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RESEARCH ARTICLE

Design and Development of Cost-Effective Handmade 3D Laryngeal Models for Effective Medical Education in Low-Resource Settings

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ABSTRACT

Background: Understanding the spatial and functional anatomy of the larynx is critical for medical education and clinical procedures involving the airway, phonation and respiratory control. However, cadaveric dissection and commercially produced models are often inaccessible or unaffordable by institutions in low-resource settings. This study aimed to design and evaluate a cost-effective, large-scale handmade three-dimensional (3D) laryngeal model for undergraduate anatomy teaching. **Methods:** Using locally-available materials (iron mesh, wire, wood dust, adhesive, enamel paints), anatomically accurate 3D models of the human larynx were fabricated. Each model incorporated key laryngeal cartilages, membranes, folds, and intrinsic muscles, with a hinge mechanism enabling movable visualization of the laryngeal inlet. The models were used in structured anatomy sessions for undergraduate students and evaluated qualitatively based on visibility, engagement, and conceptual understanding. **Results:** The handmade 3D laryngeal models successfully reproduced detailed anatomical structures from multiple perspectives- superior, anterior, posterior, medial, and lateral. Enlarged model dimensions improved group visibility for up to 50 students. Students reported enhanced spatial comprehension and higher engagement compared with traditional 2D diagrams. The models were inexpensive, durable, and easy to repair, demonstrating strong applicability in low-resource educational environments. **Conclusion:** Handmade large-scale 3D laryngeal models provide a simple, low-cost, and educationally effective teaching tool for medical anatomy, particularly in institutions with limited access to cadaveric material or advanced simulation technology. Their implementation promotes better spatial understanding, interactivity, and procedural confidence in airway management.

Keywords: Larynx, anatomical model, medical education, anatomy teaching, 3D handmade model, low-cost simulation

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INTRODUCTION

In the evolving landscape of medical education, the demand for accessible and effective anatomical teaching tools has driven innovation beyond traditional, costly commercial models. Recent studies highlight the efficacy of 3D anatomical models, which offer high-fidelity representations of complex structures at low production costs, enhancing student engagement and anatomical understanding [1]. The preparation of 3D anatomical models for medical education typically involves digital imaging from CT or MRI scans, followed by segmentation using software like 3D Slicer to isolate structures such as the mediastinum, upper abdomen, or pelvis, and subsequent 3D printing with affordable materials like PLA or TPU for patient-specific replicas [2-3]. The entire process is expensive and involves various high-end tools and software. Thus, handmade models can replicate intricate anatomical details. Several researchers have pioneered the creation of 3D printed anatomical models by converting digital reconstructions into tangible teaching aids for intricate structures like the heart, long bones, etc. [4-5], whereas others have designed custom 3D models of complex systems, including the inner ear, oculomotor apparatus, cardiopulmonary structures, cerebrovascular network etc., based on imaging data [6-8]. The preparation of simple handmade anatomical models represents a cost-effective and innovative approach to medical education, particularly in resource-limited settings.

The study of complex anatomical structures in medical education is always extremely important. Structures such as the human larynx are essential because they play a critical role in multiple vital functions, including respiration, phonation and airway protection. The posterior view of the larynx, showing the arytenoid and cricoid cartilages, is the most difficult area for students to conceptualize without a physical aid [9]. Traditional teaching methods like 2D diagrams or cadaveric dissection often fall short in conveying the larynx's three-dimensional dynamics and spatial relationships, leading to gaps in clinical competence for procedures like intubation or laryngoscopy. The larynx is a highly specialized organ located in the anterior neck, composed of cartilages (thyroid, cricoid, arytenoid, epiglottis), intrinsic and extrinsic muscles, ligaments, and a delicate mucosal lining [10].

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Procedures like endotracheal intubation, tracheostomy, and laryngoscopy require precise anatomical knowledge. Hence, innovative teaching strategies such as three-dimensional models are increasingly being adopted to enhance spatial understanding and bridge the gap between theoretical knowledge and clinical practice. A handmade model allows for the direct observation of the laryngeal inlet's closure, a key concept in swallowing physiology. Effective and easy anatomical teaching is often challenged in low-resource settings by limited access to cadaveric specimens, high-cost commercial models and constrained infrastructure. Consequently, innovative, low-cost teaching strategies are urgently needed to bridge theoretical knowledge and hands-on clinical skills. Handmade 3D models, leveraging everyday materials like clay, foam, wire, and acrylic paints, offer a promising, democratizing alternative by faithfully replicating anatomical fidelity without sophisticated technology. The present study aimed to design and fabricate a large-scale, handmade three-dimensional (3D) teaching model that offers a rational and transformative solution. This paper introduced cost-effective handmade 3D anatomical models as a practical alternative, leveraging simple materials to democratize medical teaching in resource-limited settings.

MATERIALS AND METHODS

The study was formulated in the department of Anatomy, Diphu Medical College, Assam, India for the demonstration of an anatomical model during classroom teaching. A large-scale 3D teaching model of the human larynx was designed and fabricated to facilitate demonstration-based learning among undergraduate medical students. The dimensions of the models were deliberately enlarged beyond those of a normal human larynx to ensure clear visibility for a group of at least 50 students during classroom teaching sessions. The internal structural framework of the models were constructed using an iron net secured with iron wire, providing a rigid skeleton (Figure 1). A hinge mechanism was incorporated at the anterior aspect of the cricoid cartilage to allow partial mobility and better demonstration of internal structures.

A composite paste prepared by mixing adhesive containing polyvinyl acetate with wood dust was applied over the iron mesh framework and allowed to dry under the sunlight to ensure structural integrity. To reinforce the model and eliminate surface irregularities, a secondary coating of adhesive was applied, followed by localized applications of the wooden paste to fill any remaining gaps. Areas with surface irregularities or gaps were further refined by reapplying the wood dust paste. Once fully dried, the model surface was smoothed using sandpaper to achieve a uniform finish. The entire model was then coated with required different enamel paints for durability and aesthetic clarity. Moreover pyramidal arytenoid cartilages are fitted over the cricoid cartilage to demonstrate the rotatory movements in the vertical axis facilitating the abduction and adduction of the vocal cords manipulating the rima glottidis.

Finally, the vestibular and vocal folds/cords were fitted between the vocal processes and the thyroid cartilage, completing the functional and anatomical representation of the larynx in the model 'A'. Different intrinsic muscles, vestibular ligament and Vocal ligaments are shown which are attached accurately to the respective parts of the laryngeal cartilages. Moreover the left half of the thyroid cartilage was separated but attached with the cricothyroid muscle to demonstrate the mobility changing anterior posterior diameter of the larynx in the model 'H'.



Figure 1: Tools and materials used for model preparation- Hinges, Sand paper, Plier, Iron net & wire, Drill machine, Enamel paint (white and yellow) & Brush, Adhesives, Nylon thread, Abro tape, Nails, Scalpel, and Hacksaw blade.

Following the successful fabrication of the anatomical models, these were formally presented to undergraduate medical students and nursing students. The models served as interactive teaching aids during structured laboratory sessions, enabling hands-on exploration of key anatomical structures relevant to the curriculum.

RESULTS

The handmade 3D laryngeal models comprehensively demonstrated the anatomy of the larynx from multiple perspectives- superior, anterior, posterior, medial, lateral. Major components like the hyoid bone, thyroid, cricoid, arytenoid, corniculate, and cuneiform cartilages were clearly represented, along with thyrohyoid, quadrate, and cricovocal membranes, the conus elasticus, laryngeal saccule, vocal cords, sinus/ventricle, and intrinsic muscles.

The hinge mechanism at the anterior parts of the divided cricoid cartilage (Figure 2D) allowed mobility, facilitating visualization of the vocal cords. The superior view (Figure 2A) clearly depicted the hyoepiglottic fold, vallecula, epiglottis, and pyriform fossae. The posterior view (Figures 2B, E, G, H) illustrated the laryngeal inlet in open and closed states, the arytenoids-cricoid articulation, and intrinsic musculature. Figure 2H demonstrates the structural configuration of the laryngeal framework following sectioning procedures. In this view, the thyroid cartilage is shown divided into right and left halves. Contraction of the left cricothyroid muscle results in an increase in the anterior posterior diameter of the larynx. This configuration highlights the functional dynamics of the cricothyroid mechanism in modulating laryngeal dimensions. The lateral and anterior aspects (Figures 2C, F) showed the hyoid bone, thyroid cartilage, and thyrohyoid membrane- structures key to understanding tracheostomy landmarks. The medial view (Figure 2D) displayed the vocal folds and ventricle, highlighting their roles in phonation.

When implemented in teaching, students reported substantial improvement in spatial visualization, conceptual clarity, and engagement compared with 2D diagrams. The enlarged dimensions aided group demonstration in large classrooms. Each model production cost comparatively less than the commercially available models, was easily repairable, and resistant to repeated use. A demonstration video of the model's articulation by the author is available on YouTube [11].

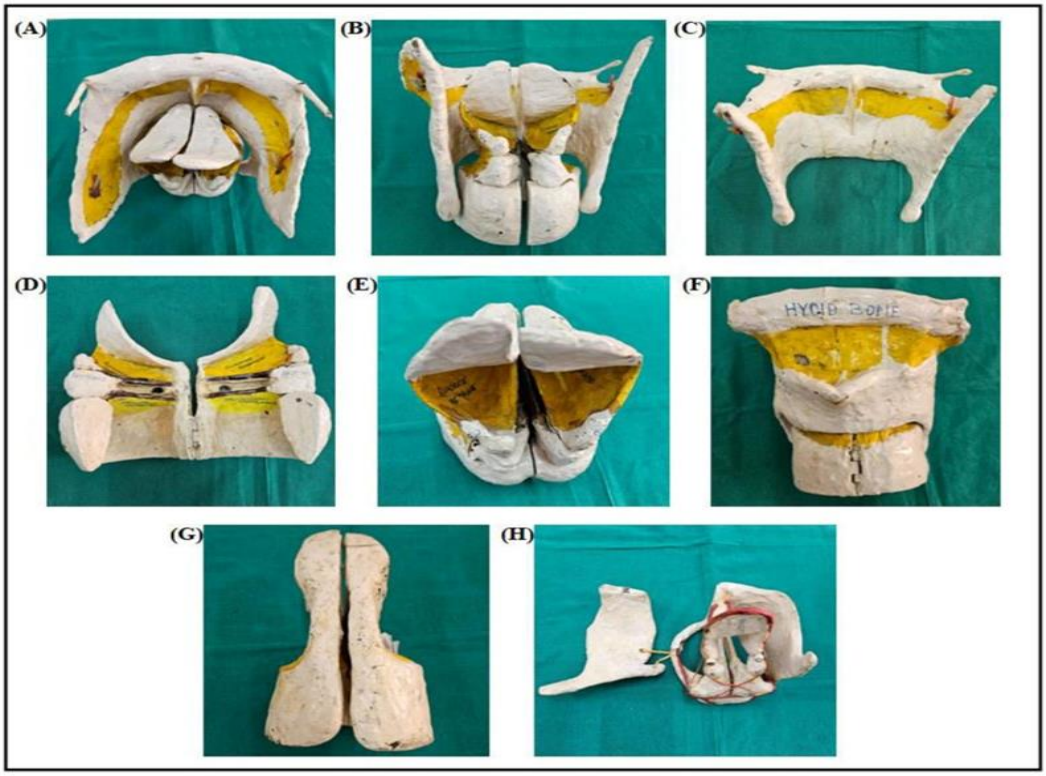


Figure 2: Picture showing different handmade 3D model of larynx (A) Superior view of larynx showing hyoepiglotic fold, vallecula, epiglottis and pyriform fossa (B) Posterior view of larynx showing laryngeal inlet, pyriform fossa, arytenoid and cricoid cartilage (C) Posterior view of hyoid bone and thyroid cartilage along with thyrohyoid membrane (D) Medial view of vocal cords and ventricle of larynx (E) Posterior view of larynx showing laryngeal inlet (F) Anterior view of larynx showing hyoid bone, thyrohyoid membrane, thyroid cartilage and cricoid cartilage (G) Posterior view of larynx showing closed laryngeal inlet (H) Posterior view of larynx showing the intrinsic muscles.

DISCUSSION

This study demonstrated that handmade, large-scale 3D anatomical models are effective pedagogical tools that can significantly enhance anatomical comprehension in resource-constrainted situations. The models achieved high anatomical fidelity and dynamic functionality at minimal cost. Previous research confirms the pedagogical value of physical models in fostering long-term retention and spatial understanding in medical students. Preece et al. demonstrated that, physical anatomical models are significantly more effective than textbooks and computer-based 3D models in improving students understanding of complex 3D anatomical relationships [12]. The hinge-enabled movement incorporated in this model allowed demonstration of the rima glottidis, true & false vocal cords and also sinus/ventricle. And phonatory mechanics- features critical to understanding airway protection. Existing research has emphasized that three-dimensional (3D) models, whether digital or physical, significantly enhance anatomical understanding by allowing learners to visualize depth, orientation, and functional relationships more effectively. Training simulators such as a low-cost, open-source, anatomically accurate 3D-printed laryngeal model developed by Lee et al. [13] and the 3D-printed thyroplasty simulator by Kostas et al. [14] confirm the value of such representations. However, access to 3D printing technology and technical expertise, which may not be available in all settings, whereas a handmade model is easy to customize, modify, repair according to teaching needs and feasible in low-resource settings without specialized equipment.

In the study, the inclusion of specific functional views, such as the medial view of the vocal cords, the thyrohyoid membrane and rotatory movements of the arytenoid cartilages, mirrors the low-fidelity modeling success discussed by Chan and Cheung, who argued that cost-effective, handmade simulators can be as effective as high-fidelity counterparts for teaching foundational

laryngeal architecture and clinical procedures like laryngoscopy [15].

Simple anatomical models, when thoughtfully designed and actively integrated into teaching, are effective tools for enhancing understanding of complex anatomical relationships and improving student learning outcomes. A previous study by Baro et al. [16] demonstrated that chalkboard teaching with model demonstrations is more effective than PowerPoint presentation for medical students learning and engagement. The enlarged size of the model enhanced spatial understanding, promoted interactive learning, and supported group teaching, thereby improving student engagement. By transforming readily available materials into functional teaching tools, these models empower future clinicians in under-resourced environments, promoting both pedagogical efficacy and enthusiasm for medical anatomy.

CONCLUSION

The handmade 3D larynx model is a cost-effective, highly accepted and educationally effective tool that enhances anatomical understanding, making it especially valuable for medical teaching. In conclusion, this handmade model proves highly effective and acceptable for undergraduate medical education in low-resource settings, with overwhelmingly positive student feedback affirming its anatomical accuracy, quality, usability and superiority over 2D methods.

Authors Contributions:

All the authors had contributed equally in this present study.

Conflict of Interests:

The authors declare no conflict of interests in this present study

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