Virtual Reality–Based Simulators for Cranial Tumor Surgery: A Systematic Review

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Key words
- Brain tumor
- Surgical performance
- Surgical planning
- Virtual immersive reality

Abbreviations and Acronyms
3D: Three-dimensional
CPA: Cerebellopontine angle
KPS: Karnofsky Performance Status
LOS: Length of stay
MERSQI: Medical Education Research Study Quality Instrument
MVA: Most vascularized attachment
OR: Operating room
VOF: Virtual operating field
VR: Virtual reality

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*Citation: World Neurosurg. (2018) 110:414-422.
https://doi.org/10.1016/j.wneu.2017.11.132*

Journal homepage: www.WORLDNEUROSURGERY.org

Available online: www.sciencedirect.com

1878-8750/$ - see front matter Published by Elsevier Inc.

■ BACKGROUND: **Virtual reality (VR) simulators have become useful tools in various fields of medicine. Prominent uses of VR technologies include assessment of physician skills and presurgical planning. VR has shown effectiveness in multiple surgical specialties, yet its use in neurosurgery remains limited.**

■ OBJECTIVE: **To examine all current literature on VR-based simulation for presurgical planning and training in cranial tumor surgeries and to assess the quality of these studies.**

■ METHODS: **PubMed and Embase were systematically searched to identify studies that used VR for presurgical planning and/or studies that investigated the use of VR as a training tool from inception to May 25, 2017.**

■ RESULTS: **The initial search identified 1662 articles. Thirty-seven full-text articles were assessed for inclusion. Nine studies were included. These studies were subdivided into presurgical planning and training using VR.**

■ CONCLUSIONS: **Prospects for VR are bright when surgical planning and skills training are considered. In terms of surgical planning, VR has noted and documented usefulness in the planning of cranial surgeries. Further, VR has been central to establishing reproducible benchmarks of performance in relation to cranial tumor resection, which are helpful not only in showing face and construct validity but also in enhancing neurosurgical training in a way not previously examined. Although additional studies are needed to better delineate the precise role of VR in each of these capacities, these studies stand to show the usefulness of VR in the neurosurgery and highlight the need for further investigation.**

INTRODUCTION

As technology advances and improves, tools used with education and training continue to evolve to incorporate these advances. In medicine, postgraduate surgical training frequently uses virtual reality (VR)-based simulation for both the teaching and assessment of skills. As a new approach, the introduction of VR has been met with popularity and holds exciting prospects for both surgical training and preoperative surgical planning of complex procedures because it allows for patient-specific safe environments in which surgeons may hone their skills without risking patient safety.[1,2] Although VR is already commonplace for many surgical specialties,[3-5] adaptation into neurosurgery has been slow and evidence that outlines its usefulness is scant. Current literature on the topic is limited in scope because studies are largely focused on showing validity of VR and are often small in scale and lack important controls and adequate statistical power, making the use of VR in neurosurgery uncertain.[1]

Surgical training is an imperative and central aspect of all surgical education. However, real challenges exist between the balancing of patient safety with the need for surgical training. This issue is acutely apparent throughout the neurosurgical specialty. VR offers a novel and exciting solution to these problems, challenging years of tradition, and bypassing legal and ethical quandaries raised by the need to train future generations and maintain patient safety by permitting trainees to simulate intrasurgical stresses and adverse events in a safe environment, all without any risk to patient safety.[6] Additional strengths offered by VR include the near limitless opportunities for surgeons and residents alike to train in realistic environments.[7-11] The relative expense of VR-based simulators is lower than the alternative traditional training models, rendering superiority in this respect as well.[12] VR is also adjustable to the trainee's skill level and can provide a unique performance evaluation profile for the individual. Novice trainees can therefore have the difficulty of their sessions reduced or increased depending on their individual learning needs. In addition, the progress of a trainee can be monitored over time, providing useful feedback to help trainees pinpoint areas of potential weakness. When used across programs, VR can be used to compare and certify trainees.[13] These benefits make VR a likely component of neurosurgical curricula in the future.[14]

Throughout neurosurgery, various procedures have been simulated in VR. There are various studies investigating the usefulness of VR for endovascular surgeries, spinal surgeries, ventriculostomies, endoscopic approaches, and tumor resection, as well as core surgical skills.[1] However, to our knowledge, a systematic review of VR-based simulators for training and presurgical planning of cranial tumor surgery has not been completed. Only technical reviews, small studies, and a review of the effect of simulation on broad neurosurgical skill acquisition and surgical performance are available.[1] Our study reviews all currently available literature on VR-based simulators for neurosurgical education or presurgical planning of cranial tumor surgery. Furthermore, we assess the quality of the available literature and provide a basis and direction for future studies of this nature.

METHODS

We performed a systematic review to identify all peer-reviewed literature on VR-based simulators used for either neurosurgical training or presurgical planning of cranial tumor surgery. We conducted this search using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for reporting systematic reviews.[15]

Search Strategy

Our systematic search was conducted using 2 electronic databases: PubMed and Embase. We searched for literature from inception to May 25, 2017. A PubMed keyword search using the Boolean search terms ((((((virtual OR mixed OR augmented) reality) OR 3D))) AND (simulat* OR train*)) AND (cranium OR cranial) was used. Furthermore, PubMed was searched using MeSH (Medical Subject Heading) terms ("Simulation Training"[Mesh]) AND "Neurosurgical Procedures"[Mesh]. Embase search terms included "neurosurgery" AND "virtual reality" OR "mixed reality" OR "augmented reality." Our inclusion criteria limited our systematic review to studies that had quantitative analysis of metrics used to assess the VR simulation in training and education or presurgical planning of cranial tumor surgery regardless of study design. For the purposes of our search, cranial tumor surgery included any tumor involving the brain and any tumor resection using any surgical technique. We included only studies that had cranial-based tumor surgery as the primary focus and therefore excluded studies that assessed multiple procedures in their assessment of performance metrics. For example, a study assessing broad surgical skills that included the performance of more than 1 task (e.g., brain tumor resection, ventriculostomy, and aneurysm clamping) was excluded because of the confounding tasks. Further, studies were excluded if the simulation was conducted completely on a computer screen (i.e., no instrument handling) or if the simulation had no virtual component (e.g., three-dimensional [3D] printed models). Only studies published in peer-reviewed journals and those found in English were included.

Study Selection

A systematic search in the manner outlined earlier was performed to identify all available articles (duplicates were removed). Next, all articles identified by the search were screened by titles and abstracts. Eligibility was then determined by full-text analysis. Review articles were manually searched for relevant articles. Ambiguous articles were included in the next step for further analysis until inclusion or exclusion criteria could be accurately determined. Remaining articles that fit our inclusion criteria were incorporated into our review.

Quality Assessment

The Medical Education Research Study Quality Instrument (MERSQI)[16] was used to assess the quality of the studies included. MERSQI is a tool used to measure the methodological quality of studies in medical education and its validity has been well established. It evaluates 10 domains (e.g., study design, type of data, and outcomes) to provide a score with a maximum of 18 possible points: the more points, the higher the methodological quality. The MERSQI score of each study in this systematic review was tabulated.

RESULTS

Study Characteristics

Using the search strategy outlined earlier and after removing duplicates, 1662 articles were identified. These articles were then screened by titles and abstracts, yielding 37 articles. These 37 articles were evaluated for eligibility using full-text evaluation, resulting in the inclusion of 9 articles. The screening process is shown in **Figure 1**. The characteristics of all 9 articles are reported in **Table 1**. The 9 articles were then divided into 2 subgroups: 5 simulator-only studies used for training purposes with no real-life surgery[17-21] and 4 studies on presurgical planning with real surgeries performed after simulation.[22-25] Four studies were conducted in Canada,[17-20] 3 in China,[22-24] 1 in Japan,[25] and another in the United States.[21] Of the Canadian studies, 3 are by the same investigators[17-19] and an additional study is from that same institution.[20] Two studies from China are likewise from the same institution.[22,24] All studies are independent of each other. Five studies were performed completely ex vivo (i.e., simulator only) and all 5 were performed using the NeuroTouch (National Research Council Canada [NRC], Ottawa, Canada) VR simulator.[17-21] The remaining 4 studies had both an ex vivo and an in vivo component (i.e., presurgical planning followed by actual surgery); 3 were performed using the Dextroscope (Volume Interactions Pte. Ltd., Singapore) VR system[22-24] and the fourth was performed using an unidentified simulator.[25]

VR-Based Simulation Studies for Presurgical Planning

Four studies coupled VR-based simulation with presurgical planning[22-25] and a summary is shown in **Table 2**. All 4 studies sought to validate the use of VR-based simulators for the planning of various cranial tumors. Three are of a case series design that lacks controls but measures important metrics (e.g., percentage of tumor resected and Karnofsky Performance Status [KPS])[22,23,25]; one is a prospective controlled study that focuses on both surgical metrics as well as patient outcomes over time.[24] The number of study participants ranged from 8 to 84, with a mean of 49.25 ± 15.92. Each study examined the use of VR for the planning of tumor resection in different areas of the brain.

Three of the 4 studies examined were case series. Qiu et al.[22] is a report on a case series study aimed to evaluate the application of VR for the planning of resection of tumors involved with the primary motor cortex. Each of the 45 patients had magnetic