Review Article

Advancing Medical Education: Exploring Virtual Dissection Tables and Skill Labs for Innovative Visualisation and Simulation Techniques

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Human gross anatomy, traditionally taught through cadaver dissection, faces challenges due to increasing class sizes, cadaver shortages, and high maintenance costs. This review explores advanced visualization and simulation techniques, such as virtual dissection tables and three-dimensional visualization technologies, as innovative teaching methods that enhance spatial understanding, knowledge retention, and student engagement. Traditional cadaver-based education is hindered by ethical concerns, logistical complexities, and emotional stress, and the time-consuming, often unpleasant nature of dissections deters regular participation, despite the valuable and lasting learning experiences they offer during clinical rotations. Modern visualization technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), offer immersive learning experiences that address these limitations. Virtual dissection tables like CADAVIZ allow the manipulation of 3D anatomical models, enhancing spatial understanding and collaborative learning. Skill labs and simulation techniques further revolutionize medical education by optimizing patient safety and clinical skills in a risk-free environment and integrating haptics into virtual dissection tables and simulators promising even more effective training experiences. This review highlights the potential of these advanced tools to create a more inclusive, engaging, and effective learning environment, addressing the limitations of traditional methods and meeting the diverse needs of contemporary medical students.

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Introduction

Human gross anatomy has traditionally been a cornerstone of medical education, with cadaver dissection playing a central role (Fig. 1) (Boscolo-Berto *et al*., 2020). However, the rise in class sizes and a shortage of cadavers have necessitated the development of innovative, student-focused teaching approaches. Interactive three-dimensional techniques have shown the potential in improving spatial understanding and retention of anatomical knowledge (Boscolo-Berto *et al*., 2020).

The high costs, maintenance needs, and limited access to cadavers have driven educators to explore alternatives such as computer-based tools like three-dimensional visualization technology (3DVT) (Wainman *et al*., 2020). While these tools have been shown to enhance spatial understanding and learning outcomes, their effectiveness compared to traditional methods remains a topic of debate (Wainman *et al*., 2020).

The landscape of medical education and surgical training has evolved significantly, with emerging challenges prompting the adoption of innovative methods. Digital three-dimensional visualization technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), offer immersive experiences that deepen anatomical education by providing a comprehensive view of the human body (Wang *et al*., 2024). These technologies overcome the limitations of traditional methods by offering a three-dimensional perspective crucial for understanding spatial relationships among anatomical structures (Wang *et al*., 2024).

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The emphasis on patient safety has profoundly influenced global medical education. The Institute of Medicine's 1999 report, "To Err Is Human," highlighted the significant impact of medical errors on patient outcomes (Al-Elq *et al*., 2010). In response, many medical schools have integrated problem-based learning and clinical skills laboratories into their curricula, though the adoption of simulation-based learning varies across regions (Al-Elq *et al*., 2010).

Anatomy education has shifted from traditional cadaveric dissection to the use of virtual dissection tools and three-dimensional models (Dissabandara *et al*., 2015; Mohammad *et al*., 2023). Advances in three-dimensional visualization technologies offer promising new methods that combine the strengths of traditional approaches with modern innovations (Dissabandara *et al*., 2015; Mohammad *et al*., 2023). As healthcare practices evolve, there is a growing need for new training models, with technology-enhanced simulation emerging as a potential solution (Cook *et al*., 2011).

Experiential learning has long been a core component of professional apprenticeships, yet it carries considerable risks in medical training (Daneman, 2019). The traditional "see one, do one, teach one" approach leaves little margin for error, underscoring the need for realistic medical simulations that allow for intensive practice in a risk-free environment (Daneman, 2019).

The rapid advancements in medical education, driven by changing population needs and technological progress, require innovative strategies to effectively educate and prepare medical students (Aliaga, 2022). Clinical simulation, which provides an interactive and safe replication of real-world experiences, has become a crucial methodology in this context (Aliaga, 2022).

In recent years, there has been a growing interest in using simulation to enhance patient safety and care (Gaba, 2004). Simulation techniques replicate key aspects of real-world experiences interactively, enabling participants to engage as if they were in actual clinical settings. This review examines the integration of advanced visualization tools like CADAVIZ and skills labs in medical education, highlighting their potential to transform training and improve patient outcomes (Gaba, 2004).

Traditional Anatomy Education vs. Modern Approaches

Traditional cadaver-based anatomy education has several limitations:

The shortage of cadavers, driven by the increasing number of medical students, limits hands-on learning opportunities (Boscolo-Berto *et al*., 2020). Additionally, maintaining cadaver labs poses a significant financial burden, challenging the feasibility of many educational institutions (Wainman *et al*., 2020). Body donation programs also raise ethical concerns and logistical complexities. Attendance at dissections is influenced by various factors, including student's interest and the perceived disadvantages of non-attendance. The time-consuming nature, unpleasant odors, and perceived boredom often deter regular participation (Dissabandara *et al*., 2015). While some studies suggest that cadaveric dissection can cause significant emotional stress, most students in the study found it only mildly stressful, and stress was not a significant factor in non-attendance (Dissabandara *et al*., 2015).

Need for More Effective and Engaging Methods

Given these constraints, there is a pressing need for more effective and engaging teaching methods. Modern approaches, such as virtual dissection tables and three-dimensional visualization technologies, present promising alternatives. These innovative tools offer interactive and immersive experiences that enhance spatial understanding and the retention of anatomical knowledge (Boscolo-Berto *et al*., 2020; Wang *et al*., 2024).

Advantages of Modern Approaches

Virtual dissection has proven highly beneficial, with 70% of students finding it more engaging which is crucial for deeper understanding and retention of anatomical concepts. Interactive physical models offer similar learning benefits as VR models but are more inclusive, accommodating students with a broader range of visuospatial abilities. Modern tools also help manage cognitive load more effectively by providing multiple views and user-controlled interactions, essential for understanding complex anatomical structures (Garg *et al*., 1999; Levinson *et al*., 2007; Khot *et al*., 2013).

Fig 1: Traditional cadaveric dissection in medical education

Recommendations for Modern Anatomy Education

Given the time constraints and the focus on clinical applicability in modern medical curricula, it is essential to integrate dissection with other active learning strategies. Scenario-based dissections, which use clinical scenarios during dissection sessions, can enhance engagement and help students grasp the clinical relevance of anatomical knowledge (Dissabandara *et al*., 2015). Additionally, incorporating simulation and visualization technologies, such as virtual dissection tables and 3D visualization tools, can provide an immersive learning experience that caters to students with diverse learning preferences and visuospatial abilities (Dissabandara *et al*., 2015).

Research and Development Needs

Further research is necessary to enhance VR technology to better support students with varying visuospatial abilities. Additionally, understanding how to balance the cognitive load in VR environments is crucial to ensure all students can benefit from these advanced learning tools. Ongoing evaluation of the effectiveness of VR models versus traditional methods is essential to optimize anatomy education. Thus, while traditional cadaver-based methods have been foundational in medical education, integrating modern visualization and simulation techniques is essential for creating a more inclusive, engaging, and effective learning environment. This hybrid model addresses the limitations of traditional methods and meets the diverse needs of contemporary medical students (Dissabandara *et al*., 2015).

Virtual Dissection Tables and CADAVIZ

Virtual Dissection Tables is a cutting-edge tool that offers an interactive platform for studying human anatomy (D. Chytas *et al*., 2023). These tables simulate cadaver dissections on high-resolution touchscreens with advanced software, enabling students to delve into and manipulate 3D anatomical models. Users can rotate, zoom, and dissect these models layer by layer, acquiring an in-depth understanding of anatomical structures and their spatial relationships (D. Chytas *et al*., 2023).

The tables typically feature labeled structures, immediate access to information, and integrated case studies, which enrich the learning process by providing context and intricate details (D. Chytas *et al*., 2023). Educators can customize dissections to concentrate on particular areas or systems, meeting educational objectives (D. Chytas *et al*., 2023). The large touchscreen facilitates group learning, encouraging dialogue and a more profound comprehension among students (D. Chytas *et al*., 2023).

Fig 2: Virtual dissection table in use for anatomy education

Cadaviz (Fig. 2), a specific virtual dissection table, enables users to virtually dissect cadavers and visualize anatomical structures in great detail. Medical students can investigate full-sized human bodies, using their fingers as a scalpel to conduct dissections at any angle and depth, uncovering detailed anatomical features.

Virtual dissection tables provide superior image magnification, accessibility during pandemics, the option to reverse mistakes, and overall convenience, which saves time and eliminates the need for physical dissection spaces (O.A. Onigbinde *et al*., 2021). They offer a single cadaver per user, avoiding overcrowding and ensuring the preservation of organs and body parts, a contrast to traditional methods where parts may degrade over time (O.A. Onigbinde *et al*., 2021). Virtual dissection also removes the risk of cuts, exposure to harmful chemicals, and discomfort, permitting endless manipulations and anatomical representations (O.A. Onigbinde *et al*., 2021). Additionally, it provides pathological examples for comparison.

Skill Labs and Simulation Techniques

Skill labs and simulation in healthcare hold the promise of revolutionizing the industry, with significant implications for patient safety and clinical training (Gaba, 2004). By optimizing structures and systems for safety, quality, and efficiency, simulation can address the shortcomings of current healthcare systems, which often rely on unsystematic apprenticeship models and emphasize individual knowledge over team performance (Gaba, 2004). The integration of continuous, systematic training, rehearsal, performance assessment, and refinement in clinical practice mirrors high-reliability organizations like commercial aviation, although it requires more than simply adding simulation to existing frameworks (Gaba, 2004).

Simulation techniques can enhance patient safety indirectly by improving recruitment and retention of skilled personnel, acting as catalysts for cultural change, and boosting quality and risk management (Gaba, 2004). They span diverse applications across various dimensions, including education, performance assessment, clinical rehearsal, and research. For example, simulations are now being used for high-stakes examinations and invasive treatment rehearsals, such as complex surgical procedures (Gaba, 2004).

Healthcare simulation and skill labs target individuals and teams across all experience levels, from early learners to seasoned professionals, and span multiple domains such as surgery, obstetrics, critical care, and emergency medicine (Gaba, 2004). The technology ranges from low-tech verbal simulations to sophisticated virtual reality systems, with applications that include individual skill acquisition, team training, and organizational drills (Gaba, 2004).

The cost of simulation varies widely, depending on the target population, purpose, and technology used (Gaba, 2004). Nevertheless, it offers a valuable tool for experiential learning, potentially reducing the reliance on real patient interactions for novice practitioners (Gaba, 2004). In summary, the integration of simulation into healthcare education and practice promises to enhance patient safety, improve clinical outcomes, and foster a culture of continuous learning and improvement (Gaba, 2004).

Future Directions

The future of virtual anatomy education is poised for significant advancements through the integration of haptics technology (Fig. 3) (Kapoor S. *et al*., 2014). Haptics offers immediate and intuitive tactile feedback, enhancing the understanding of relevant information and improving performance by providing timely feedback to avoid distractions and minimize ambiguity. It also delivers multisensory experiences that help prioritize critical information, increase clinical proficiency, and reduce medical errors and costs (Kapoor S. *et al*., 2014).

In clinical skill acquisition, haptics is being utilized in medical and dental examinations, such as endoscopy, laparoscopy, sigmoidoscopy, and bronchoscopy, to improve the perception of haptic information (Kapoor S. *et al*., 2014). Haptic simulators are now part of the medical curriculum, enhancing the training and evaluation of clinical skills across various disciplines, including surgery, interventional radiology, anesthesiology, dentistry, veterinary medicine, and allied health professions (Kapoor S. *et al*., 2014). These simulators complement traditional training methods and offer significant benefits, particularly in fields where hands-on training is challenging or unethical (Kapoor S. *et al*., 2014).

Fig 3: Haptics technology

The integration of technology in medical procedures is increasingly minimizing the need for direct patient-clinician contact. Innovations like bilateral teleoperators, "smart" instruments with tactile feedback, and sensory substitution systems are designed to improve haptic feedback for clinicians, enhancing the efficacy of interventions in fields such as interventional radiology and remote surgeries (Kapoor S. *et al*., 2014).

Advancements in haptic technology are set to further refine tactile feedback, making tools like virtual dissection tables and simulators more realistic and effective for medical training (Kapoor S. *et al*., 2014). Simulation environments with advanced haptic feedback in virtual reality will offer a more immersive and comprehensive educational experience (Kapoor S. *et al*., 2014). The application of haptics is expected to extend into new medical areas and procedures, increasing the reach and influence of virtual anatomy education (Kapoor S. *et al*., 2014). Moreover, as technology progresses, the cost of haptic devices is anticipated to fall, making them more accessible worldwide and democratizing advanced medical education (Kapoor S. *et al*., 2014). These developments underscore the transformative impact of haptic technology on virtual anatomy education, leading to more effective, efficient, and accessible training methods (Kapoor S. *et al*., 2014).

Conclusion

The adoption of cutting-edge visualization and simulation technologies is revolutionizing anatomy education, overcoming the constraints of traditional cadaver-based techniques. Virtual dissection tables and tools like CADAVIZ improve spatial comprehension and engagement, providing a more accessible and personalized learning experience. Skill labs and simulations complement clinical training, offering secure settings for skill acquisition. Although traditional dissection retains its value, a blended approach that incorporates modern technologies promises to enhance educational outcomes.

Author Contributions

First author: Concept and design of study or acquisition of data or analysis and interpretation of data; Drafting the article or revising it critically for important intellectual content; and Final approval of the version to be published. Second author: Concept and design of study or acquisition of data or analysis and interpretation of data; Drafting the article or revising it critically for important intellectual content; and Final approval of the version to be published.

Conflict of Interests

All authors are employees of ImmersiveVision Technology Private Limited. The authors declare no conflict of interest.

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