Received: 25 October 2023 | Revised: 16 January 2024 | Accepted: 13 March 2024

DOI: 10.1002/ase.2419

RESEARCH REPORT

Anatomical Sciences Education WILEY

A comparison of virtual reality anatomy models to prosections in station-based anatomy teaching

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Funding information
Queen Mary Innovation

Abstract

Immersive virtual reality (i-VR) is a powerful tool that can be used to explore virtual models in three dimensions. It could therefore be a valuable tool to supplement anatomical teaching by providing opportunities to explore spatial anatomical relationships in a virtual environment. However, there is a lack of consensus in the literature as to its effectiveness as a teaching modality when compared to the use of cadaveric material. The aim of our study was to compare the effectiveness of i-VR in facilitating understanding of different anatomical regions when compared with cadaveric prosections for a cohort of first- and second-year undergraduate medical students. Students ($n = 92$) enrolled in the MBBS program at Queen Mary University of London undertook an assessment, answering questions using either Oculus i-VR headsets, the Human Anatomy VR™ application, or prosection materials. Utilizing ANOVA with Sidak's multiple comparison test, we found no significant difference between prosections and i-VR scores in the abdomen ($p = 0.6745$), upper limb ($p = 0.8557$), or lower limb groups ($p = 0.9973$), suggesting that i-VR may be a viable alternative to prosections in these regions. However, students scored significantly higher when using prosections when compared to i-VR for the thoracic region ($p < 0.0001$). This may be due to a greater need for visuospatial understanding of 3D relationships when viewing anatomical cavities, which is challenged by a virtual environment. Our study supports the use of i-VR in anatomical teaching but highlights that there is significant variation in the efficacy of this tool for the study of different anatomical regions.

KEYWORDS
anatomy, anatomy education, applied anatomy, digital anatomy, learning technology, prosection, virtual reality

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INTRODUCTION

Anatomy is a fundamental component of the knowledge base required for clinical practice and is primarily considered a visual science, requiring identification of structures and understanding of spatial relationships. Acquisition of adequate visuospatial reasoning and appreciation of three-dimensional (3D) relationships can be challenging for students, particularly through teaching resources reliant on two-dimensional (2D) forms of delivery such as graphic images, textbooks, and traditional university lectures.[1] For this reason, anatomy education has historically been delivered through the use of cadaveric tissue. Here, the anatomy can be studied in a 3D context. This 3D visuospatial awareness is an integral component when studying this complex 3D discipline.[2,3]

Cadaveric dissection and prosections form the mainstay of anatomy education across 39 medical schools within the United Kingdom and Republic of Ireland.[4] Although the use of cadaveric resources is widely established, the practice has its limitations. This teaching practice is entirely reliant on the generosity of donors, the ability of institutions to finance specialized laboratory space and dissection equipment, and to maintain safety and accessibility restrictions.

Within the United Kingdom, all cadaveric material is obtained through willed donor programs, with activity in England, Wales, and Northern Ireland governed by the Human Tissue Act[5] and activity in Scotland regulated under the Human Tissue (Scotland) Act.[6] While the International Federation of Associations of Anatomists (IFAA) advocates for the use of willed body donation, there remains substantial variation worldwide in regulations around body donation and use. Countries outside of Europe, North America, and Oceania commonly rely on the use of unclaimed bodies. A small minority of countries may also use the bodies of executed persons.[7] As donation within the United Kingdom relies largely on the kindness of donors, it is not uncommon for institutions to struggle to meet their donor requirements for an academic year. Barriers to cadaveric-based teaching can stem from cultural and ethical dilemmas associated with body donation.[8-12] For institutions where there are barriers to cadaveric-based teaching resources, digital resources such as virtual reality (VR) anatomy models may be effective ways to improve access to anatomy education.

The medical curriculum requires continuous adaptation and restructure to account for changes within the healthcare industry and evolving health outcomes of the general public.[4] The United Kingdom's General Medical Council's Standards for Medical Education and Training state that a requirement in the delivery of teaching medicine is for learners to have access to technologically enhanced and simulation-based learning resources. This technology-driven pedagogy is reflected in the growing demand for technologically competent physicians and in the growing digitization of the medical curriculum.[13] This digital shift has recently been amplified by the COVID-19 pandemic. Along with the growing trend in the reduction of hours dedicated to teaching anatomy in medical institutions across the globe,[4,14–16] these aforementioned challenges and factors have led to a growing body of interest in the applications of digital resources to supplement or replace cadaveric resources.

Immersive virtual reality (i-VR) is a 3D technology that presents a promising tool for medical education and has demonstrated effectiveness in facilitating clinical imaging interpretation, clinical skills simulation, and the use of 360° video for peri-operative planning.[17-19] I-VR offers a sufficiently realistic environment to immerse the audience and can be considered a sliding scale, where non-immersive VR represents an unrealistic setting (e.g., examining a single model in 3D without a generated world around you). Additionally, I-VR presents an approach by which it is possible to overcome the limitations presented by cadaveric-based teaching materials while providing a virtual 3D learning environment. I-VR allows users to experience and interact with a virtual environment through sensory stimuli (sight, hearing, and motion) using high resolution head-mounted displays (HMD) and haptic controllers, which are equipped with stereo headphones and motion tracking systems.[1] I-VR allows the active participant to interact with and influence their surroundings.

VR, in both immersive and non-immersive forms, has consistently been reported to promote positive user satisfaction, confidence, and engagement; however, the effect of VR on learning outcomes remains challenging to establish.[20] This is somewhat owed to the rapidly evolving nature of VR technology, resulting in significant heterogeneity between studies.[1,20,21] Furthermore, there is a lack of evidence comparing i-VR technologies to cadaveric-based anatomy teaching, with most studies focusing on non-immersive forms of VR or comparisons to 2D images.[22-26] One major limitation of this existing body of research is that it fails to take into account an understanding of the core principles underpinning VR technology, erroneously assuming a high degree of translatability between 2D and 3D platforms of delivery. As evidenced by Luursema et al.[1], stereopsis plays a distinguishing factor when comparing 2D and 3D images. It should therefore be considered that the measured effectiveness of non-immersive VR platforms may not accurately reflect that of an immersive 3D learning environment.

As evidenced by limitations in the existing literature, there is a distinct lack of insight regarding the effectiveness of immersive VR technologies for anatomy education and how this compares to cadaveric materials. Our study, therefore, aimed to establish student attainment through a series of anatomical questions utilizing either i-VR or cadaveric prosections. By taking a regional anatomical approach, we hope to identify factors that may impact the success of i-VR-based teaching resources and gain insight into how I-VR may best be implemented to support the undergraduate anatomy curriculum.

MATERIALS AND METHODS

Study design and participants

The study was designed as a station-based anatomy practical with the delivery of a questionnaire-based assessment. Participants consisted of undergraduate first- and second-year medical students enrolled in an optional dissection student-selected component (SSC) at Queen Mary University of London during the 2022/2023 academic year. The first-year MBBS cohort was composed of 348 students, and the second-year MBBS cohort was composed of 420 students. All first- and second-year medical students undertaking a two-week student-selected module in cadaveric dissection were invited to participate. Students who declined participation or did not provide consent for data usage were excluded from the study.

Students were grouped based on the theme of their dissection module and were randomly assigned to use either VR or cadaveric prosection materials to complete the questionnaire. The study consisted of six paired stations across two circuits, designed to evaluate application and understanding of regional anatomy, and students were provided 10 min at each station, 1 h total. Each paired station included either an i-VR headset and associated i-VR anatomy model software or an associated prosection to allow comparison between the two modalities, as demonstrated by Figure 1.

Virtual reality software and hardware

The selected i-VR devices were Oculus Quest 2 headsets. Through the headset and use of the haptic controllers, participants accessed *Virtual Medicine*™, a VR software that includes 3D models of the human body and allows users to select and drag different body structures while having access to an information panel with information about the selected structure. This content was screencast onto a shared monitor so that students' partners who were not using the headset could see the software's content.

Study groups

Participants were assigned to one of four study groups depending on which anatomical reigon they were investigating during the SSC module. First-year students were allocated to either upper or lower limb groups, while second-year students were allocated to abdomen or thorax groups.

Within each study group, participants were randomized to one of two assessment circuits: Circuit A or Circuit B. Both circuits had a mixture of both i-VR and prosection stations, as demonstrated by Figure 1. All participants were provided a 10-min tutorial on the VR headset and software. Participants in the prosection stations had the opportunity to engage with specimens using appropriate personal protective equipment.

Questionnaire and station development

Each participant was asked to complete a questionnaire with questions specific to each of the 6 stations in their circuit, relevant to their study group region. A panel of anatomy and clinical teaching staff were involved in the development and selection of questions for inclusion. Factors such as prior anatomical knowledge and the level of student engagement during the SSC module could have acted as confounding factors. While it is impossible to completely remove the bias of previous knowledge, to minimize bias, we aimed to develop questions outside of the scope of the taught curriculum, requiring the application of knowledge through the use of either learning modality. Pilot questionnaires were reviewed by senior academic staff with a thorough knowledge of the taught curriculum, who removed and changed content that is delivered across the course.

Individual prosections were selected from cadaveric teaching specimens. *Human Anatomy VR by Virtual Medicine*™ was set up at each i-VR station to closely mirror its paired prosection station on the opposite circuit.

Statistical analysis

Data were collected from participants during eight sessions over a period of 9 months. Questionnaire responses were recorded in very short answer format. Responses were blind-marked by two academic staff members. Data was subsequently digitized and

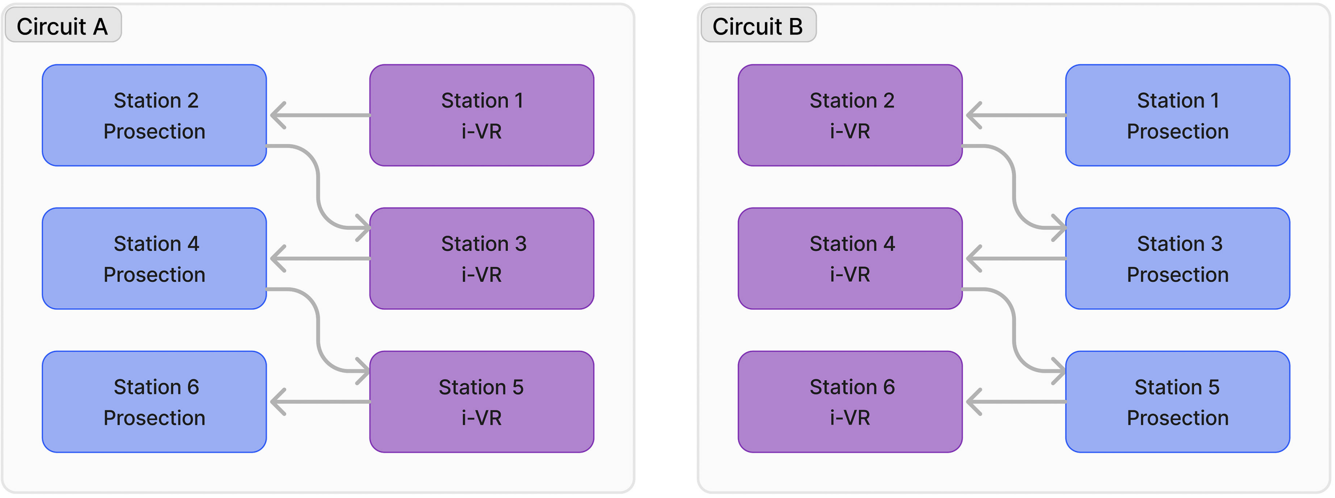

FIGURE 1 Flowchart depicting the experimental design. Participants move through station 1 through 6 with 10 min allocated to each station.

then analyzed using GraphPad Prism version 10.0.0 for Windows, GraphPad Software, Boston, Massachusetts, USA, http://www.graphpad.com. The group-level analysis was performed using a Mann–Whitney *U* test for unpaired observations and Wilcoxon tests for paired observations. Subgroup regional analyses were performed using a 2-way ANOVA with Sidak's multiple comparisons test. Statistically significant differences were reported at $p < 0.05$.

Ethical considerations

The project was registered and approved by the Queen Mary Ethics Research Committee (IPREC.ELS160922). All participants provided informed written consent for the use of their data in this study. Anonymity and confidentiality of participant information were strictly maintained throughout the course of the study. All cadaveric material used in the study was handled in accordance with the[5] as regulated by the Human Tissue Authority and on the licensed premises of the Turnbull Centre for Anatomy and Physiology at Queen Mary, University of London.

RESULTS

Number of participants

A total of 92 students participated in the study. There were 34 (37%) students in the thorax group, 16 (17%) students in the abdomen group, 28 (30%) students in the upper limb group, and 14 (15%) students in the lower limb group.

Comparison of test scores between circuit A and B

A comparison of students' scores in Circuits A and B was carried out, and median student scores were equal in both groups (Group A: median = 53.23% $n = 45$, Group B median = 53.23% $n = 47$) with no significant difference in group scores ($p = 0.832$ Mann–Whitney *U* test). Furthermore, there was no significant difference between Circuit A and Circuit B student scores when analyzed by anatomical region (thorax $p = 0.082$, abdomen: $p = 0.993$, upper limb: $p = 0.999$, lower limb: $p > 0.999$, ANOVA with Sidak's multiple comparison test).

Comparison of prosection versus i-VR test scores

Combined scores across the overall study cohort showed that students scored significantly higher using prosection when compared to i-VR (Prosection: 56.25% vs. i-VR: 50.00%, $p = 0.012$, Wilcoxon test), as shown in Figure 2.

Student scores using i-VR versus prosection were also compared within each anatomical region, as shown in Figure 3. In the thorax group, student scores were significantly higher when using prosection (56.2%) compared to i-VR (44.5%, $p < 0.0001$, ANOVA with Sidak's multiple comparison test). There were no significant differences found in the abdomen (Prosection: 60.8% vs. i-VR: 56.2%, $p = 0.675$), upper limb (Prosection: 38% vs. i-VR: 40.6%, $p = 0.856$), or lower limb group (Prosection: 72.6% vs. i-VR: 71.4%, $p = 0.997$).

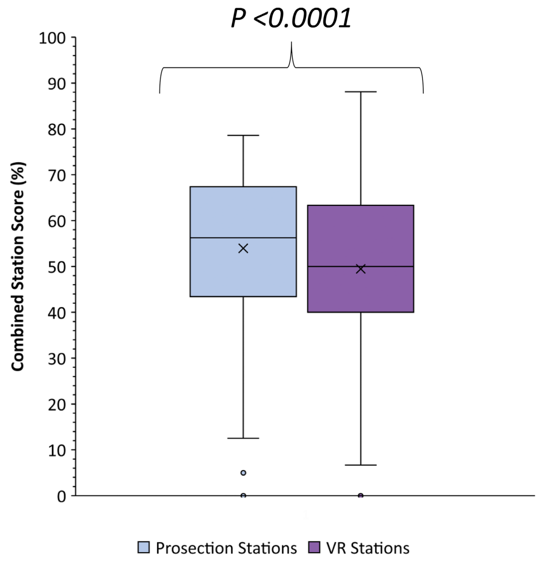

FIGURE 2 Overall combined station scores across the study cohort: Prosection versus i-VR. Box and whisker plots demonstrate range of combined prosection and i-VR station scores. Overall, students performed significantly better on assessed stations when using cadaveric prosection materials (median score: 56.25%) compared to i-VR (median score: 50.00%; $p = 0.012$, Mann–Witney *U* test).

DISCUSSION

Regional disparity

Our study highlights, for the first time, the existence of regional disparity in the effectiveness of i-VR anatomy models, yielding a greater understanding of the limitations of VR technology in anatomy education. Our findings also indicate a particular weakness in the ability of i-VR in facilitating an understanding of 3D anatomical relationships when compared with cadaveric prosection.

Consistent with the findings of Codd and Choudhury,[23] which investigated a non-immersive VR technology, we found i-VR to be equally effective as cadaveric resources in facilitating understanding of the musculoskeletal anatomy of the limbs. In contrast, our study demonstrates that i-VR is significantly less effective than cadaveric prosection in facilitating understanding of 3D anatomical relationships within the thorax.

One explanation for this regional disparity may be related to the notion that the thorax is a *cavity* or *space* and that the limbs are not considered *spaces* but rather *objects*. Visuospatial awareness is underpinned by the fact that the visual pathway is fundamentally divided into two pathways: the dorsal and ventral streams relaying information on *spaces* and *objects*, respectively.[27,28] Therefore,

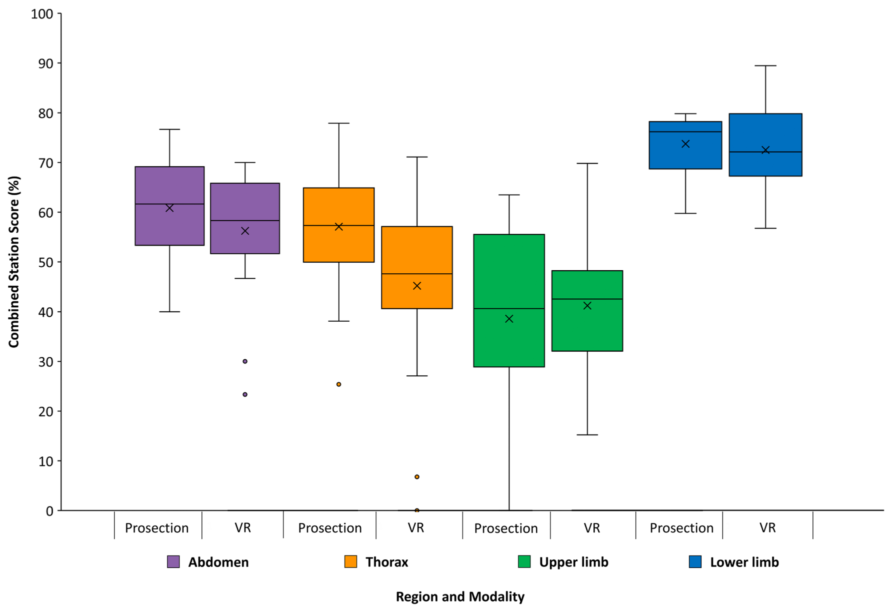

FIGURE 3 Box and whisker plot showing combined station scores analyzed by anatomical region. No significant difference was shown in combined assessment scores between prosection and i-VR groups for regional anatomy of the abdomen ($p=0.675$), upper limb ($p=0.856$), or lower limb groups ($p=0.997$). Within the thorax group, combined assessment scores were significantly higher when using prosection (median score: 56.2%) compared to i-VR (median score: 44.5%, ANOVA with Sidak's multiple comparison test, $p<0.0001$).

information from studying anatomical cavities like the thorax and abdomen may be processed in a different visual pathway than information from studying limbs. The difference in scores from our results presents the interesting possibility that virtual reality technologies may be taking advantage of the ventral stream and therefore performing well for anatomical regions that do not need a high degree of 3D visuospatial awareness.

Recommendations for VR in anatomy education

When considering best practice guidelines for the use of i-VR in anatomy education, a more favorable approach may be to incorporate i-VR alongside traditional teaching methods rather than replace them outright. In anatomy lectures and laboratory tutorials, 2D images are often used in presentations to teach anatomical structures. It may be helpful to implement i-VR technologies to teach specific anatomical regions that are better understood with a 3D medium than 2D images, such as the limbs. Additionally, by taking advantage of the screen casting function, educators may share the 3D virtual environment and narrate their immersive anatomy journey to students in real-time.

Another point to consider when establishing best practice guidelines for i-VR is to account for the frequency of use. It has been demonstrated that isolated i-VR interventions seem to have less well-reported efficacy as a tool for anatomical education.[29] Additionally, there is evidence that efforts to simultaneously combine VR with practical interventions, such as imaging interpretation or procedural training, may be beneficial, suggesting it may remain a viable means to enhance application and understanding once a foundation of anatomy knowledge has been established.[30-32] This leads to the suggestion that the implementation of i-VR technologies at later stages in the anatomy curricula may be more efficacious.

Lastly, i-VR technology for anatomy education may also be an excellent resource for educators in geographic regions where access to cadavers is limited, particularly where there are cultural or religious beliefs that limits the use of cadavers, or in institutions that may lack funding for cadaveric laboratories. For example, at Masinde Muliro University of Science and Technology, Kenya, students were provided VR headsets and were virtually instructed by anatomy educators at Stanford University.[33] There remains a paucity of research regarding the use of i-VR in low-income settings, but as accessibility to i-VR technology improves, it may become key in mitigating inequalities within anatomy education.[20]

Development of instructional design

Most of the current experimental literature surrounding VR in anatomy education focuses on the usability of the software and hardware, missing out on the association of VR to learning theories in which experience of teaching and learning anatomy is founded.[34] Learning theories help educators develop their practices and build the foundation for all teaching and learning experiences. Underpinning the use of VR in anatomy education on pedagogical theories helps to produce positive evidence-based teaching and learning experiences.

The cadaveric-based learning experience takes advantage of the social constructivist and connectivist approaches to learning. Dissections and prosections focus on an element of collaborative work during which students engage with their peers to construct an understanding using the cadaveric material. This is similarly demonstrated in the way that this study uses VR technology; students are paired and build an understanding using the VR anatomy models together via the shared screencast. One exception that is misaligned with connectivism is that VR lacks the personal element that students bring to a learning experience. When engaging with cadaveric material, students are also exposed to concepts such as body donation, the kinetic experience of handling human tissue, tying in their experiences from clinical settings, as well as the salient emotional experience. In the virtual landscape, it was noticed that the sole component students commented on was their experience with the usability and design of the software, detracting from the collaborative and human-centered learning experience.

Limitations and future directions

The limitations identified in this study are defined by two categories: technological issues and sample size. Throughout the study, there were a few technological issues with either the lagging of the i-VR headset or its ability to screencast onto the shared monitor. As evidenced by qualitative feedback from the sessions, many students mentioned the difficulties of engaging with the i-VR stations when the headsets would refresh, lag, or irregularly communicate with the haptic controllers. For many students, this would have been their first use of i-VR, while they would be relatively familiar with handling cadaveric material.

Future research could consider the use of pre-recorded instructional training videos in addition to the in-person training prior to the study or teaching session. In addition, while the software was chosen as it represented the highest quality and usability in the field at the time, we expect future innovations will increase immersion, intuitiveness, and interactivity, which will impact findings. Finally, it is important to highlight the differences in the sample size across the four themed groups. Groups ranged from having the largest size of 34 to the smallest size of 14.

The design of this study aimed to minimize the influence of preexisting knowledge by asking students questions that were outside of the scope of what they had learned at this stage of their anatomical education. However, it is impossible to completely remove this obstacle other than by recruiting students with no prior anatomical knowledge or teaching, which would not be possible in a group of medical students.

It is also not possible to know from this study the effect of i-VR on long-term retention. While both cadaveric resources and i-VR present a novel learning experience that may enhance students' memory of the session, in an increasingly digital world, it is likely the novelty of i-VR will diminish, while cadaveric resources will remain an unusual and often profound experience which stays with the students. It would be a valuable future direction to compare longer-term anatomical knowledge across institutions utilizing virtual and cadaveric teaching methods.

As demonstrated by this study, i-VR anatomy models can provide an alternate teaching tool for prosections. However, our results indicate that when incorporating the use of i-VR anatomy models in practical teaching, it is important to consider that different regions and systems are not replicated in equal quality in i-VR. The authors therefore recommend that i-VR act as a supplementary resource in addition to the use of whole-body cadavers, prosections, jarred specimens, plastinates, and plastic models.

ACKNOWLEDGMENTS

The authors sincerely thank the donors who have gifted their bodies to anatomical examination and to the families of donors. Their contribution ultimately allows for the improvement of patient care through training of future physicians and through research.

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How to cite this article: Ail G, Freer F, Chan CS, Jones M, Broad J, Canale GP, et al. A comparison of virtual reality anatomy models to prosections in station-based anatomy teaching. Anat Sci Educ. 2024;00:1–7. https://doi.org/10.1002/ase.2419