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Review Article

Enhancing neuro-ophthalmic surgical education: The role of neuroanatomy and 3D digital technologies – An overview

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ABSTRACT

Background: Neuro-ophthalmology, bridging neurology and ophthalmology, highlights the nervous system's crucial role in vision, encompassing afferent and efferent pathways. The evolution of this field has emphasized the importance of neuroanatomy for precise surgical interventions, presenting educational challenges in blending complex anatomical knowledge with surgical skills. This review examines the interplay between neuroanatomy and surgical practices in neuro-ophthalmology, aiming to identify educational gaps and suggest improvements.

Methods: A literature search across databases such as PubMed, Scopus, and Web of Science was conducted, focusing on the implications of neuroanatomy in neuro-ophthalmic surgery education and practice. The review synthesizes insights from both recent and foundational studies to highlight current understandings and future research directions, particularly in educational approaches.

Results: Findings indicate that 3D digital modeling and virtual reality have significantly enhanced neuro-ophthalmic surgical education by providing immersive and engaging learning experiences. For instance, detailed 3D brain atlases offer comprehensive resources for understanding the central nervous system's normal and pathological states. Although studies show that 3D and traditional 2D methods achieve similar post-test results, 3D methods notably improve engagement and motivation, suggesting a shift toward more interactive learning environments.

Conclusion: Integrating both traditional and innovative educational tools is crucial for the progression of neuro-ophthalmic surgical training. This balance helps overcome educational hurdles and better prepare future surgeons. Continuous research and collaboration are essential to refine educational strategies, ultimately aiming to enhance patient care in neuro-ophthalmology.

Keywords: 3D digital modeling, Neuroanatomy, Neuro-ophthalmology, Surgical education, Virtual reality

INTRODUCTION

Neuro-ophthalmology serves as the crossroads between neurology and ophthalmology. It deals with the nervous system's role in vision, in particular, the afferent and efferent visual pathways that extend from the retina to the visual cortex.[6] Neuroanatomy's critical role in neuro-ophthalmic and neurosurgery cannot be overstated, serving as the cornerstone on which precise and effective surgical interventions are built. This narrative review seeks to explore the intricate interplay between neuroanatomy and neurosurgical practices within the realm of neuro-ophthalmology, a field that has seen substantial evolution from its historical roots to the modern era.[6,15] Despite significant advancements, the education of aspiring neuro-ophthalmic surgeons faces challenges, notably in integrating complex neuroanatomical knowledge with practical surgical skills. Our aim is to review current literature that details the current status of neuro-ophthalmic surgical training, identifies current deficiencies in education, and offers a vision for improvement.

MATERIALS AND METHODS

The methodology for the narrative review involves a literature search in databases such as PubMed, Scopus, and Web of Science, focusing on keywords related to neuroanatomy, neuro-ophthalmology, and surgical education. The review prioritizes recent articles complemented by foundational studies for context. Inclusion criteria target studies on neuroanatomy's educational and practical roles in neuro-ophthalmic surgery, with a qualitative analysis of selected articles to assess their contributions to the field. This approach aims to synthesize current insights and identify areas for future research in neuro-ophthalmic surgical education.

RESULTS

The results section of our narrative review highlights the transformative role of 3D digital modeling and virtual reality (VR) technologies in enhancing the educational landscape. The pioneering work by Nowinski and Thaung[15] has been instrumental in defining the state-of-the-art 3D digital brain atlases, covering both normal and disordered states of the central nervous system. Their efforts culminated in the creation of an advanced, detailed, and interactive 3D atlas of the whole human brain, which has been made freely accessible and continues to receive updates. This digital atlas includes thousands of 3D structures of the head and neck, significantly contributing to the depth and breadth of neuroanatomical education [Table 1].

3D virtual resources of educational anatomy were also sought, but this time within the teaching environment. In fact, Stepan *et al.*[19] and Brewer *et al.*[4] compared the educational value of 3D resources to conventional 2D means; they found that, while on the anatomy post-test, both performances were equal, experiences by 3D model users rated their experience more positively, and users supported higher motivation. In sum, therefore, these are findings that do actually suggest quite a positive reception and pedagogical effectiveness for 3D virtual resources within neuroanatomical and neurosurgical education. The trend is going towards more interactivity and higher learning.

DISCUSSION

Integration of advanced technologies in surgical education

Multiple studies reported the effect of utilizing computer-based tools in neuroanatomy teaching.[7,9,20] Most studies on computer-based neuroanatomy tools demonstrated positive effects, including improved student performance and favorable attitudes. However, a minority of studies found no significant impact on grades and lower student engagement compared to traditional methods. Further research is required to ascertain the general effectiveness of these tools.[2]

It introduces techniques that enrich training landscapes for neuro-ophthalmic and neurosurgeons, such as VR and 3D modeling. This technology enhances understanding of neuro-anatomical structures and neurosurgical methods through immersive and interactive learning experiences. Estevez *et al.*[8] and Kockro *et al.*[12] further show how 3D teaching aids enable visualization of anatomical structures in multiple planes, facilitating a more intuitive understanding of spatial relationships required in neuro-ophthalmic surgery. However, the benefits of these technologies might be debatable. For instance, Azer concludes, "There is no high-level evidence to support that the use of 3D models is superior to traditional tools for teaching anatomy."[3]

These tools have roles beyond undergraduate medical education, extending into specialized fields such as neurosurgery to enhance clinical practice readiness. VR technology holds promise for medical education and practice but requires further evaluation to understand its full capabilities and limitations.[16]

Cadaveric dissection's enduring value

It has rightly been said and discussed quite clearly by Macchi *et al.*[14] and Rae *et al.*[16] that despite great advances in technology, traditional cadaveric dissection remains an irreplaceable procedure for providing tactile feedback, which offers a realistic appreciation of tissue textures and variations. Cadaveric dissection in wet laboratories has been found to enhance student motivation and performance. These laboratories aim to improve students' three-dimensional and cross-sectional anatomy knowledge while developing practical skills in imaging techniques. Moreover, cadaveric dissection is pivotal in neurosurgery, offering an unparalleled platform to hone surgical techniques and understand brain anatomy deeply. It facilitates the practice of innovative approaches in a no-risk environment. There is a strong correlation between motivation, academic performance, and mastery of anatomical knowledge, indicating that wet

Table 1: Strategic advances in neuroanatomy education: Impacts on neurosurgical and ophthalmological expertise.

Study (author, year)	Educational strategy	Enhanced impact on neuroanatomy learning
Macchi *et al.* (2007)[14]	Cadaveric dissection	Facilitated intricate understanding of neuroanatomical relationships, critical for surgical precision and patient outcomes
Hall *et al.* (2013)[10]	Near peer teaching	Amplified comprehension of complex neuroanatomical structures, enhancing diagnostic and surgical acumen
Hall *et al.* (2014)[11]	Near peer teaching	Strengthened grasp of neuroanatomical intricacies, improving surgical planning and execution
Allen *et al.* (2016)[1]	3D e-learning modules	Augmented mastery of neuroanatomical complexity, essential for navigating advanced surgical interventions
Rae *et al.* (2016)[16]	Cadaveric dissection	Deepened retention of neuroanatomical knowledge, pivotal for surgical decision-making and patient care
Stephens *et al.* (2016)[19]	Near peer teaching	Elevated neuroanatomical understanding, fostering innovation in neurosurgical and ophthalmological procedures

laboratory activities support the development of critical thinking and clinical reasoning skills, making them a valuable teaching resource.[13,17]

The role of peer teaching

Effective near-peer teaching strategies, illustrated in the study by Hall *et al.*[10,11] and a related study by Stephens *et al.*[19], reiterate the significant benefits of collaborative learning in neurosurgical education. Medical students actively seek opportunities for peer teaching, considering it an indispensable aspect of acquiring skills essential for future clinicians. The success of peer teaching largely depends on congeniality factors, such as the use of familiar language and sharing the same social roles, highlighting the importance of experience in teaching and professional behavior.[18,21]

Challenges and limitations

While the integration of VR, 3D modeling, and other innovative teaching methods hold promise, several challenges persist. The high cost of technology, the steep learning curve associated with new software, and the need for continual updates to reflect the latest surgical and anatomical knowledge are significant barriers. Furthermore, the tactile sensation and the nuanced feel of real tissue manipulation during surgery are not fully replicable in a virtual environment, indicating a gap that technology has yet to bridge fully.

Future directions

Looking forward, the incorporation of artificial intelligence and machine learning into educational tools could personalize learning experiences, adapt to individual student needs, and simulate a wider range of surgical scenarios. The development of more sophisticated haptic feedback systems could also enhance the realism of VR simulations, making them more valuable for surgical training.

Over time, neuro-ophthalmology has redefined surgical education, hence an evolution with innovation coupled with tradition. As described very convincingly by Estevez *et al.*[8], Chan *et al.*[5], and Kockro *et al.*[12], VR integrated into 3D modeling has very bright opportunities in the improvement of surgical training. However, the enduring value of cadaveric dissection and the effectiveness of peer teaching highlight the continued relevance of traditional educational strategies. Balancing these approaches while overcoming existing challenges will be crucial for training the next generation of neuro-ophthalmic surgeons. Future work will need to continue researching in the field and technology that could be used, in interdisciplinary work—all for optimizing educational outcomes and maximizing patient care in this area of neuro-ophthalmology.

CONCLUSION

The evolution of neuro-ophthalmic surgical education intertwines traditional practices with modern innovations, balancing the enduring value of hands-on techniques with the potential of new technologies. This synergy is essential for advancing surgical training, overcoming current challenges, and preparing future neuro-ophthalmic surgeons. Continuous research, technological improvements, and collaborative efforts are crucial for enhancing educational strategies and ultimately bettering patient care in the specialty.

Ethical approval

The Institutional Review Board approval is not required.

Declaration of patient consent

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Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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