation in a more realistic, beating heart setting, the Ramphal simulator can be used.

Cardiopulmonary Bypass

Used in the training of perfusionists and surgeons, cardiopulmonary bypass simulators are intended to be highly interactive [4, 5]. The simulators provide multiple physiologic conditions and permit the trainee to manage the steps preceding and during cardiopulmonary bypass, including intraoperative crisis management. The Ramphal simulator is thus well suited for cardiopulmonary bypass simulation. Other "high-tech, high-fidelity" cardiopulmonary bypass simulators, such as the Orpheus perfusion simulator (ULCO

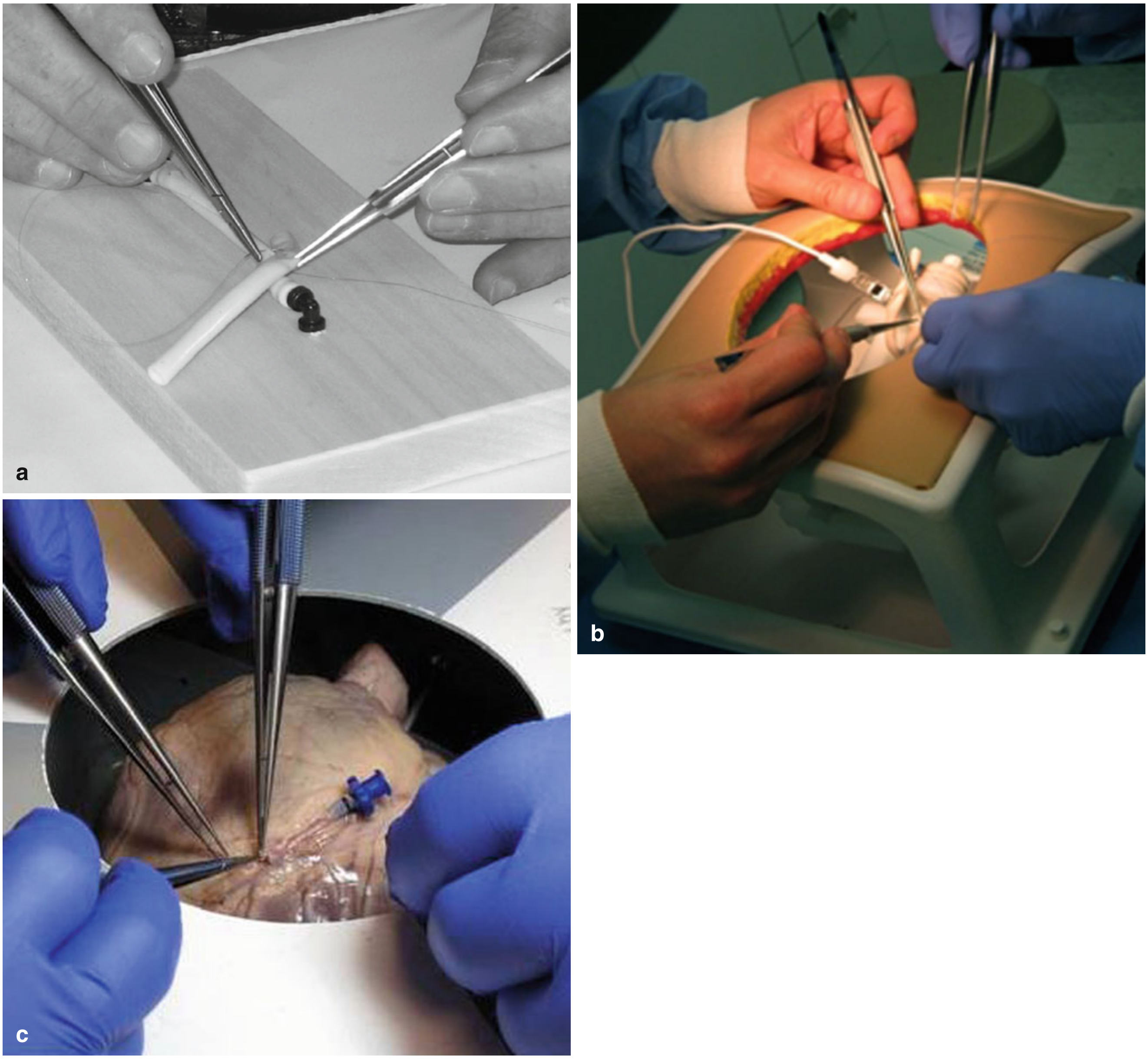

Fig. 19.1 Small vessel anastomosis: (**a**) An anastomotic block can be constructed using a wood block on which are mounted ¼ in. angled irrigation connectors. A synthetic graft can be positioned in place using the connectors (Reprinted from Fann et al. [3], with permission from Elsevier). (**b**) Mounted in the portable chest model is a synthetic target vessel; to simulate vein graft for anastomosis, another synthetic vessel is used. (**c**) For the tissue-based or "wet-lab" component, porcine hearts are prepared and positioned so as to expose the left anterior descending artery in a container

Medical), are commercially available with assessment modules, recognizing that such simulators are expensive (Fig. 19.4). A commonly employed method to learn about cardiopulmonary bypass circuit is to have access to a perfusion pump and arrange a tutorial with the perfusionist.

Aortic Valve Replacement

Synthetic models are adequate in teaching important components such as surgical anatomy and approach to placing annular sutures [4]. The aortic root model is available from the Chamberlain Group and can be attached to the HeartCase simulator (Fig. 19.5a). The objectives are to train proper needle angle for suture placement, effective knot tying in a deep confined space, placing sutures in the valve sewing cuff, and seating the valve prosthesis. For tissue-based simulation, porcine hearts are placed in a container and situated so as to present the ascending aorta and aortic root (Fig. 19.5b) [4]. The aortotomy is made followed by excision of the leaflets and the muscle bar under the right coronary cusp. Interrupted sutures are placed followed by the

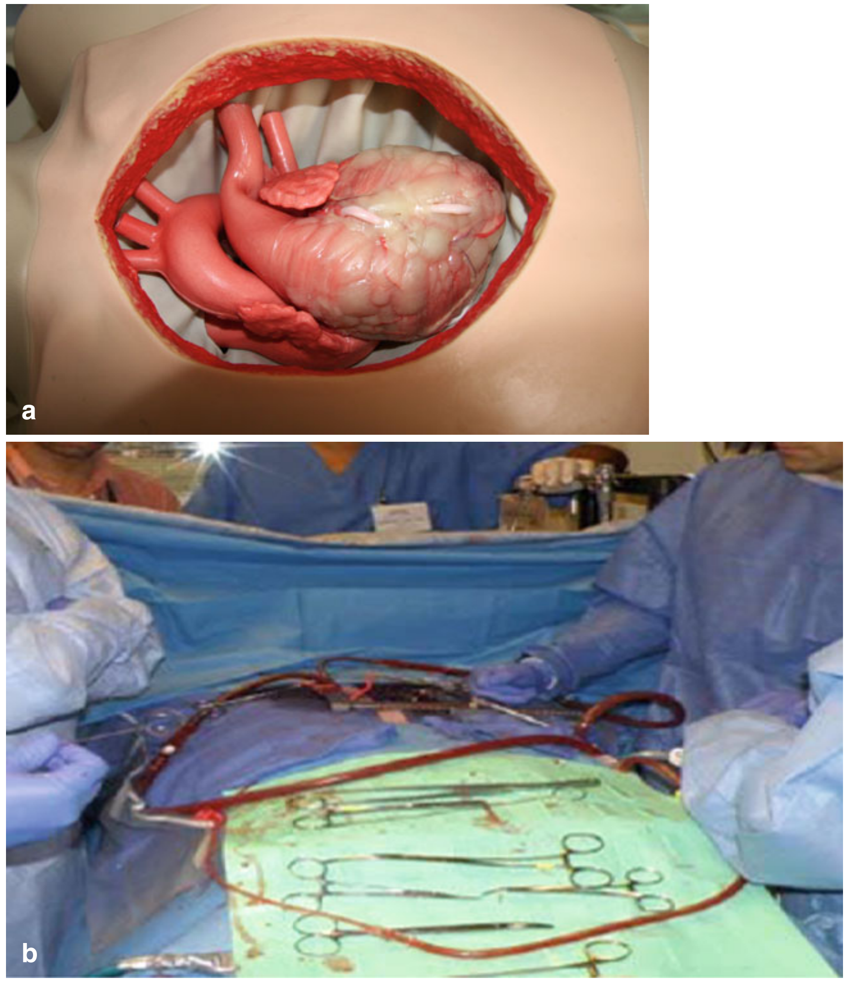

Fig. 19.2 Beating heart simulator: (**a**) The beating heart model is constructed of silicone and connected to a controller and external compressor. Partially embedded in the myocardium are 2-mm target coronary arteries. The heart is placed in a plastic torso simulating the pericardial well. (**b**) The Ramphal cardiac surgery simulator is a high-fidelity computer-controlled tissue-based simulator that allows the trainee to perform tasks such as beating heart and arrested heart surgery. Additionally, it provides cardiopulmonary bypass simulation and crisis management

placement and seating of the prosthesis. This model lends itself to standardized training, as it is currently used in many centers [4].

Mitral Valve Repair

The synthetic mitral valve attachment is a silicone-based cylinder placed in the portable HeartCase model (Fig. 19.6a) [4, 6]. The synthetic model provides a method to learn basic components of mitral valve surgery, such as exposure techniques and needle angles, but it is limited in its fidelity [4]. To more accurately simulate the mitral leaflets and annulus requires the use of a porcine heart model, which is placed in the container and situated so as to present the left atrium and mitral annular plane. The left atrium is opened and the mitral valve and annulus exposed in an "anatomically correct" configuration (Fig. 19.6b) [4, 6]. Interrupted annular sutures are placed and annuloplasty ring situated and secured. The porcine model is realistic but can pose some challenges with anterior-posterior orientation in the setup [4].

Aortic Root Replacement

For the tissue-based aortic root replacement simulator, explanted porcine hearts are placed in the container and situated so as to present ascending aorta and aortic root [4]. The porcine aorta and root are resected after creation of the coronary ostial buttons. A composite valve graft (or just a Dacron graft) or an expired aortic homograft (CryoLife, Inc. Kennesaw, GA), if available, is prepared and anastomosed as a root replacement using polypropylene sutures for coronary button reimplantation [4]. This realistic, tissue-based model has been helpful in familiarizing the trainee with the complexity of this procedure [4].

Thoracic Surgery Simulators

Hilar Dissection and Pulmonary Resection

A porcine heart-lung block placed within the chest cavity of a mannequin simulates the necessary maneuvers of hilar dissection and pulmonary resection through a thoracotomy incision

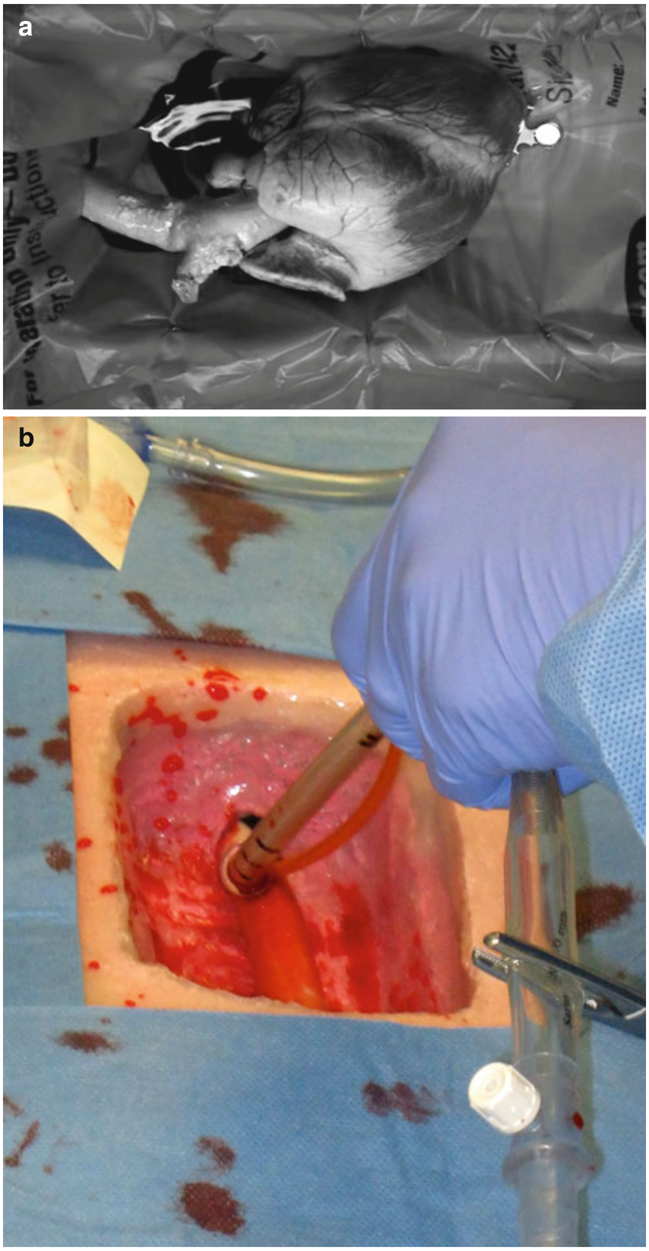

Fig. 19.3 Aortic cannulation: (**a**) For the perfused non-beating porcine heart placed in a container, the arch vessels are oversewn, and a portion of the descending aorta in continuity with the ascending aorta provides a long segment to practice multiple aortic and cardioplegia cannulations. (**b**) A porcine descending thoracic aorta is secured in a plastic thoracic model. The pressurized aorta allows placement of purse-string sutures and multiple aortic cannulations (Reprinted from Fann et al. [4], with permission from Elsevier)

(Fig. 19.7) [4, 11]. Either the right or left lung can be used. This tissue-based simulator replicates the confined space in which pulmonary resections are performed and provides a method to practice hilar dissection and resection skills. The objectives are to identify anatomic landmarks, dissect and encircle the hilar vessels and bronchus, and ligate and divide

Fig. 19.4 Cardiopulmonary bypass: The Silastic heart model is placed in a plastic thorax and attached to the Orpheus cardiopulmonary bypass simulator. This simulation exercise allows the trainee to understand the cardiopulmonary bypass circuit and to participate in emergency and crisis management (Reprinted from Hicks et al. [5], with permission from Elsevier)

vascular structures using sutures and staplers. This model is moderately realistic recognizing variability of porcine anatomy relative to human anatomy and the fragility of the vascular structures [4].

Esophageal Anastomosis

Placed within a thoracic mannequin, a porcine heart-lung-esophagus block simulates the thoracotomy providing access to the posterior mediastinum [4]. The esophagus, positioned and secured in the posterior cavity, is isolated and transected. The two free ends are re-approximated in either one or two layers. This model permits alignment and approximation of the esophageal ends, proper placement of sutures within the esophageal wall, and securing the sutures following placement [4]. By including the stomach in the tissue block, esophagogastric anastomosis can be simulated. Additionally, providing and resolving tension on the anastomosis can be introduced, and creating longitudinal incision (with longer mucosal than muscular incision) would simulate esophageal rupture requiring the trainee to perform appropriate repair [4].

Rigid Bronchoscopy

Using conventional bronchoscopic equipment, the TruCorp AirSim simulator (Belfast, N. Ireland) is a model of the oral pharynx, larynx, and the tracheobronchial tree out to the segmental anatomy (Fig. 19.8) [4]. The model also allows simulation of awake bronchoscopy, bronchial stent placement, and removal of foreign body [4]. Since the image of the bronchoscope can be projected and the position of the light on the bronchoscope can be visualized through the wall of the model, assessment of resident performance in navigation is possible.

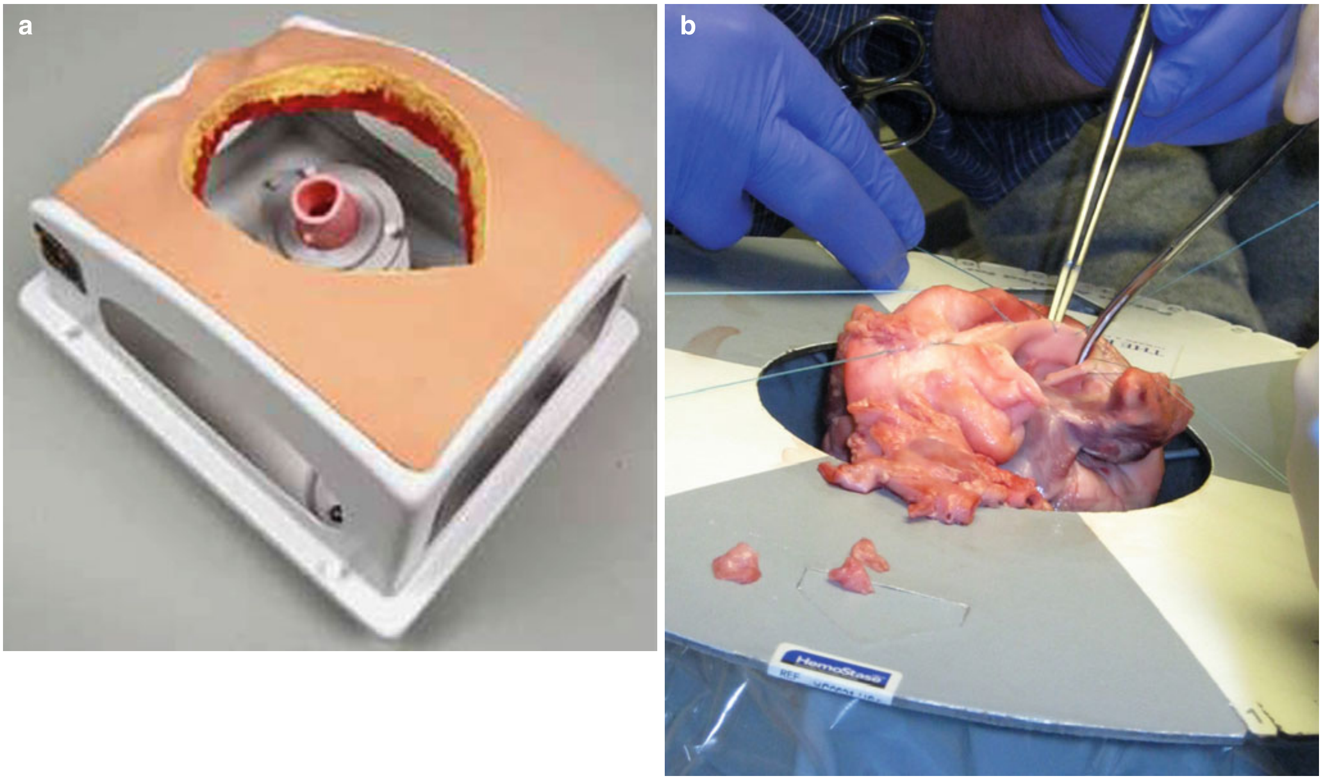

Fig. 19.5 Aortic valve replacement: (**a**) Mounted in a portable HeartCase chest model is a silicone-based aortic valve model which requires the trainee to understand proper needle angles, working in a deep, confined space, and seating the prosthesis. (**b**) For the tissue-based aortic valve replacement model, a porcine heart is placed in a container and situated so as to present the ascending aorta and aortic root. The aortotomy is made followed by excision of the leaflets and implantation of the aortic valve (Reprinted from Fann et al. [4], with permission from Elsevier)

Another bronchoscopic simulator is the CAE Accutouch EndoscopyVR Surgical Simulator (CAE, Montreal, Quebec), which is a highly sophisticated virtual reality simulator.

Video-Assisted Thoracoscopic Surgery (VATS) Lobectomy

A left porcine heart-lung block placed within the chest cavity of a mannequin is accessed via working ports to allow for video-assisted resection (Fig. 19.9) [4]. This exercise replicates the confined thoracic space in which pulmonary resections are performed and also provide a model to practice hilar dissection and resection skills. This simulator allows for identifying anatomic landmarks, maneuvering the thoracoscope and pulmonary structures, dissecting and encircling hilar vessels and bronchus, and dividing the structures using the endoscopic staplers. Recognizing interspecies differences, this model may be more complex than a case in the clinical setting, but it does provide simulation of many advanced maneuvers [4].

Tracheal Resection

A porcine tracheal-esophageal segment placed within the open neck of a mannequin simulates tracheal resection and anastomosis (Fig. 19.10) [4]. This realistic exercise reproduces the confined space in which tracheal resections are performed and provides a model to practice such resection and anastomosis. Given the shorter period of time required for this exercise, additional procedures, such as tracheostomy and tracheal release maneuvers, can be added [4].

Sleeve Resection

As an extension of the pulmonary resection simulator, a porcine heart-lung block placed within the chest cavity of a mannequin simulates the necessary maneuvers of sleeve resection via a thoracotomy (Fig. 19.11) [4]. This exercise replicates the confined thoracic space in which sleeve resections are performed. This realistic model permits airway mobilization and understanding the principles of bronchial anastomosis [4].

Pleural and Mediastinal Disorders

To date, simulation with pleural and mediastinal disorders has been limited to mediastinoscopy, anterior mediastinotomy, and video-assisted thoracoscopic procedures. Simulators used at the Boot Camp include a mediastinoscopy model made of the head, neck, and thorax of a mannequin with a synthetic airway and mediastinal structures strategically placed in the anterior aspect of the upper thorax (Fig. 19.12). Mediastinoscopy is performed with conventional instrumentation and video monitor.

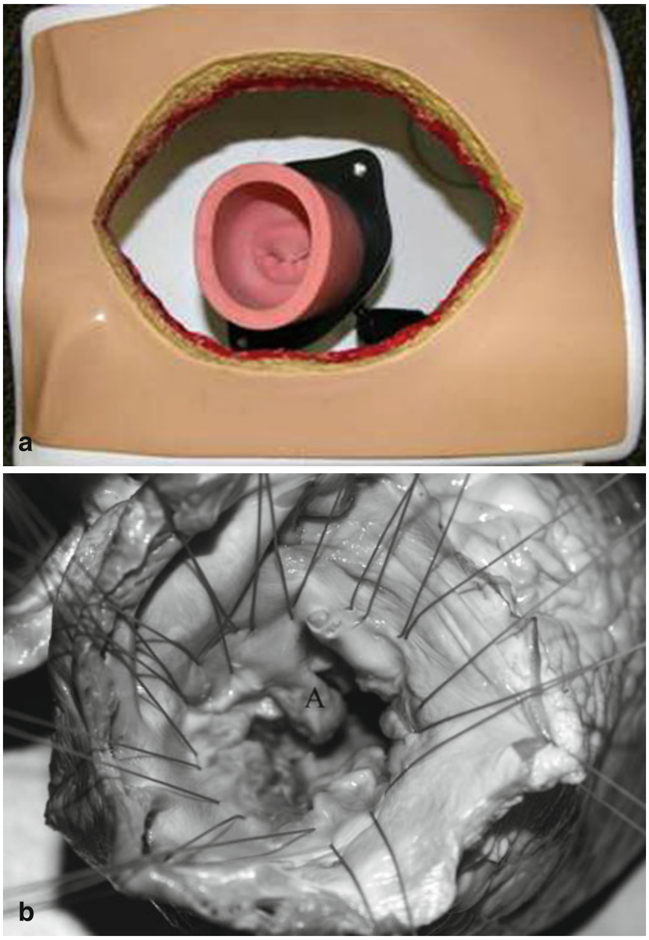

Fig. 19.6 Mitral valve repair: (**a**) The synthetic mitral valve model is placed in portable chest model. (**b**) For the tissue-based simulator, porcine hearts are placed in the container and situated so as to present the mitral valve. The left atrium is retracted so as to expose the mitral valve and annuloplasty performed. *A* anterior leaflet (Reprinted from Joyce et al. [6], with permission from Elsevier)

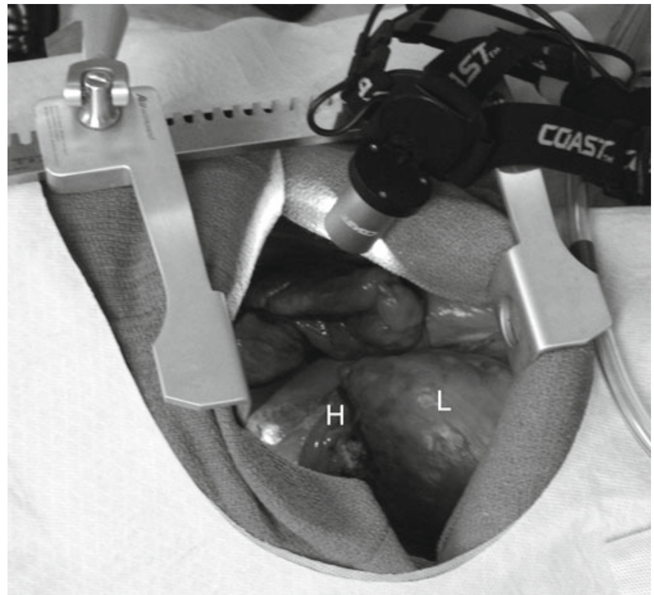

Fig. 19.7 Hilar dissection: a porcine heart-lung block placed within the chest cavity of a mannequin simulates the necessary maneuvers of hilar dissection through a thoracotomy incision. *H* hilum, *L* lung (Reprinted from Fann et al. [4], with permission from Elsevier)

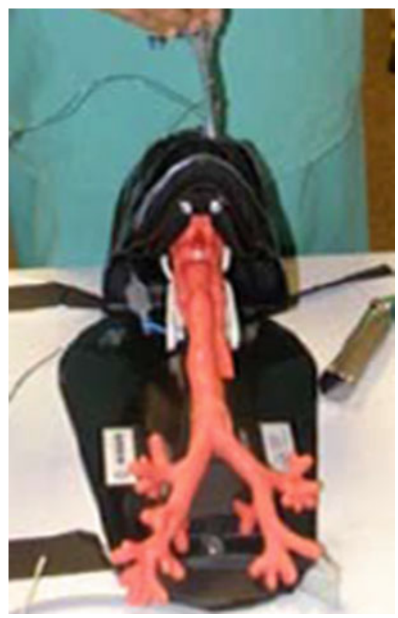

Fig. 19.8 Bronchoscopy: using conventional bronchoscopic equipment, the TruCorp AirSim model simulates the tracheobronchial tree

Fig. 19.9 Video-assisted thoracoscopic surgery (VATS) lobectomy: a left porcine heart-lung block placed within the chest cavity of a mannequin is accessed via working ports to allow for video-assisted resection (Reprinted from Fann et al. [4], with permission from Elsevier)

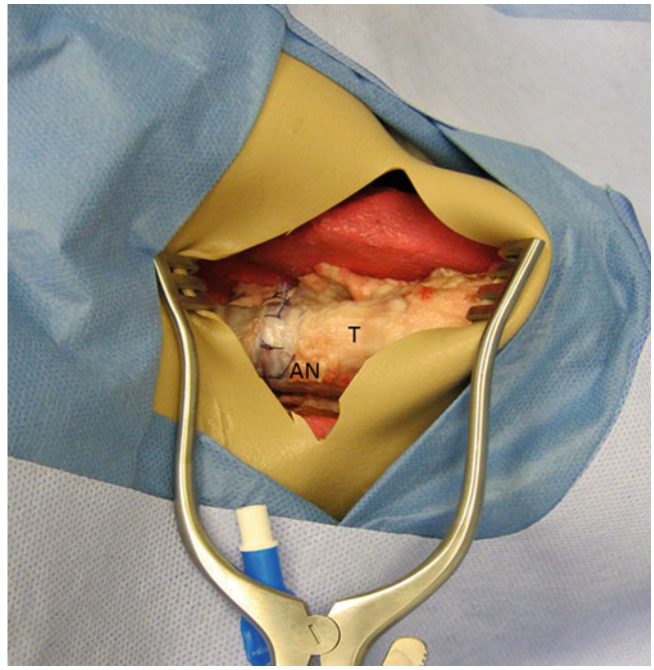

Fig. 19.10 Tracheal resection: a porcine tracheal-esophageal segment placed within the open neck of a mannequin simulates tracheal resection and anastomosis (*T* trachea, *An* anastomosis) (Reprinted from Fann et al. [4], with permission from Elsevier).

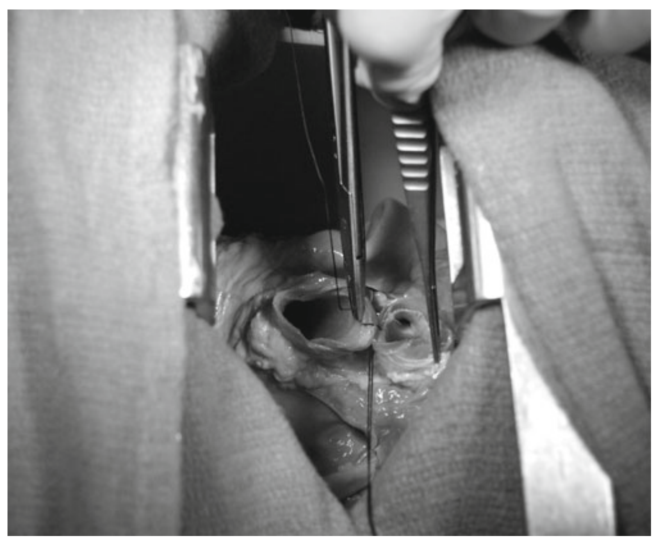

Fig. 19.11 Sleeve resection: a porcine heart-lung block placed within the chest cavity of a mannequin (similar to the hilar dissection model) simulates the necessary maneuvers of sleeve resection (Reprinted from Fann et al. [4], with permission from Elsevier)

Performance Assessment

Because surgical residents at the same training level may be at different technical proficiency levels, simulation-based learning is one means to assess performance and provide practice and remediation [2–6, 9, 16–19, 29–32]. Ultimately, surgery training may be competence based and not solely determined by the number of years in training or the number of procedures performed. Reliable and valid methods of assessment and passing standards for skills performance must be defined if such criterion-based system is to be implemented. Current and evolving assessment tools are based on direct observation and video recordings of a particular simulated procedure and include the use of task-specific checklists and global rating scales, such as the Objective Structured Assessment of Technical Skills (OSATS) developed at the University of Toronto and the Southern Illinois University Verification of Proficiency [2–6, 9, 16–19, 29–32]. To date, performance assessment in cardiothoracic surgery simulation has been reported for coronary anastomosis, cardiopulmonary bypass, mitral valve surgery, and pulmonary surgery [2–6, 9, 10]. Proposed rating scales for performance assessment created for the simulators used at the Senior Tour will require further modifications, including comprehensive anchoring points [4].

Fig. 19.12 Mediastinoscopy: developed at the Boot Camp, a mediastinoscopy simulator is constructed of the head, neck, and thorax of a mannequin with a synthetic airway and mediastinal structures strategically placed in the anterior aspect of the upper thorax. Mediastinoscopy is performed with conventional instrumentation and video monitor

For coronary anastomosis, Fann et al. evaluated distributed practice using a portable task station and a beating heart model in training coronary anastomosis [2]. With eight cardiothoracic surgery residents, times to completion for anastomosis on the task station decreased 20% after 1 week of practice (351 ±111 to 281 ± 53 s), and times to completion for beating heart anastomosis decreased 15% at 1 week (426 ± 115 to 362 ± 94 s). Distributed practice using the task station resulted in improvement in ability to perform the anastomosis as assessed by times to completion and 5-point rating scale (Table 19.1). Not all residents improved, however, consistent with a "ceiling effect" with the simulator and a "plateau effect" with the trainee [2]. To assess the value of focused training or massed practice, 33 first-year cardiothoracic surgery residents at the first Boot Camp participated in a 4-h coronary anastomosis session [3]. During the session, components of anastomosis were assessed using a 3-point rating scale. Performance was video recorded and reviewed by three surgeons in a blinded fashion. There was significant improvement from the initial assessment compared to the end of session, which were confirmed with video recordings [3]. Thus, the 4-h focused training using porcine model and task station resulted in improved ability to perform an anastomosis. In evaluating vascular anastomosis, Price et al. assessed 39 surgery trainees randomized to expert-guided tutorial alone versus expert-guided tutorial with self-directed practice [9]. Those who had the opportunity for self-directed simulator practice performed anastomoses more adeptly, more quickly, and at a higher quality [9]. Consistent with previous findings, simulator training should be incorporated into the curriculum, and trainees should have access to this modality for independent practice.

Joyce et al. evaluated simulation-based learning in skill acquisition in mitral valve surgery [6]. Eleven cardiothoracic surgery residents performed mitral annuloplasty in the porcine model. The video-recorded performance was reviewed by an attending surgeon providing audio formative feedback superimposed on video recordings; these recordings were returned to residents for review. After a 3-week practice period using the plastic model, residents repeated mitral annuloplasty in the porcine model. The time to completion improved from a mean of 31 ± 9 to 25 ± 6 min after the 3-week period. At 3 weeks, improvement in the technical components was achieved in all residents (Table 19.2) [6]. Thus, simulation-based learning employing formative feedback results in overall improved performance in a mitral annuloplasty model.

At the Boot Camp in 2009, Hicks et al. evaluated a modular approach to skills mastery related to cardiopulmonary bypass and crisis scenarios [5]. Thirty-two first-year cardiothoracic surgery residents were trained for four consecutive hours in cardiopulmonary bypass skills using a perfused non-beating heart model, computer-controlled simulator, and perfused beating heart simulator. Based on their performance using the cardiopulmonary bypass simulator, each resident was assessed using a checklist rating score on perfusion management and one crisis scenario (Table 19.3) [5]. For initiation and termination of cardiopulmonary bypass, most residents performed the tasks and sequence correctly. Some elements were not performed correctly. For instance, three

Table 19.1 Coronary artery anastomosis assessment

Resident name ______________________ **Year of training** ______________ **Date** ____________

Evaluator _________________________ **Time to completion** _________________

	Poor		Average		Excel
1. Arteriotomy (porcine model: able to identify target, proper use of blade, single groove, centered)	1	2	3	4	5
2. Graft orientation (proper orientation for toe-heel, appropriate start and end points)	1	2	3	4	5
3. Bite appropriate (entry and exit points, number of punctures, even and consistent distance from edge)	1	2	3	4	5
4. Spacing appropriate (even spacing, consistent distance from previous bite, too close vs. too far)	1	2	3	4	5
5. Use of Castroviejo/Jacobson needle holder (finger placement, instrument rotation, facility, needle placement, pronation and supination, proper finger and hand motion, lack of wrist motion)	1	2	3	4	5
6. Use of forceps (facility, hand motion, assist needle placement, appropriate traction ontissue)	1	2	3	4	5
7. Needle angles (proper angle relative to tissue and needle holder, consider depth of field, anticipating subsequent angles)	1	2	3	4	5
8. Needle transfer (needle placement and preparation from stitch to stitch, use of instrument and hand to mount needle)	1	2	3	4	5
9. Suture management/tension (too loose vs. tight, use tension to assist exposure, avoid entanglement)	1	2	3	4	5

Definitions:

5. Excellent, able to accomplish goal without hesitation, showing excellent progress and flow
4. Good, able to accomplish goal deliberately, with minimal hesitation, showing good progress and flow
3. Average, able to accomplish goal with hesitation, discontinuous progress and flow
2. Below average, able to partially accomplishgoal with hesitation
1. Poor, unable to accomplish goal; marked hesitation

Modified from Fann et al. [2]

Table 19.2 Mitral valve repair

Resident name__________________________ **Year of training**____________ **Date** ____________

Evaluator_________________________

	Poor		Average		Excel
1. Identify posterior mitral annulus (demonstrate annulus, i.e., decussation or junction of leaflet and atrial wall, for suture placement)	1	2	3	4	5
2. Identify anterior mitral annulus (demonstrate annulus, i.e., junction of leaflet and fibroskeleton, for suture placement)	1	2	3	4	5
3. Needle angles (proper angle to permit needle point to puncture orthogonal to tissue plane; consider depth of field, and space constraints)	1	2	3	4	5
4. Needle removal from annulus (follow curve of the needle to minimize tissue trauma)	1	2	3	4	5
5. Tissue handling (gentle manipulationwithout excessive tension and tissue trauma)	1	2	3	4	5
6. Depth of bite (proper depth of entry and exit points; proper and consistent depth of needle and suture)	1	2	3	4	5
7. Suture advance along annulus (proper distance of suture travel in annulus, not too small or large)	1	2	3	4	5
8. Spacing between sutures (even spacing; consistent distance from previous bite, not too close or too far)	1	2	3	4	5
9. Situating mitral ring (proper orientation relative to the annulus; proper suture placement from edge; proper suture spacing)	1	2	3	4	5
10. Knot-tying (adequate tension, facility; follow for finger and hand to secure knots, not too loose or tight)	1	2	3	4	5
11. Suture management/tension (avoid entanglement; use tension and traction to assist exposure)	1	2	3	4	5

Definitions:

5. Excellent, able to accomplish goal without hesitation, showing excellent progress and flow
4. Good, able to accomplish goal deliberately, with minimal hesitation, showing good progress and flow
3. Average, able to accomplish goal with hesitation, discontinuous progress and flow
2. Below average, able to partially accomplish goal with hesitation
1. Poor, unable to accomplish goal; marked hesitation

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Table 19.3 Cardiopulmonary bypass

Assessment

Resident name ______________________________ **Year of training** __________________ **Date** _______________

Evaluator __________________________

Steps	Satisfactory		Comments
Initiation:			
Assure adequate activated clotting time	Y	N	
Communicate with perfusionist	Y	N	
Check line pressure	Y	N	
Assess venous drainage	Y	N	
Vent placement	Y	N	
Cardioplegia	Y	N	
Cross-clamp	Y	N	
Termination:			
Removal of cross-clamp	Y	N	
De-airing procedures	Y	N	
Vent removal	Y	N	
Weaning CPB:			
Ventilator is on	Y	N	
Temperature satisfactory	Y	N	
TEE to assess intracardiac air	Y	N	
TEE to assess cardiac function	Y	N	
No bleeding in inaccessible areas	Y	N	
Acceptable rhythm / pacing wires	Y	N	
Need for inotropic support	Y	N	
Termination of bypass	Y	N	
Decannulation	Y	N	

Economy of time and motion	1	2	3	4	5
	1= many unnecessary/ disorganized movements		3=organized time/motion, some unnecessary movement		5=maximum economy of movement and efficiency

Final rating (circle one) Demonstrates competence Needs further practice

Additional comments:

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CPB Cardiopulmonary bypass, *TEE* Transesophageal echocardiography residents did not verify the activated clotting time prior to cardiopulmonary bypass initiation. Four residents demonstrated inadequate communication with the perfusionist, including lack of assertiveness and unclear commands. In crisis scenarios, management of massive air embolism was challenging with the most errors; poor venous drainage and high arterial line pressure scenarios were managed with fewer errors. For the protamine reaction scenario, all residents identified the problem, but in three cases, heparin was not re-dosed prior to resuming cardiopulmonary bypass for right ventricular failure. Based on a modular approach, technical skills and knowledge of cardiopulmonary bypass can be acquired and assessed using simulation, but further work employing more comprehensive educational modules will lead to mastery of these critical skills [5].

Initiatives in Cardiothoracic Surgery

Despite progress to date, educational and logistical concerns of cardiothoracic surgery simulation training remain [3–5]. Identified barriers to adoption include but are not limited to faculty time and commitment, facility and personnel cost, cost of equipment and supplies, trainee's time away from clinical activity, identifying appropriate simulators, defining comprehensive curriculum, and, perhaps the most challenging, organizational or specialty "buy-in" [4]. By defining the educational objectives, simulation can be incorporated formally in the residency program with scheduled courses and a means to provide adequate materials. Development of a technical skills curriculum at the national level has been through the Joint Council on Thoracic Surgery Education and locally by a number of institutions supported by institutional and national grants [1–6, 10–12, 33]. Incorporated into the skills training is emphasis on practice in the laboratory with formative feedback and at home using portable simulators. Weekly modular components, including coronary anastomosis, valve surgery, cardiopulmonary bypass, and crisis management, are directed at application of graduated skills with assessment. This project will require the continued, dedicated efforts of cardiothoracic surgical educators.

The Thoracic Surgery Directors Association and the American Board of Thoracic Surgery organized the first Boot Camp at the University of North Carolina in August 2008 to provide focused simulation-based training for approximately one-third of all first-year cardiothoracic surgery residents in the United States [3, 5, 14, 15]. In the ensuing 3 years, the Boot Camp, with support from the Joint Council on Thoracic Surgery Education, has emphasized training of essential components of cardiothoracic surgery, directed resources to development of assessment tools, and established a venue to educate faculty in the utility of simulation-based learning. Along with basic surgical skills training for cardiothoracic surgery residents, the directive of the Boot Camp has been to evaluate and develop surgical simulators and to explore novel approaches to the surgical training using simulation.

To increase the group of expert educators in training residents and to disseminate novel training methods to residency programs were the basis for the development of the Senior Tour, which originally comprised 13 senior cardiothoracic surgical educators [4]. The intent of the initial Senior Tour session was to introduce the members to simulation-based learning and to provide them with an opportunity to train residents using these modalities. At the meeting in January 2011, Senior Tour members evaluated the current simulators and identified methods to improve the training exercises, addressed constraints to simulation-based learning, and defined the process of starting simulation programs. Although many simulators stressed important concepts of a certain task, they do not fully simulate the clinical operative experience (Table 19.4). Along with simulator development, rating scales for performance assessment were proposed for nine simulators [4]. By providing the necessary tools, such as task trainers and assessment tools, Senior Tour members can assist in initiating surgical simulation efforts locally and provide regular programmatic evaluation to ensure that proposed simulators are of value. The Senior Tour continues to expand and currently comprises over 20 retired cardiothoracic surgeons who are committed to surgical education.

One important issue in the implementation of skills session in all specialties is whether time should be taken from clinical activity and directed into the simulation laboratory. Although some educators contend that such an approach would provide a favorable teaching experience in a controlled, laboratory environment, it is not clear that clinical hours should be redirected into a simulated environment. Some institutions have already mandated scheduled time in the simulation laboratory. Other efforts have been made to customize the training so that a resident can focus on certain skills at a time not disruptive to clinical care. Many institutions have employed physician extenders and technicians to provide access to and training in the simulation laboratory when the resident has clinical "downtime." As the benefits of simulation-based skills training become better defined, we anticipate that there will be scheduled time in the laboratory that minimizes clinical conflicts.

The cost of developing a surgical simulation laboratory remains challenging. Along with the requirement for space and equipment, such as operating room table, overhead lighting, and surgical instruments, unique to cardiothoracic surgery is the reliance on tissue-based simulators and the need for refrigeration. Although many of the simulators have been developed by local surgical educators, important is allocation of resources for the purchase of disposables and the maintenance costs required with many simulators.

Table 19.4 Summary evaluation of simulators used at the Senior Tour

	Time required to set up	Time required to complete	Complexity of simulator	Degree of perceived realism	Stressed important technical skills	Compared to operative experience
Small vessel anastomosis						
Synthetic	+	+	+	+	+++	+
Tissue-based	++	+	+	+++	+++	++
Aortic cannulation	++	+	+	++	++	++
Cardiopulmonary bypass	++	+++	+++	+++	+++	+++
Hilar dissection	++	++	++	+++	+++	++
Esophageal anastomosis	++	++	++	+++	+++	++
Rigid bronchoscopy	+	+	++	++	+++	++
Aortic valve replacement	++	++	+	+++	+++	++
Mitral valve repair						
Synthetic	+	++	+	+	++	+
Tissue-based	++	++	+	++	+++	++
Aortic root replacement	++	+++	++	+++	+++	+++
VATS lobectomy	++	++	++	++	+++	++
Tracheal resection	++	++	++	++	++	++
Sleeve resection	++	++	++	++	++	++

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+ less time, low level, or less agreement, ++ moderate time, mid level, moderate agreement, +++ longer time, high level, or more agreement
VATS video-assisted thoracoscopic surgery

Conclusion

Surgical simulation can provide a less stressful environment for graduated training of technical skills and training in crisis management; additionally, such an approach may be one means by which proficiency can be assessed. The leadership in cardiothoracic surgery has provided focused programs to advance and formalize simulation-based learning, including the Thoracic Surgery Foundation for Research and Education Visioning Conference and the Boot Camp and Senior Tour supported by the Thoracic Surgery Directors Association, the American Board of Thoracic Surgery, and the Joint Council on Thoracic Surgery Education. These efforts have increased our understanding of the utility of simulators in education, resulted in the development of performance assessment, and provided a venue to address barriers to adoption. Because procedures in surgery can be partitioned into components, one emphasis in cardiothoracic surgery simulation has been to provide the trainee with models that can be used for deliberate and distributed practice. Ultimately, it is recognized that cardiothoracic surgery training must be proficiency based. One challenge of a competence-based system of education is how to establish passing standards for technical skills ability; also, reliable and valid methods of assessment need to be developed if such a system is to be implemented. Thus, simulation-based learning may not only provide an opportunity to identify the methods for training and remediation but also help to define the competence levels for each stage of training.

References

1. Carpenter AJ, Yang SC, Uhlig PN, Colson YL. Envisioning simulation in the future of thoracic surgical education. J Thorac Cardiovasc Surg. 2008;135:477–84.
2. Fann JI, Caffarelli AD, Georgette G, Howard SK, Gaba DM, Youngblood P, et al. Improvement in coronary anastomosis with cardiac surgery simulation. J Thorac Cardiovasc Surg. 2008;136:1486–91.
3. Fann JI, Calhoon JH, Carpenter AJ, Merrill WH, Brown JW, Poston RS, et al. Simulation in coronary artery anastomosis early in residency training: the Boot Camp experience. J Thorac Cardiovasc Surg. 2010;139:1275–81.
4. Fann JI, Feins RH, Hicks Jr GL, Nesbitt J, Hammon J, Crawford F, et al. Evaluation of simulation training in cardiothoracic surgery: the Senior Tour perspective. J Thorac Cardiovasc Surg. 2012;143:264–72.
5. Hicks Jr GL, Gangemi J, Angona Jr RD, Ramphal PS, Feins RH, Fann JI. Cardiopulmonary bypass simulation and assessment at the Boot Camp. J Thorac Cardiovasc Surg. 2011;141:284–92.
6. Joyce DL, Dhillon TS, Caffarelli AD, Joyce DD, Tsirigotis DN, Burdon TA, et al. Simulation and skills training in mitral valve surgery. J Thorac Cardiovasc Surg. 2011;141:107–12.
7. Ramphal PS, Coore DN, Craven MP, et al. A high fidelity tissue-based cardiac surgical simulator. Eur J Cardiothorac Surg. 2005;27:910–6.
8. Munsch C. Establishing and using a cardiac surgical skills laboratory (monograph). Leeds: Wetlab Ltd., The Royal College of Surgeons of England; 2005.
9. Price J, Naik V, Boodhwani M, Brandys T, Hendry P, Lam BK. A randomized evaluation of simulation training on performance of vascular anastomosis on a high-fidelity in vivo model: the role of deliberate practice. J Thorac Cardiovasc Surg. 2011;142:496–503.
10. Carter YM, Marshall MB. Open lobectomy simulator is an effective tool for teaching thoracic surgical skills. Ann Thorac Surg. 2009;87:1546–50.
11. Tesche LJ, Feins RH, Dedmon MM, Newton KN, Egan TM, Haithcock BE, et al. Simulation experience enhances medical students' interest in cardiothoracic surgery. Ann Thorac Surg. 2010;90:1967–74.

12. Solomon B, Bizekis C, Dellis SL, Donington JS, Oliker A, Balsam LB, et al. Simulating video-assisted thoracoscopic lobectomy: a virtual reality cognitive task simulation. J Thorac Cardiovasc Surg. 2011;141:249–55.
13. Lodge D, Grantcharov T. Training and assessment of technical skills and competency in cardiac surgery. Eur J Cardiothorac Surg. 2011;39:287–93.
14. Feins RH. Expert commentary: cardiothoracic surgical simulation. J Thorac Cardiovasc Surg. 2008;135:485–6.
15. Hicks Jr GL, Brown JW, Calhoon JH, Merrill WH. You never know unless you try. J Thorac Cardiovasc Surg. 2008;136:814–5.
16. Hance J, Aggarwal R, Stanbridge R, Blauth C, Munz Y, Darzi A, et al. Objective assessment of technical skills in cardiac surgery. Eur J Cardiothorac Surg. 2005;28:157–62.
17. Reznick RK, MacRae H. Teaching surgical skills—changes in the wind. N Eng J Med. 2006;355:2664–9.
18. Reznick R, Regehr G, MacRae H, Martin J, McCulloch W. Testing technical skill via an innovative “bench station” examination. Am J Surg. 1996;172:226–30.
19. Reznick RK. Teaching and testing technical skills. Am J Surg. 1993;165:358–61.
20. Palter VN, Grantcharov T, Harvey A, Macrae HM. Ex vivo technical skills training transfers to the operating room and enhances cognitive learning: a randomized controlled trial. Ann Surg. 2011;253:886–9.
21. Beard JD, Jolly BC, Newbie DI, Thomas WEG, Donnelly TJ, Southgate LJ. Assessing the technical skills of surgical trainees. Br J Surg. 2005;92:778–82.
22. Martin JA, Regehr G, Reznick R, MacRae H, Murnaghan J, Hutchison C, et al. Objective structured assessment of technical skill (OSATS) for surgical residents. Br J Surg. 1997;84:273–8.
23. Stanbridge RD, O’Regan D, Cherian A, Ramanan R. Use of pulsatile beating heart model for training surgeons in beating heart surgery. Heart Surg Forum. 1999;2:300–4.
24. Reuthebuch O, Lang A, Groscurth P, Lachat M, Turina M, Zund G. Advanced training model for beating heart coronary artery surgery: the Zurich heart-trainer. Eur J Cardiothorac Surg. 2002;22:244–8.
25. Bashar Izzat M, El-Zufari H, Yim APC. Training model for “beating-heart” coronary artery anastomoses. Ann Thorac Surg. 1998;66:580–1.
26. Donias HW, Schwartz T, Tang DG, et al. A porcine beating heart model for robotic coronary artery surgery. Heart Surg Forum. 2003;6:249–53.
27. WetLab, Ltd, website in the United Kingdom. http://www.wetlab.co.uk. Accessed 20 Mar 2013.
28. Schiralli MP, Hicks GL, Angona RE, Gangemi JJ. An inexpensive cardiac bypass cannulation simulator: facing challenges of modern training. Ann Thorac Surg. 2010;89:2056–7.
29. Moulton CA, Dubrowski A, MacRae H, Graham B, Grober E, Reznick R. Teaching surgical skills: what kind of practice makes perfect? Ann Surg. 2006;244:400–9.
30. Seymour NE, Gallagher AG, Roman SA, O’Brien MK, Bansal VK, Andersen DK, et al. Virtual reality training improves operating room performance. Ann Surg. 2002;236:458–64.
31. Sidhu RS, Park J, Brydges R, MacRae HM, Dubrowski A. Laboratory-based vascular anastomosis training: a randomized controlled trial evaluating the effects of bench model fidelity and level of training on skill acquisition. J Vasc Surg. 2007;45:343–9.
32. Southern Illinois University Verification of Proficiency website. http://www.siumed.edu/surgery/surgical_skills/verification_of_proficency.html. Accessed 20 Mar 2013.
33. Verrier ED. Joint council on thoracic surgical education: an investment in our future. J Thorac Cardiovasc Surg. 2011;141:318–21.