How to Fabricate a 3D-Printed High-Fidelity Bronchial Tree for Bronchoscopy Simulation: A Brief Report

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Introduction

Three-dimensional (3D) printing technology was first conceptualized in the early 1980s as a means of rapid prototyping.[1] Also referred to as additive manufacturing,[2] this technology has revolutionized the fields of engineering and product design and aided the rapid production of customized physical objects, especially small-sized ones.[3]

In the 1960s, flexible bronchoscopy was introduced as a diagnostic instrument.[4] Flexible bronchoscopy is a well-established and relatively safe procedure for both diagnostic and therapeutic interventions targeting a variety of pulmonary diseases.[5] However, bronchoscopies performed by untrained or inexperienced personnel may result in high risks of complications and misdiagnosed disease.[6,7] Simulation-based training is commonly used for bronchoscopy. In general, simulation-based training is more effective than the traditional apprenticeship model.[8] However, access to commercially available simulators that fulfill the needs of both trainers and trainees is difficult. Therefore, an adequate simulator must be developed to enhance the quality of bronchoscopy training.

In this study, we successfully used 3D-printing technology to develop a 3D bronchial tree model as a high-fidelity simulator for bronchoscopy, and we then demonstrated the validity of this model.

Methods

This section details each step of the development of our 3D-printed bronchial tree model.

Image Acquiring and Processing to Produce a 3D Model

We first designed our 3D bronchial tree model using the Magics 22.02 3D image processing and analysis software (Materialise, Leuven, Belgium) (Fig. 1A). To create the basic outline of the 3D model, we used a white-light handheld 3D scanner (EinScan Pro 2X Plus, Shining 3D Tech, Hangzhou, China) to scan the commercially available models of bronchial trees. We also bought a royalty-free lung 3D computed tomography (CT) scan file from a third-party web site (https://sketchfab.com) as a reference for our originally created 3D bronchial tree model. Generally, for educational models, both convenience and cost of repair are regarded as critical concerns. Thus, we divided our bronchial tree into 12 parts with 11 adapter rings for

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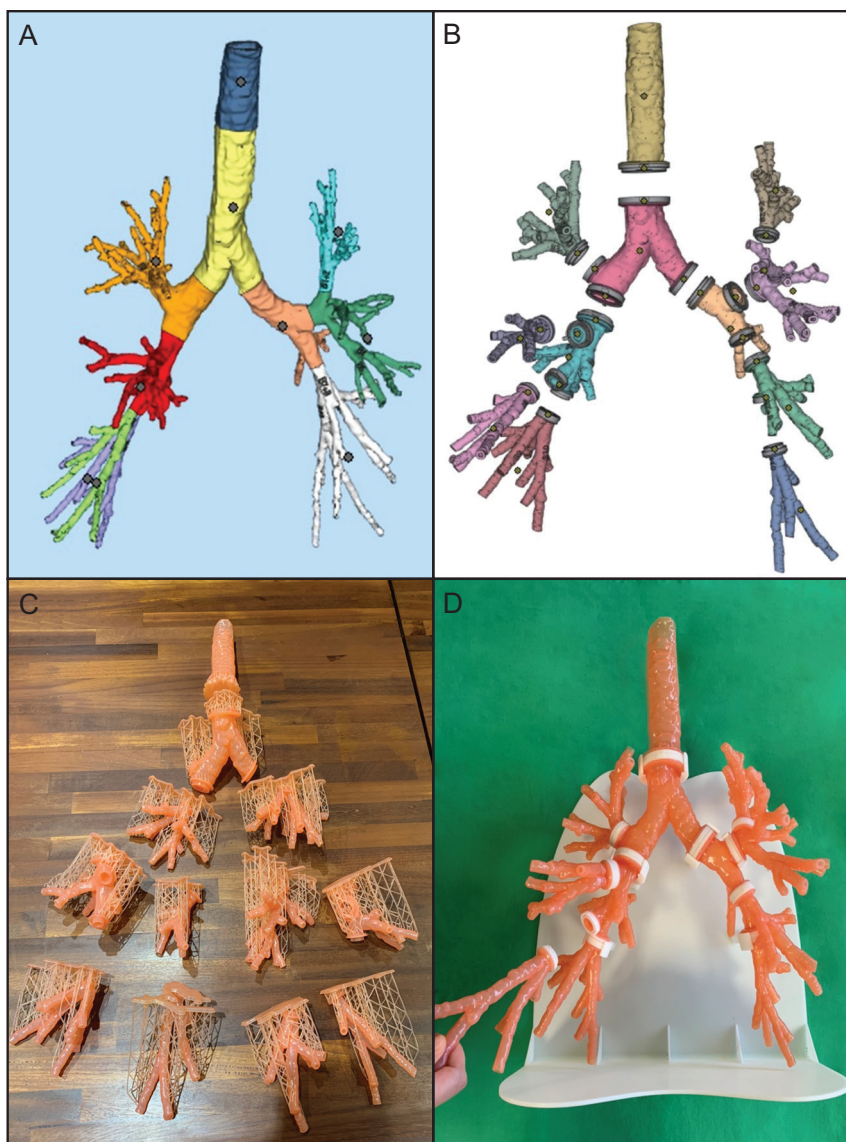
Fig. 1. (A) 3D bronchial tree model displayed in the Magics 3D preparation software (Materialise), (B) configuration of the 12 parts of the 3D bronchial tree, (C) 3D-printed bronchial tree with support material, (D) assembled 3D bronchoscopy simulator.

assembly (Fig. 1B), a design that aids in reproduction and replacement.

Transfer to a 3D Printer

We first converted the edited 3D files into a printable Standard Triangle Language (.stl) format and then uploaded them to a 3D printer using PreForm 3D-printing software (version 3.21, Formlabs, Somerville, Massachusetts).

Additive Manufacturing

We used 2 stereolithography (SLA) 3D printers to print the bronchial tree (Form 3, Formlabs) and adapter rings

(Lite 600, UnionTech, St. Charles, Illinois). To create a high-fidelity model, we extensively searched for an ideal material, and we finally decided to use a flexible resin. We used SLA with a Laser Spring Pink resin (Laser Spring Pink PT-SP001PK, ApplyLabWork, Torrance, California) to fabricate the main body of the bronchial tree. Laser Spring Pink is a pink, flexible, and resilient resin that can be repeatedly bent and compressed. This resin is suitable for creating tissue-like parts that aid in the study of the human anatomy. During this process, the printer deposits 0.05-mm layers of photopolymer for both the model and the support material, which are then immediately cured by UV light. Next, the support material (Fig. 1C) is removed using manual cutting. We then used SLA with a Somos Imagine 8000 resin
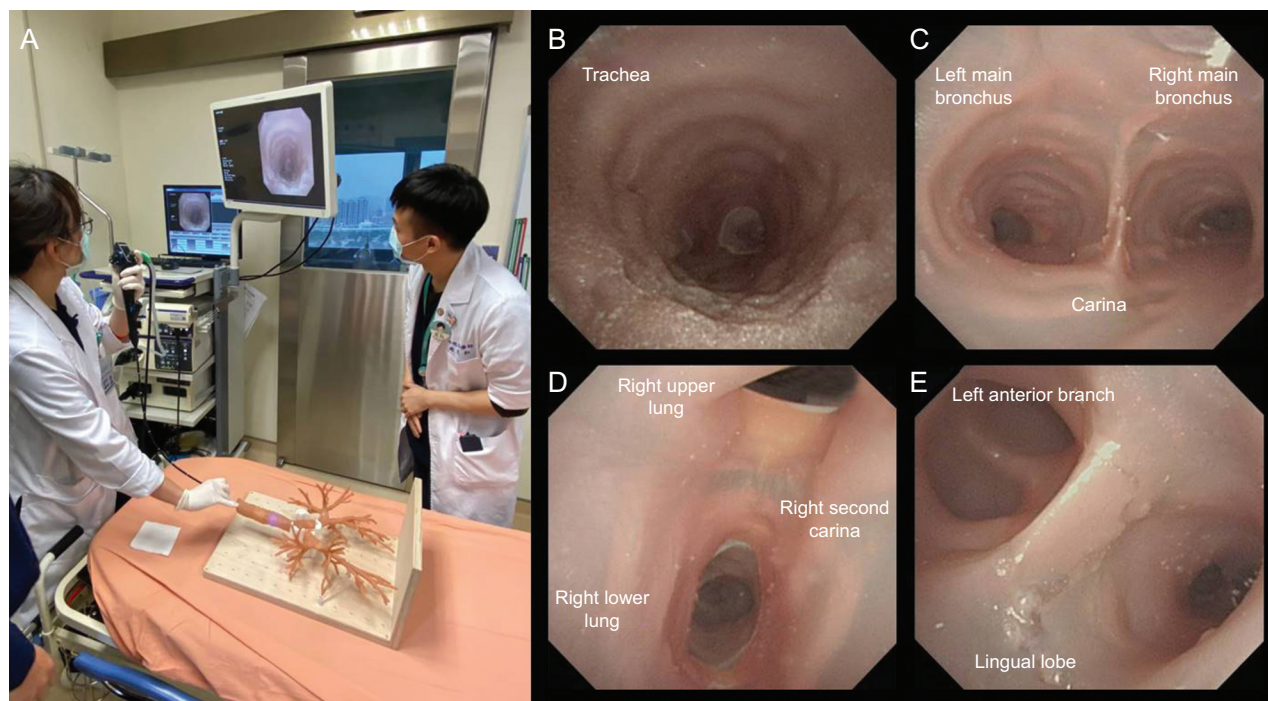
Fig. 2. 3D bronchoscopy simulator verification with bronchoscopy. Images acquired from bronchoscopy.

(SI8000, DSM Desotech, Elgin, Illinois) to fabricate the adapter rings. Somos Imagine 8000 is a low-viscosity liquid photopolymer that is used to fabricate water-resistant, durable, and accurate 3D parts. During this process, the printer deposits 0.1-mm layers of photopolymer for both the model and the support material, which are then immediately cured by UV light. In total, we spent approximately 132 h printing the 3D objects, 40 h conducting postprocessing, and 8 h assembling the bronchial tree model.

Verification of the Bronchial Tree Model

First, we delivered the assembled 3D bronchoscopy tree model (Fig. 1D) to pulmonologists for validation. Subsequently, we used a bronchoscope (BF-Q290, Olympus, Tokyo, Japan) to verify the anatomy and evaluate the accessibility of the bronchoscopy simulator. This study was approved by the institutional review board of Fu Jen Catholic University Hospital, New Taipei City, Taiwan (FJUH109038).

Results

We successfully used 3D printing to construct a life-sized, detachable, high-fidelity 3D bronchial tree model. To mimic a real human tracheobronchial tree, we used a soft, pink-colored resin. This bronchial tree model has a hollow design, which allows the bronchoscope to pass through the airway until it reaches specific bronchopulmonary segments.

Three highly experienced pulmonologists participated in the validation of our model and completed a questionnaire (Fig. 2). Using the subjective rating responses, we calculated a Cronbach alpha of 0.825, which indicated the reliability of the rating component of the questionnaire. All 3 pulmonologists provided positive feedback regarding our 3D-printed bronchoscopy simulator. They also strongly approved of its color and either strongly approved or approved of its maneuverability and the realism that it offers. However, not all pulmonologists approved of the simulator's anatomical accuracy, highlighting that the angle of the left main bronchus should be larger and that the C-shaped cartilage on the anterior and lateral walls and the poster membranous wall of the trachea should bear more resemblance to those of a real human. Nevertheless, all pulmonologists stated that this model can be used in future applications, and all of them were willing to recommended it to others for bronchoscopy training. They also offered several suggestions for improvements or upgrades. Among these suggestions were those on extending the airway model to the thyroid cartilage, larynx, and vocal cord and on creating pathological models, such as a tumor or stenosis model.

Discussion

Compared with commercially available simulators, 3D-printed bronchoscopy simulators are regarded as the most anatomically realistic simulators.[9] In this study, we used a

soft, resilient, pink-colored resin, which is an ideal 3D-printing material for fabricating medical models and mani-kins. Both surface appearance and color are key elements in successfully fabricating high-fidelity simulators. The resin that we used in this study had a Shore hardness of approximately 56–59 (A scale), which is adjustable by set-ting the thickness of the layers. Moreover, our bronchial tree model had a hollow, flexible design, which elicited favorable feedback among operators during bronchoscopy simulation.

Maintenance is the most problematic aspect of commer-cial bronchoscopy simulators. Transbronchial biopsy is a diagnostic procedure that is used to obtain lung tissue and fluid samples, which is regarded as a basic and critical pro-cedure that every pulmonologist should be aware of. To reconstruct clinical scenarios, extra additives or fluids are sometimes used during training programs. However, these bronchoscopy training sessions damage simulators over time. In this study, we overcame this challenge by designing a 3D-printed bronchoscopy simulator with 12 separate parts, a design that offers improved maintenance and cleaning capabilities. This design does not require the replacement of the whole simulator in case of damage. Instead, only spe-cific parts are replaced when irreparable damage occurs.

Customized 3D-printed models can be used when trainers or teachers face limitations in the use of traditional manikins and medical simulators during training programs or anat-omy courses. Thanks to the 3D-printing technology, trainers and teachers can design their own 3D models to overcome any challenges that they may face. In general, simulation-based education with high-fidelity simulators makes learn-ing more efficient in both preclinical and clinical settings.[10] Moreover, simulation-based clinical training allows inex-perienced learners to learn about a clinical scenario in a safe and controlled environment.[11] Therefore, high-fidelity mani-kins or simulators are primarily used during simulation-based clinical training programs.[12] 3D printing enables the direct creation of a realistic 3D model by 3D scanning an object[13] or by converting a 2-dimensional CT image, as a printable .stl mesh file,[14] into a 3D model. To closely resem-ble the soft biological tissues of real human organs, an adequate material must be chosen.[15] Therefore, in this study, we used a soft, pink-colored resin to fabricate the main body of the bronchial tree. Notably, some materials require post-processing to soften the printed structures.

This study has several limitations. First, we did not fabricate a pathological model. Therefore, we were unable to verify whether our 3D bronchial tree is applicable for specific skills with pathological specimens, such as biopsy and endobron-chial ultrasound. Second, we invited only 3 pulmonologists to validate our 3D bronchoscopy simulator. Hence, future studies on 3D bronchoscopy simulators should comprise a larger sam-ple of trainers and trainees. In this study, we used 3D-printing technology to fabricate a customized, high-fidelity bronchos-copy simulator with a detachable design to allow the users to conveniently maintain and clean it.

This 3D-printed bronchial tree model was validated by pulmonologists for use in bronchoscopy simulation train-ing. The use of 3D printing has potential in training, par-ticularly in helping trainees become familiar with the complex anatomical model of a bronchial tree.

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