Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Assessment of mixed reality-based head-mounted display for neuroanatomy education in medical students

Syougo Tanabe
Osaka Medical and Pharmaceutical University
Ryo Hiramatsu
hiramatsu@ompu.ac.jp
Osaka Medical and Pharmaceutical University
Rina Shidoh-Kazuki
Osaka Medical and Pharmaceutical University
Kenichirou Eza
Osaka Medical and Pharmaceutical University
Masahiro Kameda
Osaka Medical and Pharmaceutical University
Naosuke Nonoguchi
Osaka Medical and Pharmaceutical University
Motomasa Furuse
Osaka Medical and Pharmaceutical University
Shinji Kawabata
Osaka Medical and Pharmaceutical University
Toshihiro Takami
Osaka Medical and Pharmaceutical University
Masahiko Wanibuchi
Osaka Medical and Pharmaceutical University

Research Article

Keywords: Mixed reality, Neuroanatomy education, Head-mounted display

Posted Date: September 3rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10362487/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background

Many medical students develop an aversion to neurology because of insufficient understanding of neuroanatomical structures and limited educational opportunities. Extended reality (XR), an umbrella term encompassing virtual reality (VR), augmented reality (AR), and mixed reality (MR), has attracted considerable attention as a novel educational tool for addressing challenges in neuroanatomy education. In this study, questionnaire-based evaluations were subsequently conducted to investigate the potential usefulness of MR-based head-mounted display (HMD) for future neuroanatomy education.

Methods

Three-dimensional images derived from neurosurgical cases were created and displayed using an MR-based HMD. Thirty-one medical students experienced the educational program and subsequently completed a questionnaire. Each of the 10 questionnaire items (Q1-Q10) was quantitatively evaluated using a 10-point Likert scale. To quantify learners' psychological constructs, seven questionnaire items (Q1-Q7) were aggregated into two Likert scales: the "Usefulness" scale (Q1- Q4) and the "Interest and Motivation for Learning" scale (Q5-Q7).

Results

The mean scores for the "Usefulness" scale and the "Interest and Motivation for Learning" scale were 9.27 ± 1.21 and 8.85 ± 1.44 (mean ± standard deviation), respectively. In contrast, the mean score for "User Satisfaction with Operability" (Q8) was 7.42 ± 1.84. Additionally, the score for "Physical Strain" (Q10) was low (1.68 ± 1.01).

Conclusions

Both the "Usefulness" and the "Interest and Motivation for Learning" scale demonstrated high scores. In contrast, "User Satisfaction with Operability" was relatively lower, although "Physical Strain" remained minimal. These findings suggest that MR-based HMDs are promising educational tools for neuroanatomy education.

Introduction

Neurology is widely regarded as one of the most challenging subjects in the medical curriculum for medical students [1]. In 1994, Josefowicz coined the term "neurophobia" to describe "a fear of neuroscience and clinical neurology resulting from the inability to apply basic scientific knowledge to clinical situations [2]. Neurophobia not only discourages students from studying neurology but may also

influence future career choices in the field. Previous studies have suggested that neurophobia arises from the intimidating complexity of neuroanatomy and neuropathology [3–6]. Neuroanatomy is particularly difficult within medical education because it requires an understanding of numerous complex three-dimensional structures [7–10]. Indeed, several studies have demonstrated that many medical students dislike neurology because of insufficient understanding of neuroanatomical structures and limited educational opportunities [3, 5, 11, 12]. Therefore, novel educational approaches are needed to overcome these barriers. Furthermore, the COVID-19 pandemic had a substantial impact on anatomy education, leading to the cancellation or restriction of traditional cadaver-based anatomy dissections and accelerating the transition from face-to-face instruction to online or hybrid learning environments [13, 14].

Against this background, extended reality (XR) has emerged as a potential alternative educational modality for anatomy instruction. XR is a collective term encompassing virtual reality (VR), augmented reality (AR), and mixed reality (MR). VR provides users with the sensation of immersion in a completely virtual environment [16]. In contrast, AR overlays computer-generated graphics onto the real world through a device such as a camera-equipped display [17]. MR further integrates virtual objects with the real-world environment in real time, typically using see-through wearable devices. Advances in wearable technologies and XR computing have demonstrated considerable potential in the medical field, particularly in anatomy education, preoperative planning, and intraoperative surgical navigation [17]. Previous studies from the United States have reported that anatomy education using head-mounted displays (HMDs) and MR technology can achieve learning outcomes comparable to those of conventional face-to-face instruction [15].

Therefore, in the present study, medical students were provided with the opportunity to experience three-dimensional models derived from preoperative neurosurgical cases using an MR-based HMD. Questionnaire-based evaluations were subsequently conducted to investigate the potential usefulness of this educational tool for future neuroanatomy education.

Methods

All procedures related to the study were conducted on anonymized files in full compliance

with the Declaration of Helsinki and Good Clinical Practice guidelines. This study received ethical approval from the research ethics committee at the Osaka Medical and Pharmaceutical University (approval number: 2024 − 245).

Acquisition and Preparation of 3D images

Four cases (clinoidal meningioma, pituitary adenoma, vestibular schwannoma, and trigeminal neuralgia) treated at the Department of Neurosurgery and Neuroendovascular Surgery, Osaka Medical and Pharmaceutical University Hospital, between July 2019 and December 2024 were included for this study. Preoperative imaging data consisted of 0.5-mm slice head computed tomography (CT), 0.5-mm slice

three-dimensional computed tomography angiography (3D-CTA), and 1.4-mm slice three-dimensional magnetic resonance imaging (3D-MRI), which was reconstructed into 1.0-mm slices using multiplanar reconstruction. In addition, contrast-enhanced MRI and fast imaging employing steady-state acquisition (FIESTA) sequences were utilized. Using a dedicated workstation (SYNAPSE VINCENT; Fujifilm Healthcare Corporation, Tokyo, Japan), the skin, bone, brain parenchyma, arteries, veins, and lesions were segmented and extracted from the imaging datasets. For brain tumor cases, lesion extraction was performed using contrast-enhanced MRI, whereas FIESTA sequences were used in the trigeminal neuralgia case. The extracted Digital Imaging and Communications in Medicine (DICOM) data were converted into stereolithography (STL) format and uploaded to Holoeyes MD (Holoeyes Inc., Tokyo, Japan) for colorization and three-dimensional reconstruction. The reconstructed 3D models were visualized using a Meta Quest 3 head-mounted display (HMD) (Meta Platforms Inc., Menlo Park, CA, USA) through a dedicated application.

Neuroanatomy education session with MR-based HMD

The participants were 31 medical students undergoing clinical training in the Department of Neurosurgery and Neuroendovascular Surgery at Osaka Medical and Pharmaceutical University Hospital, including 15 fourth-year students, 15 fifth-year students, and 1 sixth-year student. Each session consisted of 5–6 students and was conducted as follows:

1) Anonymized CT / MRI images of each case were reviewed on a monitor.

2) Instruction was provided on the use of the MR-based HMD.

3) Students participated in a neuroanatomical learning experience using the MR-based HMD in neurosurgical cases.

Each session lasted approximately 30–40 minutes. After the session, the medical students anonymously completed a questionnaire consisting of 10 items and free-response sections. The questionnaire items were based on previous studies [18, 19] (Table 1).

Quantitative evaluation

The questionnaire consisted of 10 items (Q1–Q10), each rated on a 10-point Likert scale. Responses for individual Likert items and composite Likert scales were expressed as the mean ± standard deviation (SD), median, and interquartile range (IQR) [20, 21] (Table 1). To quantify learners' psychological constructs, questionnaire items considered to assess the same construct were combined to create composite Likert scales. In this study, Q1–Q4 were combined to form the "Usefulness" scale, and Q5–Q7 were combined to form the "Interest and Motivation for Learning" scale. Q8 ("User Satisfaction with Operability"), Q9 ("Satisfaction with Neuroanatomy Education Sessions"), and Q10 ("Physical Strain") were analyzed as individual Likert items. Likert item and scale scores were standardized, and

respondents were categorized according to their scores as follows: scores of 0–6 indicated dissatisfaction with the MR-based HMD system, scores of 7–8 indicated moderate satisfaction or neutrality, and scores of 9–10 indicated high satisfaction and strong interest in the MR-based HMD system. Decimal values were rounded to the nearest whole number. Internal consistency of the constructed Likert scales were evaluated using Cronbach's α coefficient. Values of $\alpha \geq 0.70$ were considered indicative of acceptable internal consistency, $\alpha \geq 0.80$ of good internal consistency, and $\alpha \geq 0.90$ of excellent reliability [22]. Furthermore, to investigate whether evaluations of the neuroanatomy learning experience using MR-based HMD differed according to gender (male or female) or academic year (fourth, fifth, or sixth year), univariate analyses were performed to compare groups for each questionnaire item (Q1–Q10) and the composite Likert scale scores. The Mann–Whitney U test was used for gender-based comparisons, whereas the Kruskal–Wallis test was used for comparisons among academic years. A p-value < 0.05 was considered statistically significant.

Qualitative evaluation

In this study, to explore the benefits and challenges of the learning experience using the MR-based HMD that could not be fully captured through quantitative data alone, a free-response section was included in the questionnaire to collect medical students' subjective opinions. These responses were subsequently analyzed qualitatively using thematic analysis.

Statistical analysis

JMP® Student Edition version 18.2.0 (SAS Institute Inc., Cary, NC, USA) was used for the statistical analysis of quantitative data, whereas MAXQDA (LightStone, Tokyo, Japan) was used for the thematic analysis of qualitative data.

Results

Three-dimensional reconstruction was successfully completed in all four cases. The average time required to generate a 3D model on the workstation was approximately 30 minutes per case. Organ segmentation was performed automatically, enabling even inexperienced physicians to generate high-quality images with ease. Uploading the STL data to the HMD system and preparing the models for visualization required approximately 5–6 minutes. All reconstructed models were clearly visualized on the HMD, demonstrating excellent depiction of the three-dimensional anatomical structures (Fig. 1). A 10-item Likert-scale questionnaire (Q1–Q10) was administered to medical students following the neuroanatomy education session (Table 1).

Seven of the ten questionnaire items were categorized into two Likert scales: the "Usefulness" scale and the "Interest and Motivation to Learn" scale. Cronbach's alpha coefficients were calculated for each Likert scale.

Seven of the 10 items were categorized into two Likert scales: the “Usefulness” scale and the “Interest and Motivation to Learn” scale. Cronbach’s α coefficients were calculated for each Likert scale. The Cronbach’s α coefficient for the “Usefulness” scale (Q1–Q4) was 0.792, whereas that for the “Interest and Motivation to Learn” scale (Q5–Q7) was 0.847 (Table 2). The remaining items—Q8, “User Satisfaction with Operability”; Q9, “Satisfaction with the Neuroanatomy Education Session”; and Q10, “Physical Strain”—were evaluated independently using a 10-point Likert scale (Table 1). The mean score for the “Usefulness” scale was 9.27 ± 1.21 (mean ± SD), with a median of 10 and an upper quartile of 10. The mean score for the “Interest and Motivation to Learn” scale was 8.85 ± 1.44 (mean ± SD), with a median of 10 and an upper quartile of 10 (Table 3). No statistically significant differences were found for any of the questionnaire items (Q1-Q10) or Likert scales by gender (female or male) and grade level (4th, 5th, or 6th grade) (Table 4).

Thematic analysis of the free-form responses identified the following five themes (Table 5).

1) Enhanced anatomical understanding and spatial visualization abilities

2) Increased motivation for learning

3) Expectations regarding its application in surgical training

4) Issues related to device usability

5) Expectations for integration into medical education

Discussion

Anatomy, a fundamental part of medical education, requires a deep understanding of the complex spatial relationships and structures within the human body. Traditionally, this understanding has been facilitated through methods such as cadaver dissections, textbooks, and 2D imaging [20]. However, these methods have limitations, including the high cost of maintaining cadavers, ethical concerns, and the static nature of 2D representations, which fail to adequately convey the 3D complexity of human anatomy [21]. Furthermore, neuroanatomy has been characterized as one of the most challenging components of the anatomy curriculum due to the inherent complexity of specific neuroanatomical concepts and associated neuroanatomical structures [7–10]. Remarkably, neuroanatomy has its own individual place in a medical curriculum, and it is often taught separately from gross anatomy courses as a stand-alone course, with a specific amount of teaching hours dedicated to it and its associated laboratory practicals [22, 23]. In recent years, there has been growing concern within the medical profession and medical education about students' inadequate knowledge of neuroanatomy [22, 24].

XR is attracting attention as a new educational tool that can complement these traditional challenges in neuroanatomy education for medical students [25–28]. A systematic review of VR simulations as anatomy education tools for medical students reported between 2019 and 2024 found that 71% of the studies found that VR simulations had a greater learning effect than conventional methods [29].

Furthermore, in a report conducted via online survey of medical students' views on the use of mixed reality (MR) in neurosurgery medical education, 87% of medical students expressed a high interest in the establishment of an MR course in the field of neurosurgery, and 73% responded that they would be interested in incorporating MR into the medical education curriculum [30].

In this study, Japanese medical students received neuroanatomy education using MR-based HMD as an educational tool, followed by a questionnaire-based evaluation. High scores were obtained for both the “Usefulness Scale” (mean ± SD, 9.26 ± 0.91) and the “Interest and Motivation for Learning Scale” (mean ± SD, 8.85 ± 1.23) on the Likert scale assessment (Table 1). Free-response comments related to the “Usefulness Scale” included statements such as, “It was easier to understand the spatial relationships between lesions and the brain and blood vessels,” and “Using an MR-based HMD facilitated comprehension of anatomical structures more effectively than viewing them on a monitor.” These findings suggest that, in the field of neurosurgery, which requires advanced three-dimensional spatial recognition [31], MR-based HMDs may reduce cognitive load by visualizing anatomical structures and thereby facilitate understanding of complex neuroanatomy. In addition, free-response comments regarding the “Interest and Motivation for Learning Scale” included remarks such as, “My interest in neurosurgical diseases increased,” “I would recommend this to other students,” and “I would like to participate in similar learning opportunities in the future.” These responses indicate that MR-based HMDs may promote positive attitudes and enhance motivation toward learning neuroanatomy. Collectively, these findings suggest that MR-based HMDs can supplement traditional text-based educational methods by fostering enjoyment and active engagement in learning. On the other hand, regarding “User Satisfaction with Operability,” the median score for the Likert-scale item corresponding to Q8 was relatively low at 7, and only 26% of medical students assigned a score of 9 or higher out of 10. In the free-response section, some students described the system as “easy to use,” whereas others reported that it “required time to become familiar with.” Therefore, when implementing MR-based HMDs in educational settings, it may be important to provide introductory explanations and brief tutorials on device operation at the beginning of the learning session. Regarding “Satisfaction with Neuroanatomy Education Sessions” the median score for the Likert-scale item corresponding to Q9 was 9, with 65% of students assigning a score of 9 or higher out of 10, indicating a high level of satisfaction with the learning experience. Finally, with respect to “physical burden,” the median Likert-scale score for Q10 was 1, and 81% of students selected scores of 2 or lower out of 10. No free-response comments reported adverse effects such as dizziness, nausea, or vomiting. These findings suggest that neuroanatomy education conducted under the device and usage conditions employed in this study (groups of 5–6 students, sessions lasting 30–40 minutes) imposes minimal physical burden on learners. Furthermore, this study examined the influence of gender and academic year, and no statistically significant differences were identified between groups in either the Likert-scale items (Q1–Q10) or the composite Likert scales (Table 4). These results indicate that the educational experience using MR-based HMDs was not biased toward specific learner characteristics and provided consistent educational benefits across a broad range of learners. Thematic analysis of all free-response comments identified the following five themes: (1) Enhanced anatomical understanding and spatial visualization abilities; (2)

Increased motivation for learning; (3) Expectations regarding its application in surgical training; (4) Issues related to device usability; and (5) Expectations for integration into medical education (Table 5). These qualitative findings complement the quantitative results and further support the educational value of MR-based HMDs in neuroanatomy education, both in terms of learner satisfaction and perceived educational effectiveness.

Conclusion

Learning neuroanatomy using MR-based HMDs received high ratings for both “Usefulness” and “Interest and motivation in learning”. Furthermore, learning outcomes were not significantly influenced by gender or academic year, suggesting the potential applicability of this educational approach across a wide range of learners. However, ratings for “User Satisfaction with Operability” were relatively low. Although these findings indicate that MR-based HMDs represent a promising educational tool for neuroanatomy education, they also highlight the importance of providing clear operational guidance and introductory tutorials at the beginning of training when implementing this technology in educational settings.

Declarations

Acknowledgements

Not applicable.

Author Contributions:

Conceptualization, R.H. and S.T.; Methodology, R.H. and S.T; Software, S.T.; Validation, R.H. and M.W.; Formal analysis, R.H., S.T., R-S-K, and K.E.; Investigation, S.T., M.K., and N.N.; Resources, M.F. S.K, and T.T.; Data curation, R.H. and S.T.; Writing - original draft preparation, R.H. and S.T.; writing - review and editing, R.H. and M.W.; Visualization, S.T.; Supervision, R.H.; Project administration, R.H. and S.T. All authors have read and agreed to the published version of the manuscript.

Funding

Open access funding provided by Osaka Medical and Pharmaceutical University.

Data availability

All data generated or analyzed during this study are not publicly available on ethical grounds. However, enquiries regarding these data can be directed to the corresponding author.

Ethics approval

This study was approved by the Ethics Committee of Osaka Medical and Pharmaceutical University Hospital (approval number: 2024-245).

Consent to participate

Informed consent was obtained from all participants using an opt-out approach.

Consent for publication

Informed consent was obtained from all participants using an opt-out approach.

Competing interests

The authors declare that they have no competing interests.

References

1. Solorzano GE, Józefowicz RF. Neurophobia: a chronic disease of medical students. Neurology. 2015;85(2):116–7. https://doi.org/10.1212/WNL.0000000000001751.
2. Jozefowicz RF. Neurophobia: the fear of neurology among medical students. Arch Neurol. 1994;51(4):328–9.
3. Murphy S, Carey E, Dablouk L, Alomairi J, Maasarani J, Ong JB, et al. Neurophobia amongst medical students: Hype or reality. Brain Spine. 2024;4:104134. https://doi.org/10.1016/j.bas.2024.104134.
4. Han F, Zhang Y, Wang P, Wu D, Zhou LX, Ni J. Neurophobia among medical students and resident trainees in a tertiary comprehensive hospital in China. BMC Med Educ. 2023;23(1):824. https://doi.org/10.1186/s12909-023-04812-1.
5. Jukna Š, Puteikis K, Mameniškienė R. Perception of neurology among undergraduate medical students - what can be done to counter neurophobia during clinical studies? BMC Med Educ. 2023;23(1):447. https://doi.org/10.1186/s12909-023-04405-y.
6. Fantaneanu TA, Moreau K, Eady K, Clarkin C, DeMeulemeester C, Maclean H, et al. Neurophobia inception: a study of trainees' perceptions of neurology education. Can J Neurol Sci. 2014;41(4):421–9. https://doi.org/10.1017/S0317167100018436.
7. Kramer B, Soley JT. Medical students perception of problem topics in anatomy. East Afr Med J. 2002;79(8):408–14. https://doi.org/10.4314/eamj.v79i8.8826.
8. Javaid MA, Chakraborty S, Cryan JF, Schellekens H, Toulouse A. Understanding neurophobia: Reasons behind impaired understanding and learning of neuroanatomy in cross-disciplinary healthcare students. Anat Sci Educ. 2018;11(1):81–93. https://doi.org/10.1002/ase.1711.
9. Sotgiu MA, Mazzarello V, Bandiera P, Madeddu R, Montella A, Moxham B. Neuroanatomy, the Achille's Heel of Medical Students. A Systematic Analysis of Educational Strategies for the Teaching of Neuroanatomy. Anat Sci Educ. 2020;13(1):107–16. https://doi.org/10.1002/ase.1866.
10. Cheung CC, Bridges SM, Tipoe GL. Why is Anatomy Difficult to Learn? The Implications for Undergraduate Medical Curricula. Anat Sci Educ. 2021;14(6):752–63. https://doi.org/10.1002/ase.2071.

11. McColgan P, McKeown PP, Selai C, Doherty-Allan R, McCarron MO. Educational interventions in neurology: a comprehensive systematic review. Eur J Neurol. 2013;20(10):1006–16. https://doi.org/10.1111/ene.12236.
12. Horan J, Murphy S, O'Brien D. Neurosurgical education in Ireland; a conference and medical student experiences. Surgeon. 2020;18(3):159 – 64.
13. Byrnes KG, Kiely PA, Dunne CP, McDermott KW, Coffey JC. Communication, collaboration and contagion: Virtualisation of anatomy during COVID-19. Clin Anat. 2021;34(1):82–9. https://doi.org/10.1002/ca.23649.
14. Iwanaga J, Loukas M, Dumont AS, Tubbs RS. A review of anatomy education during and after the COVID-19 pandemic: Revisiting traditional and modern methods to achieve future innovation. Clin Anat. 2021;34(1):108–14. https://doi.org/10.1002/ca.23655.
15. Wish-Baratz S, Crofton AR, Gutierrez J, Henninger E, Griswold MA. Assessment of Mixed-Reality Technology Use in Remote Online Anatomy Education. JAMA Netw Open. 2020;3(9):e2016271.
16. Huygelier H, Schraepen B, van Ee R, Vanden Abeele V, Gillebert CR. Acceptance of immersive head-mounted virtual reality in older adults. Sci Rep. 2019;9(1):4519. https://doi.org/10.1038/s41598-019-41200-6.
17. Wong K, Yee HM, Xavier BA, Grillone GA. Applications of Augmented Reality in Otolaryngology: A Systematic Review. Otolaryngol Head Neck Surg. 2018;159(6):956–67. https://doi.org/10.1177/0194599818796476.
18. Yamazaki A, Ito T, Sugimoto M, Yoshida S, Honda K, Kawashima Y, et al. Patient-specific virtual and mixed reality for immersive, experiential anatomy education and for surgical planning in temporal bone surgery. Auris Nasus Larynx. 2021;48(6):1081–91. https://doi.org/10.1016/j.anl.2021.03.009.
19. Barteit S, Lanfermann L, Bärnighausen T, Neuhann F, Beiersmann C. Augmented, Mixed, and Virtual Reality-Based Head-Mounted Devices for Medical Education: Systematic Review. JMIR Serious Games. 2021;9(3):e29080. https://preprints.jmir.org/preprint/29080.
20. Codd AM, Choudhury B. Virtual reality anatomy: is it comparable with traditional methods in the teaching of human forearm musculoskeletal anatomy? Anat Sci Educ. 2011;4(3):119–25. https://doi.org/10.1002/ase.214.
21. Karbasi Z, Niakan Kalhori SR. Application and evaluation of virtual technologies for anatomy education to medical students: A review. Med J Islam Repub Iran. 2020;34:163. https://doi.org/10.47176/mjiri.34.163.
22. Mateen FJ, D'Eon MF. Neuroanatomy: a single institution study of knowledge loss. Med Teach. 2008;30(5):537–9. https://doi.org/10.1080/01421590802064880.
23. Hazelton L. Changing concepts of neuroanatomy teaching in medical education. Teach Learn Med. 2011;23(4):359–. https://doi.org/10.1080/10401334.2011.611777. 64.
24. Singh R, Yadav N, Pandey M, Jones DG. Is inadequate anatomical knowledge on the part of physicians hazardous for successful clinical practice? Surg Radiol Anat. 2022;44(1):83–92. https://doi.org/10.1007/s00276-021-02875-7.

25. Gurses ME, Gökalp E, Gecici NN, Gungor A, Berker M, Ivan ME, et al. Creating a neuroanatomy education model with augmented reality and virtual reality simulations of white matter tracts. J Neurosurg. 2024;141(3):865–74. https://doi.org/10.3171/2024.2.JNS2486.
26. Sandralegar A, Bernard F, Khatchatourov S, Janssen I, Schaller K, Bijlenga P, et al. Mixed reality compared to the traditional ex cathedra format for neuroanatomy learning: the value of a three-dimensional virtual environment to better understand the real world. Neurosurg Focus. 2024;56(1):E14. https://doi.org/10.3171/2023.10.FOCUS23620.
27. Aridan N, Bernstein-Eliav M, Gamzo D, Schmeidler M, Tik N, Tavor I. Neuroanatomy in virtual reality: Development and pedagogical evaluation of photogrammetry-based 3D brain models. Anat Sci Educ. 2024;17(2):239–48. https://doi.org/10.1002/ase.2359.
28. Bölek KA, De Jong G, Van der Zee CEEM, van Cappellen AM, Henssen DJHA. Mixed-methods exploration of students' motivation in using augmented reality in neuroanatomy education with prosected specimens. Anat Sci Educ. 2022;15(5):839–49. https://doi.org/10.1002/ase.2116.
29. Odogwu TS, Abuelgassem Hagahmed Mohamed E, Mishu L, Umahi I. Effect of Virtual Reality Simulation on Anatomy Learning Outcomes: A Systematic Review. Cureus. 2025;17(4):e81893.
30. Wach J, Winkler D, Vychopen M, Kropla F, Grunert R, Güresir E. Students' perspectives regarding needs for and opportunities with mixed-reality education in neurosurgery at German medical schools. Neurosurg Focus. 2024;56(1):E17. https://doi.org/10.3171/2023.10.FOCUS23628.
31. Zhang C, Gao H, Liu Z, Huang H. The Potential Value of Mixed Reality in Neurosurgery. J Craniofac Surg. 2021;32(3):940–3.

Figures

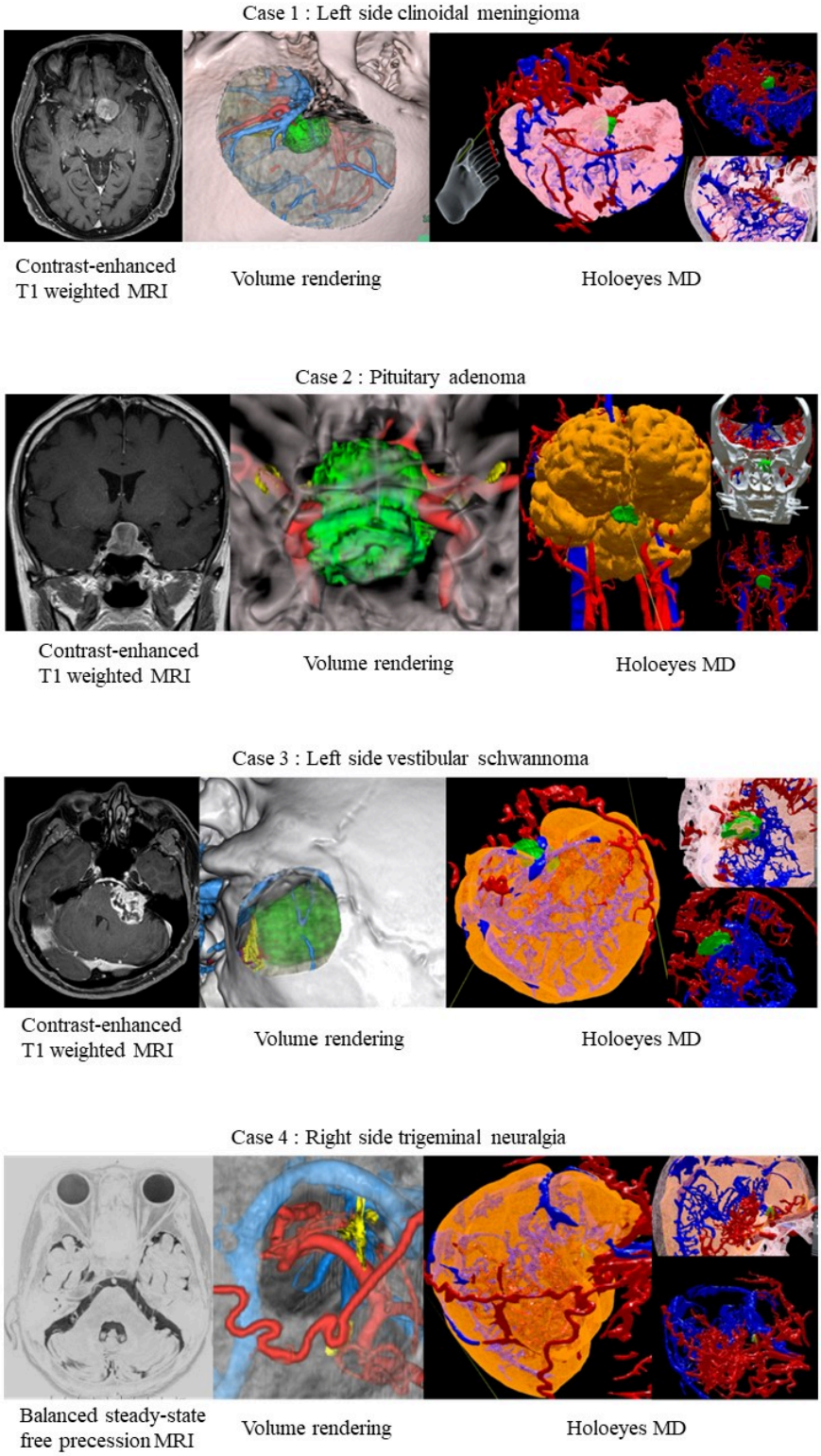


Figure 1

Case 1. Left-sided clinoidal meningioma. From left to right: MRI image, volume-rendered image, and Holoeyes MD visualization.

Case 2. Pituitary adenoma. From left to right: MRI image, volume-rendered image, and Holoeyes MD visualization.

Case 3. Left-sided vestibular schwannoma. From left to right: MRI image, volume-rendered image, and Holoeyes MD visualization.

Case 4. Right-sided trigeminal neuralgia. From left to right: MRI image, volume-rendered image, and Holoeyes MD visualization.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- BMCNeurologyTable1.xlsx
- BMCNeurologyTable3.xlsx
- BMCNeurologyTable4.xlsx
- BMCNeurologyTable5.xlsx
- BMCNeurologyTable2.xlsx