Narrative Review

Role of simulation-based training in thoracic anaesthesia

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ABSTRACT

Simulation-based training (SBT) aims to acquire technical and non-technical skills in a simulated fashion without harming the patient. Simulation helps the anaesthesiologist acquire procedural competence and non-technical abilities. In thoracic anaesthesia, various simulators are available with varying degrees of fidelity and costs. Apart from improving bronchoscopy-related skills, other potential applications of SBT include the practice of lung isolation in normal and difficult airway scenarios, troubleshooting complications during surgeries, and certification of the proficiency of anaesthesiologists. A pragmatic approach is required for choosing the simulator based on its availability, cost, and benefits. Although the literature supports SBT to improve procedural skills, retention of the skills and their translation into improving clinical outcomes remain largely unproven. Randomised, controlled studies targeting the effect of SBT on the improvement of clinical outcomes of patients are needed to prove their worth.

Keywords: Bronchoscopy, lung isolation, one-lung ventilation, simulation, simulation-based training, technical skills, thoracic anaesthesia

INTRODUCTION

Though the practice of anaesthesia has become increasingly safe, it is still associated with events which, though rare, may be life-threatening. Management of such events requires technical skills like knowledge of the subject and procedural competence and non-technical abilities such as teamwork, leadership, and crisis management. Simulation-based training (SBT) aims to acquire technical and non-technical skills in a simulated fashion without harming the patient. Technology-based simulation in anaesthesiology is helpful for training in general anaesthesia, regional anaesthesia, perioperative medicine, rare events, and crisis resource management.[1] In these settings, the use of simulation appears to improve learner satisfaction, knowledge, non-technical skills, and patient outcomes, though the magnitude of the effect is variable across studies. Additionally, SBT is currently being used to evaluate the competency in skills required for anaesthesia.[2,3]

Thorough knowledge of bronchial anatomy and the ability to perform bronchoscopy are essential skills for a thoracic anaesthesiologist. In addition, the placement of a lung isolation device (LID), safe conduct of one-lung ventilation (OLV), and troubleshooting the complications during thoracic surgery demand a thoracic anaesthesiologist's technical and non-technical skills. SBT plays an essential role in acquiring these skills. In this narrative review, we shall review the bronchoscopy simulators concerning types, their roles in training, and the practice of thoracic anaesthesia, with evidence from the literature.

Types of bronchoscopy simulators

Bronchoscopy simulators can be divided into low-fidelity and high-fidelity simulators [Table 1].

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Table 1: Comparison of properties of various bronchoscopy simulators

Parameter	Low-Fidelity Simulators				Wet-Lab simulators or Cadaveric Models	High-Fidelity Simulators	
	Tracheo-bronchial tree scaffold	Airway Mannequins	3D-printed Models	Broncho-trainers (e.g., Oxford Model)		Online Bronchoscopy simulator	Virtual Bronchoscopy Simulators
Cost	Low	Low-Medium	Low	Low to medium	Low to Medium	Low to medium	High
Anatomical realism	No	Yes	Yes	No	Yes	yes	Yes
Ability to change degrees of difficulty	Possible	No	Yes	Yes	No	No	Yes
Fidelity of physiological and pathological responses	No	No	No	No	Possible	possible	Yes
Chances of damage to the bronchoscope	Yes	Yes	Yes	Yes	Yes	No	No
Ability to learn navigational skills of bronchoscope	Yes	Yes	Yes	Yes	Yes	No	Yes
Portability	Very Easy	Easy	Very Easy	Easy	Difficult	Easy	Variable
Ability to gauge proficiency of the operator via feedback mechanism	No	Possible	No	Yes	No	No	Yes

Low-fidelity bronchoscopy simulators

Low-fidelity simulators refer to mechanical, inanimate models that mimic the anatomy of the tracheobronchial tree and the lungs, into which the actual bronchoscope can be inserted. These models include airway mannequins, 3-dimensional (3D) printed models, non-anatomical broncho-trainers, and simple tracheobronchial scaffolds made up of tubes.

Airway Mannequins

Airway mannequins are made up of silicon, medical rubber, or plastic and include the head and face, larynx, and lower tracheobronchial tree. Such simulators include the Laerdal Airway Management Trainer (Laerdal, Stavanger, Norway) or the CLA Broncho Boy (CLA, Coburg, Germany).[4,5] These models are cheap, portable, easy to clean, and durable enough to withstand repeated procedures. A well-lubricated bronchoscope can be passed into the mannequin to learn the bronchial anatomy and simple bronchoscopy-guided procedures. Additionally, the operator knows how to handle the bronchoscope, coordination, and navigation skills. Even though the human anatomy is closely simulated in the mannequin, low-fidelity simulators cannot create physiological challenges (e.g., cough, secretions, etc.) and pathological complications (e.g., deviations or compressions of the airway, bleeding, etc.) during the procedure of bronchoscopy. Also, potential damage to the bronchoscope remains a concern.

Three-Dimensional printed models

Three-dimensional printing or 'additive manufacturing' is a process where a 3D solid object is created from a digital image. The most used technique of manufacturing 3D models is- 'Fused Deposition Modelling', in which a polymer filament is extruded via a headed nozzle on a print platform. Various polymer filaments are used to make 3D models, for example, polylactic acid (PLA) or acrylonite butadiene styrene. More recently, thermoplastic filaments have been used to make semi-rigid or flexible models. The production cost depends on the filament type, design complexity, and printing methods. However, it is much less than that of high-fidelity simulators and commercially available airway mannequins. A semi-rigid or flexible 3D-printed model ranges from $1 to $150, whereas a solid model costs less than $100.[6] Also, the time required to manufacture a 3D model could be as little as 20 hours, as shown by Bustamante *et al.*[7] Digital Imaging and Communication in Medicine (DICOM) files from computed tomography scans are converted into Stereolithographic (.stl) files by computer software to make a blueprint for a 3D model. Models of abnormal or pathological anatomy can be used to train the operator to tackle airways with abnormal anatomy. Studies by Osswald *et al.*[8] and Pedersen *et al.*[9] have shown that 3D-printed models were more realistic than the commercially available simulators.

Non-anatomical Broncho-trainers

There are a few commercially available bronchoscopy trainer models, such as the Oxford Fibreoptic Teaching Box and the 'Choose-the-hole' model.[10] Oxford Box is a cylindrical box made of perplex. It has five plates, with each having several holes. The size of the hole and the combination of holes are precisely designed so that the tip of an adult fibreoptic bronchoscope (FOB) passes through them with active manipulation. The holes have non-traumatic chamfered edges to prevent damage to the FOB. The operator learns a spatial orientation of FOB manipulation with a combination of navigational skills. The 'choose-the-hole' model has three wooden plates mounted on a wooden base. Each of the plates carries several holes through which the bronchoscope is passed. The limitations of such models are non-anatomical designs, cost, and the possibility of damage to the bronchoscope.

Trachea-bronchial tree scaffolds

The design of the trachea and bronchi can be reproduced using simple connectors and corrugated tubing. Such models can be indigenously made and hence inexpensive and can be used as per the needs of the trainees. Difficulty levels can be adjusted according to the operator's experience. Dexter™ is an endoscopic system designed to improve dexterity.[10] Verma *et al*.[11] devised a simple bronchoscopy simulator comprising corrugated ventilator circuit tubing and Y-shaped connectors. These models are suitable for teaching novice trainees the basic skills of bronchoscope navigation.

Wet-lab simulation

Animal models have been used for many bronchoscopy training courses. Pig, sheep, or goats' airways are often used to learn bronchoscopy skills. Both living and dead animals can be used to improve realism; however, a highly skilled operator is required to ensure animals' safe and humane use for medical training. Bronchoscopy-guided procedures (e.g., endobronchial ultrasound, biopsy, foreign body retrieval, etc.) can be taught in the models. The dimensions often do not match the human airway.

High-fidelity simulation

High-fidelity simulation incorporates a variety of models that include either only a computer interface (e.g., online Bronchoscopy simulator) or a combination of human and computer interface (e.g. Virtual Reality Bronchoscopy Simulator).

Online bronchoscopy simulators

These are web-based applications that can be accessed using computer vs across the world. One example of such a simulator is the Bronchoscopy Simulator, developed by Kanellakos *et al*. and available on the University of Toronto website.[12] In such simulators, computer controls are used for navigation. The screen displays a realistic image of the trachea-bronchial tree. Such simulators also provide information on the bronchial anatomy through the separate boxes that pop up on the screen according to the navigation.

Virtual reality bronchoscopy simulators

These high-fidelity simulators use 'Virtual Reality Simulation' (VRS) that involves graphics, sensor technology, computer programming, and networking to create the simulation that mimics the tracheobronchial tree's anatomy, physiology, and pathologies. Despite the high cost of production and maintenance, many virtual reality simulators are commercially available. The high-fidelity simulators include a proxy bronchoscope structurally similar to the conventional bronchoscope. This bronchoscope can be inserted into the human interface of the computer (which are simulated nasal or oral passages). Simulation software then generates realistic images of the vocal cords and trachea-bronchial tree on the screen as the scope is advanced into the lower airways. As the operator navigates the bronchoscope, the computer records fine details like the number of bronchial segments entered, contact of the probe with the mucosa, amount of medication used, and duration of bronchoscopy, which help assess bronchoscopy skill with objective criteria. Physiological reflexes (e.g., cough reflex, secretions) and pathological complications (e.g., airway compression, bleeding, etc.) can be generated along with realistic scenarios like hypotension or desaturation. Thus, VRS bronchoscopy systems train the operator in anatomy and instrument handling and the management of physiological alterations and complications during the bronchoscopy. An example of a high-fidelity simulator is ORSIM (©ORSIM, Auckland, New Zealand), a portable device with a bronchoscope. It is connected to a computer interface. Introducing the bronchoscope into the box offers a highly realistic graphical representation of bronchial anatomy.[13]

Role of SBT in thoracic anaesthesia

Although the evidence for SBT is scarce in the field of thoracic anaesthesia, the following are the potential areas for its application:

Acquisition of knowledge about tracheobronchial anatomy

The anaesthesiologist's knowledge of endoscopic bronchial anatomy is the most critical factor in the successful placement of LIDs. Campos *et al*.[14] found that 39% of LIDs positioned using a FOB by the staff anaesthesiologists with limited experience in thoracic anaesthesia were malpositioned. Basic simulation in the form of high-quality images of bronchial anatomy provides only two-dimensional views. SBT using 3D print models and high-fidelity simulators helps acquire the knowledge of trachea-bronchial anatomy.

Training and development of psychomotor skills of bronchoscopy

A thoracic anaesthesiologist needs navigational and psychomotor skills in handling a bronchoscope, including hand-eye coordination, manual dexterity, anticipation of depth, rotation, and deflection of the bronchoscope's tip. Here, various task trainers like Oxford Box provide necessary significant help. Airway mannequins and 3D-printed models, with increasing degrees of fidelity, help in acquiring bronchoscopy skills. Regular reinforcement drills using simulators are required to maintain the skills after initial training.

Application of knowledge in troubleshooting of problems during the surgery

Even after successful placement of LID, intra-operative problems occur frequently, which include dislodgement of the device, bleeding, obstructed ventilation because of a herniated cuff, and so on. An inexperienced thoracic anaesthesiologist may not be able to identify and correct it promptly. Critical events like respiratory insufficiency may occur at the time of recovery from the anaesthesia, which requires prompt diagnosis and management. Practice on the simulators to deal with such events would train the anaesthesiologists to manage them efficiently.

Development of 'non-technical skills' during thoracic surgery

Critical events like acute desaturation, severe hypercarbia, and extremely high airway pressure are not uncommon during thoracic surgery. In such situations, everyone in the operation room needs to act in a coordinated manner under the leadership of an anaesthesiologist. A calm, composed mind, assertive nature, respectful communication with team members, clear directives, open mind to suggestions, and coordinated execution of skills help address the crisis. SBT has proved its effectiveness in developing essential non-technical skills for crisis management.[15]

Simulation-based competence certification

To keep pace with the global trends, the National Medical Commission of India has adopted the 'competency-based medical education' model.[16] Simulators would help evaluate anaesthesiologists' performance for thoracic anaesthesia, where an amalgamation of cognitive, psychomotor, and affective domain training can contribute to the certification of the anaesthesiology postgraduate degree.

Development of a model bank of simulators for difficult or rare case scenarios

In addition to basic anatomy and physiology training, simulation plays a vital role in efficiently delivering health care in unique, challenging, and rare cases. Examples include a patient with tracheal bronchus or a patient with a previous upper lobectomy. In such conditions, the normal anatomy of the tracheobronchial tree is replaced with altered anatomy or variations. Management of lung isolation devices in these scenarios is highly challenging. With the advent of 3D printing, computed tomograhic (CT) images of such cases can be used to prepare a 3D-printed model quickly and at a low cost. A bank of 3D-printed models of difficult airways can be used for a dry run for airway management plans, testing their effectiveness and identifying the hurdles in the execution before their applications in the actual patient.

Testing of new fibreoptic/video intubation scopes and lung isolation devices

In this competitive era, numerous manufacturers are emerging daily, each claiming the superiority of their fibreoptic bronchoscopes, video-laryngoscopes, and lung isolation devices. Airway simulators and 3D-printed models can be used to test the new devices before their application to patients.

Acquiring skills for procedures other than airway management in thoracic surgeries

Central venous cannulation and arterial line insertion are commonly performed in thoracic surgeries. Simulators like the 'Lifeform Central Venous Cannulation Simulator' (Nasco, Ft. Atkinson, WI) can help teach procedural steps, interpretation of data, and management of simulated complications.[17] Similarly, Ferrero *et al*.[18] showed that mannequin-based trans-oesophageal echocardiography (TEE) simulation helps trainees obtain better-quality images than lecture-based education. These skills can be practised and reinforced using the SBT.

Evidence of Simulation-Based Training in thoracic anaesthesia

Multiple systematic reviews have been conducted over the past ten years, evaluating the role of various types of bronchoscopy simulators. The heterogeneity of studies regarding training methods and outcome parameters has been a major drawback in drawing robust conclusions. Systematic reviews on SBT have predominantly included studies on novices, medical students, or pulmonology trainees and assessed them for skills pertinent to pulmonologists. Flexible bronchoscopy skills for an anaesthesiologist are focused on negotiating the upper and central airways, from the nares/mouth to the mainstem bronchi, particularly in distorted anatomy. Due to the vast variation in difficult airway situations, standardisation in study methodology and evidence generation in this area is difficult.

Kennedy *et al*.[19] conducted a systematic review and meta-analysis of 17 studies (including two studies on the paediatric population), comparing no intervention or non-simulation training with technology-enhanced simulation (both high-fidelity and low-fidelity) for flexible and interventional bronchoscopy, including rigid bronchoscopy. Though all studies included the bronchoscopy process as an outcome measure, only four studies used bronchoscopy assessment in actual patients. Compared with no intervention, SBT was associated with significant benefits on skills and behaviours and moderate benefits on procedural time. This benefit was not replicated in studies with real patients. The author suggested that longer or more structured training with authentic clinical context may be more effective. Also, animal models and plastic task-trainer models may be superior to virtual reality simulators. Gerretsen *et al*.[20] conducted a systematic review of 14 studies to study the effectiveness of SBT for flexible bronchoscopy and identify training features which led to effectiveness. Definitive conclusions could not be made due to variations in the methodology of the studies and a lack of assessment of patient outcomes. SBT improved anaesthesia residents' non-technical skills (e.g., communication, interpersonal, team management, behavioural skills, etc.), which were assessed objectively by the standardised Anaesthetists' Nontechnical Skills (ANTS) system.[15] It is reasonable to believe that improvement in the skills of the trainees translates into improvement in patient's clinical outcomes. However, very few studies have shown a positive impact on patient outcomes.[21] Zendejas *et al*.[22], in a systematic review of more than 50 studies, showed that SBT was associated with only small to moderate, non-significant patient benefits compared to non-simulation training. Results of another meta-analysis and systemic review of 77 anaesthesiology simulation studies (6066 participants) showed that simulation was more effective than no intervention (except for patient outcomes) and was non-inferior to non-simulation training.[1]

SBT has been rarely applied in the education of thoracic anaesthesia. Hierlmeier *et al*.[23] studied the effect of SBT in troubleshooting the malpositioned DLT in ten anesthesiology residents. It showed that the time to correct the position of DLT and the percentage of trainees who could correct the position of DLT successfully improved after two simulation-based sessions and didactic presentations. Campos *et al*.[24] noted that SBT and computer-based training were equivalent in training the non-thoracic anaesthesiologists for insertion and correct placement of DLT. Similarly, Latif *et al*.[25] found no difference between video-didactic education and simulation in the novices for lung isolation skills. Failor *et al*.[26] reported the promising use of a high-fidelity simulator in improving residents' confidence and performance scale in the placement of LIDs. Gamez *et al*.[27] reported using the simulator to compare the ease of insertion of three types of DLTs over airway exchange catheters. Similarly, El-Tahan *et al*.[28] reported using simulated easy and difficult airways to compare three different video laryngoscopes for the insertion of DLTs. Thus, SBT is being applied for combined technical-behavioural training and testing of new devices in thoracic anaesthesia.

Lastly, the use of SBT is not without its challenges and limitations. A high-fidelity simulator is an expensive commodity, with additional recurring costs of regular maintenance, repair, high-speed Internet connectivity, and software subscriptions. Most simulation-based equipment is bulky and requires adequate space to house it. Studies have shown substantial differences in the performance of different types of simulators, and one needs to be cautious while extrapolating results from one kind of simulator to another.[29,30] Also, no significant advantages were observed with high-fidelity simulators as compared with low-fidelity simulators in a few studies.[31-33] While some evidence shows that simulation-based training improves parameters such as knowledge, skills, and behaviour, the impact on patient-related outcomes remains definitively established. Finally, simulation-based scenarios used to evaluate competency need to be validated by comparison with conventional methods.

CONCLUSION

SBT, already a highly recommended part of the medical degree syllabus, is also a method for the initial training and reinforcement of standard technical and non-technical skills in anaesthesiologists. However, its translation into improved patient outcomes and its role in advanced skills training and assessment remains largely unproven. Therefore, with various simulators with varying degrees of fidelity and corresponding costs in the market, a pragmatic choice should be made, balancing the costs and benefits. Randomised, controlled, long-term studies on SBT targeting patients' clinical outcomes are needed to prove its worth.

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