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3D printed airway simulators: adding a dimension to bronchoscopy training

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The last decade has witnessed significant changes in the field of interventional pulmonology. With advances in technology, the bronchoscopist's toolkit has expanded beyond flexible bronchoscopy to include an array of advanced diagnostic and therapeutic procedures including endobronchial ultrasound, peripheral cryobiopsy, trans-parenchymal sampling methods, bronchial thermoplasty, endobronchial valve placement, and a variety of ablative therapies. In parallel, there has been a shift of credentialing bodies away from solely volume-based certification to knowledge and skills-based recognition of competency.¹

In this context, there is a need to re-examine the conventional approach to bronchoscopy training, which has largely relied on an apprenticeship-based “see one, do one, teach one” method. While there are clear advantages to learning by performing procedures on live patients, these must be weighed against the risk of harm to patients from inexperienced operators. Although flexible bronchoscopy complications are rare, trainee participation has been shown to increase procedural duration, amount of sedation required, and complication rates.² Additionally, there is variability in terms of supervisor style and exposure to sufficient numbers of complex procedures in some centres, making standardisation of teaching and objective evaluation of skill acquisition challenging. This is particularly pertinent in the initial steep portion of the learning curve of a bronchoscopic procedure.

Simulation is a validated mode of delivering bronchoscopy education in a zero-risk environment, and its incorporation in training programs is recommended.¹ Bronchoscopy simulation training currently exists in two forms: high-fidelity virtual simulators and low-fidelity physical models.³ While the latter offers significant advantages in terms of cost

and ease of development, a key limitation has been the degree of anatomical fidelity to the clinical reality.

With the advent of three-dimensional (3D) printing technology, low-fidelity simulators can now be designed to a high degree of anatomical realism with enhanced interactivity. This technology has already been shown to be of value in surgical simulation. However, its application in medical specialties, and more specifically bronchoscopy training, is largely unexplored. Since the first report of a 3D printed bronchoscopy simulator generated from patient imaging data in 2014,⁴ only a handful of studies have published (Table 1).

To provide accurate airway orientation and navigational skills, bronchoscopy simulators require a high degree of anatomical accuracy and fidelity. The strengths of 3D printed simulators in this regard are well established. In published studies, evaluation of face validity has typically been performed by collecting qualitative feedback from experienced bronchoscopists in respiratory medicine,^{5,6} anaesthetics,⁷ and thoracic surgery.⁴ Furthermore, in addition to normal anatomical variation, bespoke models have been designed to reflect a range of pathological anatomy.^{3,6} Almost unanimously, models have been judged to provide an authentic endobronchial navigation experience with respect to orientation, airway branching, and bronchoscope manipulation.

Bronchoscopy skill assessment is generally performed with modified versions of validated pre-existing tools. Using these, procedural dexterity and precision has been shown to increase with 3D printed bronchoscopy simulator training, where the benefits are three-fold. Firstly, a brief period of training using 3D printed models has been shown to result in significant improvements in novices' standards of task performance when compared to no training. In a pilot study, DeBoer *et al.* measured the median number of lung markers (6 in total) which were correctly identified in a 10 minute period. This increased from 1 vs 1 (simulator vs control group) pre-study to 6 vs 1.5 post-study, reflecting an effect size of 1.8 ($p < 0.001$).⁸ Secondly, 3D printed simulators have

discriminatory ability when combined with a validated assessment tool. Steinfert *et al.* evaluated the success rates of three participant groups with high, intermediate, and no bronchoscopy experience, in navigating and entering the superior segment of the right upper lobe and anterior segment of the left lower lobe.⁹ Within a 60 second timeframe, 100%, 64%, and 32% of the target bronchial segments were successfully entered by each group, respectively. Finally, the benefits of a short unstructured simulator training session on bronchoscopy skill quality can be retained. In a study conducted by Feng *et al.*, novices retained bronchoscopic manipulation skills 8 weeks after completing a simulation session with a 3D printed model.¹⁰ The implication of this is that learners can use 3D printed bronchoscopy simulators to track their improvements in skill over time. Furthermore, procedure completion time has also been observed to improve after training with 3D printed bronchoscopy simulators.^{8,11,12}

The cost of producing 3D printed bronchoscopy models is a distinct advantage over high-fidelity and commercially available low-fidelity simulators. 3D model production costs vary depending on the design complexity, materials used, and printing methods. Semi-flexible simulators have been reported to range from \$1 to \$150, while most rigid models cost less than \$100 to produce.^{5,11} Using a paediatric bronchoscopy model, DeBoer *et al.* estimated a 40% annualised training cost reduction per trainee when comparing their model to the nearest priced commercially available simulator, suggesting that 3D printed bronchoscopy simulators represent an economically viable method for training.⁸

As the field of bronchoscopy and interventional pulmonology evolves, so too must the training in these techniques. With increased sensitivity of radiological imaging and frequency of CT scanning through lung cancer screening programmes, the incidence of pulmonary anomalies requiring bronchoscopic tissue sampling will also rise. Furthermore, bronchoscopic techniques are becoming increasingly complex with a focus on precision sampling in real-time. In order to develop expertise, there is a concentration of such techniques at specific institutions, resulting in less opportunity for hands-on

training at other centres. In a post-Covid-19 setting, the risk to patient and proceduralist is increased in aerosol-generating-procedures, and pressures on trainees attaining competency will increase as they will often be excluded from elective procedures.

As 3D printing technology becomes more easily accessible, it offers the possibility of access to bronchoscopic simulation training by lowering the cost and increasing availability. Additionally, the versatility of 3D printing has potential to design patient-specific pathological models, thereby allowing plan and practise complex procedures before performing them in clinical practice. Collaboration between bronchoscopists, 3D printing, and endoscopic companies will be essential to develop simulators that maintain high standards of training.

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TABLE:

Table 1. 3D printed simulators for training on flexible bronchoscopy

Study	Study design	Cost	Participants	Evaluation	Conclusion
Bustamente 2014 ⁴	Observational	US\$250	Anaesthetic residents	Comparison of bronchoscopic views of a 3D printed simulator vs actual patient	3D printed simulator images were comparable to actual patient views
Byrne 2016 ⁵	Observational	AUD\$40	31 novices, 7 intermediates, 6 experts	Time taken and ability to navigate to target bronchus of 3D printed simulator	3D printed simulator discriminates proceduralist skill level
Osswald 2017 ⁷	Observational	80€	2 experienced anaesthetists	Comparison of face validity of a 3D printed simulator vs commercially available simulator	3D printed simulator was more realistic than commercially available simulator
Parotto 2017 ¹¹	Observational	USD\$5	Physicians with no bronchoscopic experience	Time taken and ability to perform pre-determined tasks in 3D printed simulator	3D printed simulator improved trainee performance
Pedersen 2017 ¹³	Randomised single-blind	US\$110	30 experienced anaesthetists and respiratory physicians	Comparison of ability to perform pre-determined tasks in 3D printed simulator vs commercially available simulator	3D printed simulator was more realistic than commercially available simulator
DeBoer 2018 ⁸	Observational	USD\$2500	27 paediatric residents	Time taken and ability to navigate to target bronchus of 3D printed simulator	3D printed simulator can be used to train basic flexible bronchoscopy skills

Ghazy 2019 ¹²	Observational	ND	10 cardiothoracic residents	Time taken and ability to navigate to target bronchus and retrieve foreign body of 3D printed simulator	3D printed simulators can be used to effectively train in flexible bronchoscopy
Ho 2019 ⁶	Observational	SGD\$135	5 experienced respiratory physicians	Navigation of 3D printed simulators with variable anatomy	3D printed simulator had realistic anatomy and bronchoscope manipulation

ND = not described

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