

Training in cardiothoracic surgery: The role for simulation

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Abstract

Adequate cardiothoracic surgical training is essential for provision of quality care to patients. In recent years, simulation-based training has been advocated as an adjunct to traditional surgical training. Advances in simulation technology has resulted in many low- and high-fidelity simulators being employed in cardiothoracic surgical training. Such models allow trainees to practice an array of realistic full-length procedures in a safe and controlled environment, with the window to make mistakes and consider them learning points. There is significant evidence to demonstrate the effectiveness of cardiothoracic surgery simulation in improving surgical skills and operating room performances in addition to building confidence among trainees. However, owing to the high financial cost of arranging it, simulation-based training is not widespread in low- and middle-income countries, including Pakistan. More work is warranted on the cost effectiveness of implementing simulation-based learning, which, in turn, would increase the uptake of simulation to enhance cardiothoracic surgical training in Pakistan.

Keywords: Surgery, Patient simulation, Simulation training, High-fidelity simulation training.

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Introduction

Adequate surgical training is essential for the provision of quality surgical care to patients. In recent years, simulation-based training (SBT) has been advocated as an adjunct to traditional training modalities in surgical training.¹ Surgical SBT provides residents and surgeons an alternative practical exposure, allowing them to make mistakes and reflect on them. This ensures better patient safety and prognoses for patients as surgeons are initially trained with simulated models before they can practice on real patients.² In addition, widespread evidence suggests effectiveness and transferability of skills learned from

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simulation into real-life operating theatre (OT) practice. Moreover, its benefits have been much highlighted during the coronavirus disease-2019 (COVID-19) pandemic.^{3,4}

However, the role of SBT in cardiothoracic surgery (CTS) and the challenges of implementing SBT related to CTS in low- and middle-income countries (LMICs) have not been well-explored in literature. The current narrative review was planned to explore the various simulators available for CTS training in addition to the benefits and challenges involved in implementing CTS SBT in the Pakistani setting.

Types of simulation

Based on their degree of imitation of human physiology, referred to as their 'fidelity', simulators can be classified as having high and low fidelity. Some argue that fidelity is a depiction of reality; better the portrayal of real-life scenarios, higher the fidelity, and vice versa.⁵ Others maintain that fidelity refers to a near-faultless representation of 'cues and stimuli'. This definition stems from the argument that even if a simulation may seem adequate to beginners, qualified clinicians may find them unsatisfactory as their experience allows them to identify even minor flaws in the design. As the depiction of reality is highly subjective, certain authors place importance on 'cues and stimuli'.⁶ Fidelity, therefore, can either be considered objective, i.e., mathematical, or subjective, i.e., depending on the performance of the learner.⁵

Important factors for determining fidelity include patient characteristics, healthcare facilities and clinical scenarios. Patient characteristics account for communication and procedural skills, and require attention to anatomical and psychological details. Healthcare facilities include the setting and the equipment available. Clinical scenario relates to how the situation progresses, and the role of the teaching party. In line with this, in low-fidelity simulations, there is inadequate sensorial stimulation from an anatomical and physiological point of view, aspects of the environment and healthcare facility need to be assumed by the trainee, and the task itself is highly supervised. Also, constant instructions from the supervisor reduces the learner's autonomy in the clinical scenario. The reverse is true for high-fidelity simulations.⁶

Simulation in CTS training

Both low- and high-fidelity simulators are employed in CTS

training for a variety of procedures, with each having its own pros and cons.

Low-fidelity simulators

Synthetic models

These are low-tech, simple, low-to-moderate-fidelity simulators used to polish basic surgical skills. Models are available for coronary artery and vascular anastomosis, including an 'anastomotic block', which is a wooden block with irrigation connectors mounted on it. These connectors allow synthetic grafts to be placed.⁷ Another is a HeartCase model (Chamberlain Group, Great Barrington, Massachusetts [MA], United States), which is a portable chest model and is being used for different types of simulations. By fitting a synthetic target vessel, it is used to simulate vessel grafting by attaching a synthetic thoracic aorta that is pressurised using a syringe or a pressure bag. Normal saline is used for thoracic aortic cannulation simulation, and attachment of a silicone-based aortic or mitral valve is used for aortic or mitral valve repair/replacement simulation, respectively.^{8,9}

High-fidelity simulators

Tissue-based porcine simulators

These include porcine heart models or porcine health-lung blocks. Porcine heart model is a 'wet-lab' simulation technique that is low-tech but high-fidelity due to its anatomic and physiological similarities to humans, allowing near-reality simulation of very complex procedures.¹⁰ These are highly comparable to actual patients and enable multiple cannulations.⁸ Such models have been utilised in simulation and training of coronary artery bypass surgery (CABG), aortic cannulation, thoracic artery surgery anastomosis, atrial cannulation, aortic valve or root replacement, and mitral valve repair.^{8,11,12}

As for porcine heart-lung blocks, several types are commercially available that are placed in the chest cavity of mannequins to simulate different aspects of thoracic surgery via thoracotomy or thoracoscopic approaches. They simulate a variety of procedures, including hilar dissection, tracheal and sleeve resection, pulmonary resection and oesophageal anastomosis by accessing the posterior mediastinum. If the stomach is included in the tissue block, oesophagogastric anastomosis can also be simulated.⁸ These models can also simulate video-assisted thoracoscopic surgery (VATS) via thoracoscopic ports, allowing identification of anatomic landmarks, performing complex manoeuvres, dissecting/encircling hilar vessels and bronchus, and using endoscopic staplers to divide structures.⁸

Beating heart model

The silicone-based model (Chamberlain Group, Great Barrington, MA, US) is externally linked to a compressor and a controller. The compressor is linked with the tubing inside the heart through the controller via two solenoid valves; one controlling the squeezing of the heart, and the other controlling the apex-to-atria pull-up. Target coronary arteries (2mm) are partially mounted into the myocardium. To simulate the pericardial wall, the heart can be mounted on a plastic torso.^{10,13}

Ramphal cardiac surgery simulator (RCSS)

This is a high-fidelity, tissue-based beating heart simulator (UltraMotionw, Ltd, Mattituck, New York) that enables the trainees to perform both beating and arrested heart surgeries, enhancing their confidence and expertise before practising directly in the OT. The model employs a porcine heart containing computer-controlled inflating balloons in each ventricle. The computer programme is capable of simulating a variety of clinical scenarios, including beating heart, arrhythmias, cardiac arrest, hypotensive states, hypertensive states, and intra-aortic balloon pump placement. Washable blood substitutes can also be used to perfuse the model. When placed in a simulated pericardial wall within a mannequin, the RCSS can imitate an array of cardiac surgery procedures. These include CABG, aortic root reconstruction or valve replacement, cardiopulmonary bypass, and heart transplantation. The computer programme can also simulate crisis situations, including accidental air instillation, aortic dissection and ventricular fibrillation, to equip the trainees with crisis management skills.^{10,14}

Orpheus perfusion simulator

The Orpheus perfusion simulator (Orpheus; Ulco Technologies, Marrickville, New South Wales, Australia) is equipped with hydraulic simulator, electronic interface unit, and real-time controlling computer software. These components can function synchronously to mimic the complete range of events that may occur during a cardiopulmonary bypass. The hydraulic simulator is placed on an OT table and connected externally to a heart-lung machine. This model also employs the existing hospital monitoring system to display arterial pressures, central venous pressures, electrocardiography and nasopharyngeal temperature.^{15,16}

Thoracic surgery simulator

The University of North Carolina (UNC) thoracic surgery (Center for Cardiothoracic Simulation; University of North Carolina, Chapel Hill, North Carolina, United States) simulator is based on a porcine heart, lung, descending aorta, trachea and oesophagus. Being a high-fidelity

simulator, this model can accurately simulate hilar dissection, open lobectomies, thoracoscopic resections or lobectomies, biopsies and pericardial window. This simulator can be employed for simulating left hilar dissection, left upper and lower lobectomies, thoracoscopic wedge resections, pleural biopsy, pericardial window and thoracoscopic lobectomy.¹⁴

Evidence for CTS simulators

Significant evidence has emerged in recent years regarding the effectiveness of simulators in CTS training. A cardiac surgery simulation programme consisting of 6 modules was designed in 2010-13 to train residents. It was found that both low- and high-fidelity simulators are well-accepted among both residents and faculty, with special focus on the effectiveness of high-fidelity simulators. A substantial 85% of the residents believed that SBT boosted their technical skills and confidence in the OT.¹⁷ The Ramphal high-fidelity cardiac surgery simulator also proved to mimic high degrees of realism, enabling the trainees to learn timely and appropriate management of adverse clinical scenarios.¹⁸ For medical students, training with video and simulation-based methods has proved more efficient compared to the traditional lecture-based teaching.^{19,20}

With regards to the utility of low-fidelity simulators, however, existing evidence remains conflicted. A randomised controlled trial (RCT) comparing skills and performance of residents and fellows in aortic and coronary anastomosis trained with low-fidelity simulation in addition to their usual curriculum versus those trained with the usual curriculum alone showed no significant difference.²¹ On the contrary, low-fidelity mitral valve surgery simulation improved surgical skills and was found to be cost-effective in CTS training.²²

Validation and performance assessment

The use of simulation technology is increasing in surgical training at a very fast pace, and it is likely to be the dominant mode of teaching in the surgical sphere soon. This makes it imperative to assess the validity and effectiveness of such training. Traditionally, surgical skills have been assessed in the OT via supervision and feedback.²³ Efforts to alleviate the subjectivity involved in such assessments have led to the development of global

assessment tools that rely on direct examination and video recordings of a simulated procedure. Among these, the Objective Structured Assessment of Technical Skills (OSATS) has emerged as one of the commonest and most validated tool to assess surgical skills of residents.²⁴ Till date, performance assessment in CTS simulation using the OSATS score has been reported for coronary anastomosis, cardiopulmonary bypass, mitral valve surgery and pulmonary surgery. The results based on performance and skills acquisition among trainees following simulated learning part of the literature (Table).

An RCT was conducted using a low-fidelity, bench model for end-to-side microvascular anastomosis simulation. Compared to the residents who did not self-practice, those practicing independently following an expert-guided simulation tutorial scored better on the OSATS scale (23.7 ± 4.7 vs 18.5 ± 3.9 , $p=0.003$) and performed the anastomosis significantly faster (777 seconds vs 977 seconds, $p=0.04$).²⁵ Another study from France designed a simulation-based curriculum for junior cardiac surgery trainees and compared its effectiveness in terms of medical education and technical, interactional and critical thinking skills essential for performing cardiopulmonary bypass. The results revealed that trainees taking the new curriculum significantly outperformed those in the traditional curriculum in technical skills (18.2 vs 14.8 , $p=0.05$) and communication skills (3.5 vs 2.2 , $p=0.013$).²⁶

Table: Components of Objective Structured Assessment of Technical Skills (OSATS) score for cardiothoracic surgery (CTS) simulation models.

	Anastomosis Task Station with synthetic target vessels for coronary artery anastomosis ¹⁵	Beating heart model by chamberlain for coronary artery anastomosis ¹⁵	Porcine and plastic heart model for mitral valve surgery ¹⁰
Graft orientation	Pre-training: 1.4 ± 0.8 Post-training: 2.1 ± 1.5	Pre-training: 1.4 ± 0.7 Post-training: 1.8 ± 1.1	Pre-training: 2.7 ± 0.9 Post-training: 3.4 ± 0.8
Appropriate bite	Pre-training: 1.5 ± 0.8 Post-training: 2.0 ± 1.0	Pre-training: 1.3 ± 0.7 Post-training: 1.7 ± 0.8	Pre-training: 3.0 ± 0.5 Post-training: 3.5 ± 0.5
Appropriate spacing	Pre-training: 1.4 ± 0.7 Post-training: 1.9 ± 0.9	Pre-training: 1.3 ± 0.7 Post-training: 1.7 ± 0.8	Pre-training: 2.9 ± 0.7 Post-training: 3.5 ± 0.7
Needle holder use	Pre-training: 1.7 ± 1.0 Post-training: 2.0 ± 1.4	Pre-training: 1.6 ± 1.3 Post-training: 1.8 ± 1.0	Pre-training: NA* Post-training: NA*
Use of forceps	Pre-training: 2.0 ± 1.3 Post-training: 2.2 ± 1.1	Pre-training: 1.6 ± 0.9 Post-training: 2.1 ± 1.0	Pre-training: NA* Post-training: NA*
Needle angles	Pre-training: 1.4 ± 0.7 Post-training: 1.8 ± 1.0	Pre-training: 1.5 ± 1.1 Post-training: 1.8 ± 0.9	Pre-training: 2.4 ± 0.6 Post-training: 3.2 ± 0.5
Needle removal/transfer	Pre-training: 1.6 ± 0.9 Post-training: 2.2 ± 1.1	Pre-training: 1.6 ± 1.2 Post-training: 2.1 ± 1.2	Pre-training: 2.7 ± 0.6 Post-training: 3.2 ± 0.7
Sutures management and tension	Pre-training: 1.4 ± 0.7 Post-training: 2.2 ± 1.2	Pre-training: 1.3 ± 0.7 Post-training: 1.8 ± 0.9	Pre-training: 2.7 ± 1.0 Post-training: 3.6 ± 0.8
Knot tying	Pre-training: 1.4 ± 0.7 Post-training: 1.6 ± 0.9	Pre-training: 1.4 ± 0.7 Post-training: 1.8 ± 0.9	Pre-training: 2.9 ± 0.9 Post-training: 3.4 ± 0.7

Means and standard deviations are presented for different components of OSATS score pre- and post-simulation-based training. NA: Not applicable.
*Modified OSATS score was used which excluded this component.

CTS simulation in Pakistan

In Pakistan, the traditional apprenticeship model of 'see one, do one, teach one' has been the more commonly followed method of training, whereby a trainee learns through experience.²⁷ However, with the advent of SBT, traditional styles of teaching have been challenged due to concerns relating to patient safety, ethical and legal barriers, increased cost of radical procedures, and procedural complications which subsequently prolong hospital stays and add to the financial burden. These challenges are less pronounced in surgical SBT, thus favouring it over traditional methods.¹

A greater emphasis in surgical training in Pakistan is placed on practicing on actual patients in the OT. This situation is not conducive to learning and can potentially complicate outcomes for patients as well.²⁸ CTS simulation can be effective in identifying surgical steps and associated risks at every step, all the while aiding in the development of cognition and judgement.²⁹ In addition, trainees can receive automated feedback on their performance, which boosts self-accountability and autonomy, allowing them to learn in a judgment-free setting. Trainees can also review their performance and improve via practice before performing the same procedure on a live patient. As medicine is a dynamic field and advancement in surgical practices are imminent, simulations also aid well-established surgeons in mastering new technical procedures.

The importance of simulation-based surgical training became particularly apparent during the COVID-19 pandemic.³⁰ Multiple COVID-19 waves overwhelmed the existing hospital capacity, leading to cancellation of elective surgeries to break transmission lines in hospital settings. In addition, many hospitals restricted the involvement of surgical trainees even in uncancelled surgeries.³¹ This situation resulted in extremely limited OT opportunities for surgical trainees, adversely affecting their training. SBT could offer a beneficial alternative in such circumstances, ensuring active participation of trainees and continuous automated feedback to improve their surgical skills.³²

Current trends in Pakistan

In Pakistan, simulation-based wet lab sessions and workshops are conducted on valve-sparing aortic root replacement, segmental lobectomy, mitral valve replacement, atrial and ventricular septal defect closures, and coronary anastomosis at the Aga Khan University Hospital (AKUH). These simulations mostly employ cow and goat hearts that are cheaper alternatives to expensive high-fidelity equipment. These workshops are led by faculty mentors who provide background information,

instructions and debriefs. Trainees also receive adequate feedback from faculty mentors on tissue handling, knowledge of anatomical relationships, and surgical skills.³³

Financial challenges and the way forward

CTS SBT remains limited in Pakistan. A major concern when implementing SBT is the financial capital required to put this mode of education into effect, especially in an LMIC setting. On the other hand, simulation can adequately equip Pakistani surgeons with the necessary skills, reducing costs associated with postoperative complications, suboptimal perioperative care, and inappropriate resource utilisation. Essentially, a one-time investment in superior simulation technology may help reduce various associated costs in the future. However, there is a paucity of evidence weighing costs versus benefits that can inform evidence-based implementation of SBT in Pakistan.

Owing to financial constraints, installing simulators in every hospital is not feasible. An alternative approach can focus on making simulators available at strategic venues where they are more accessible to trainees from various institutions. With a larger number of trainees using the same simulator, the cost per trainee would substantially decrease, making SBT more cost-effective.³⁴ Development and implementation of low-cost, low-fidelity simulators that are capable of nearly covering the full range of CTS procedures can be another alternative, particularly for Pakistan.²² The use of goat and cow heart can offer an alternative to high-cost equipment.³³

Conclusion

Considerable evidence is available to demonstrate that CTS SBT can be used to enhance surgical skills and OT performance, in addition to building confidence among trainees. Despite some commendable efforts, use of simulation in CTS training remains limited in Pakistan, attributed to the high financial costs. More work is warranted on the cost effectiveness of implementing SBT, which, in turn, would increase the uptake of simulation, and enhance CTS training in Pakistan.

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Author Contribution:

HI: Study topic, study design, literature search, data collection, analysis, writing, final approval.
 HA, UW, SMAZ, SA: Study design, literature search, data collection, analysis, writing, final approval.