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Current and future use of virtual and augmented reality in neurosurgery: a literature review

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ABSTRACT

Background: For many years the same model has been applied to neurosurgical education; and unfortunately with the shift of healthcare to political and socioeconomic areas, it forced many surgical residents and fellows to limit their OR exposure only to certain cases. With limited resources given to graduate medical education facilities, now a more optimal approach to surgical education has to be adopted. There is a need for modern hands-on, yet safe approach to crucial neurosurgical procedures. A Virtual Reality/Augmented Reality technology can provide an optimal solution to any neurosurgeon who seeks to improve his/her OR skills on demand, without compromising patient safety, wasting OR time and most importantly cost efficiently for the hospital.

Methods: We performed online search of the Google Scholar and PubMed databases for the following keywords "virtual reality," "neurosurgery," "spine surgery," "augmented reality," separately as a single word and as a phrase. Our search strategy included publications from early 2000s to 2019 years respectively.

Results: A unique combination of 3D VR/AR technology allows neurosurgeons to get a precise planning before the actual procedure, additionally, visualize a roadmap for possible complications during the surgery. Some critical tasks of complex procedures could be segmented and rehearsed before the surgery for optimal outcome. One who immerses in 3D VR can easily explore the area of interest from any possible angle.

Conclusion: Integration of VR/AR technology in the preoperative and operative fields, allows neurosurgeons to maximize efficiency, technique and even provide an educational benefit for the patients undergoing neurosurgical procedure.

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INTRODUCTION

As technology continues to rapidly progress to more realistic life-like scenarios, medicine has a very unique advantage to fully adopt and permanently employ the modern consumer solutions into real operative strategy.

Neurosurgery, as one of the most progressive and difficult fields of medicine is always striving to provide patients with the latest technology to treat the most complex procedures – as minimally invasive as possible. Therefore navigation and scanning systems are constantly utilized during cranial and spine surgery. The old methods that have been used for many years have an opportunity to be replaced with more efficient and affordable solution. This exact solution that is making many neurosurgeons worldwide to consider its usability is Virtual and Augmented Reality.

Virtual reality

Virtual Reality (VR) is a three dimensional image of artificial environment, where the user experiences combination of hardware and software as a real world, where interaction is provided in a real physical sense (**Figure 1**).[1]

The key components behind virtual reality are:

1. Three dimension environment or rendering display in neurosurgical cases; anatomical structures of interest which are recreated by Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Magentic Resonance Angiography (MRA).
2. Immersion (mental and physical), operator must understand where he/she is and what are the main goals of surgery.
3. Feedback, operator/user of virtual environment should have some sort of simulation to understand the reality of provided actions. It

could be visual (see), aural (hear) and haptic (touch).

Most of the surgical VR technology is semi-immersive and fully (head mounted display) immersive experiences. This set up allows operator to implement exact steps when operating on a real patient, by providing a recalled – deja vu experience.

Augmented reality

Augmented Reality (AR) technology in compare to VR does not immerse operator in a virtual world, but instead it augments a real life environment or in simple words adds a visual component to it. Currently, there are four types of AR, those types are marker (image recognition) based, markerless (modern GPS maps), projection based (projection of artificial image on the real anatomical surface) and superimposed (replacement or partial replacement of visual fields with augmented image).[2]

The main components of AR technology are:

1. Handheld devices or head mounted display/ head up display (HUD) to render an actual anatomical image.
2. High Definition (HD) video camera to feed the real life images.
3. Spatial location of sensors for precision of augmented anatomical organ of interest.
4. Data processing using computer hardware.

Relatively high display resolution of head up display is suggested in order to calculate the precision of surgical procedure and potential measure errors that might occur.

Figure 1. Visual representation of immersing in virtual/augmented Reality

Virtual reality use

One of the first widely used VR technologies in neurosurgery which developed for Dextroscope (Volume Interactions, Ltd.) is VIVIAN, which stands for (Virtual Intracranial Visualization and Navigation).[3,4] VIVIAN technology was actively utilized in modern hospitals for areas that difficult to access in cranial bases and deep brain areas in the late 90s and early 2000s. Moving forward to 2010, a company named "Surgical Theater" that was founded by Moty Avisar and Alon Geri was established to focus on surgical specialties. This particular company pioneered the technology called Precision VR™, which allowed neurosurgeons precisely pinpoint the strategy of operation and efficacy of their preferred approach.

The concept behind a modern virtual reality consists of transformation of 3D image into a single stereoscopic patient model by using CT, MRI and MRA scans. So possibility of recreating an exact image for the complex brain lesions or vascular malformations is accurate by utilizing this cost-efficient method. Additionally, implementations of VR have been achieved with minimally invasive, endoscopic[5,6] and third ventriculostomy procedures.[7] After utilizing this technology the night before the surgery, many neurosurgical residents recalled details of anatomical structures and lesions they observed during immersion into a VR world. A utilization of VR technology allowed residents to be more confident with their surgical decision-making.

Nowadays, neurosurgeons around the world are actively involved in the development of VR use in their daily practice. Neurosurgeons at University of Tokyo showcased a correct prediction of troubled vessels in 94% of the neurovascular compression cases with facial spasm and trigeminal neuralgia ($p = 0.015$ Fisher), by using VR technology for preoperative planning.[8]

On the patient side, VR allows patients to understand complexity of the procedure in a very visual way. While many technical words might be hard to explain to non-medical patients, visualization certainly puts things in prospective for patient's education. This statement was proven to be true, when in 2016 Stanford Medical School opened its first "Neurosurgical Simulation and Virtual Reality Center". It is the first institution in the Pacific Northwest that used a patient specific and 360 degree VR for direct patient engagement. To this day this technology has proven to be a huge success for its neurosurgical patients.[9]

Below, we summarized benefits of using a modern VR technology in neurosurgery:

A. The utilization of this 3D VR technology allows neurosurgeons for better visibility of anatomical structures in relation to problematic areas.

B. Hands-on simulations of actual surgical concept several days before surgery.

C. Overview of pathological structures and possible prediction of complications.[10]

Augmented reality use

In comparison to Virtual Reality or VR, Augmented Reality (AR) recreates a haptic real world graphics, which are very similar to the real world (**Figure 2**). It is the haptic feeling that was mostly lacking in Virtual Reality that AR provided as substitution. When a neurosurgeon uses VR in the operative settings, an operator has to mentally transform that image into the real patient. In contrast, by utilizing AR technology the image is directly displayed on the patient's anatomy. In neurosurgical field, the real data source in most of the ORs is the actual microscope, where 3D projections reflected into the binocular optics of the microscope, precisely aligns the field the surgeon is working on. This AR surface based approach is more convenient and less manipulative in compare to reference devices such as bayonet pointer, which is used in traditional neuronavigation.[11]

When it comes to registration, most of the AR Microscope Assisted Guided Interventions (MAGI) should have fiducial or skin surface markers for correct pathological information transmission to the surgical field. For the actual visualization, AR stepped out of the traditional VR's CT/MRI registration and instead, was mostly utilized with wireframes and texture maps.[11]

According to the recent PubMed publications, AR implementation in neurosurgery is widely used with neurooncology, followed by neurovascular cases and recently applied in spine surgeries. In neurooncological surgeries, AR played an integral role in excision of gliomas and meningiomas, whereas neurovascular cases led with aneurysms and Arteriovenous Malformations (AVMs).[12] Additionally, according to the publications about systematic reviews of AR technology; it can be successfully applied to the treatment plan of hydrocephalus, Subarachnoid Hemorrhage (SAH) and external ventricular drain placements.[11] A study on employment of AR or HUD during intracranial surgery has shown that HUD application was excellent in 91.6% of cases. Not only the microscope based HUD was used during traditional neuronavigation periods such as identification of lesions, but also in guiding the correct positioning of the patient and marking of skin incisions.[13] In spinal surgeries, surgeons who employed AR on cadavers reported an accuracy of pedicle screw placements in thoracic spine by 85% in contrast to 64% with a freehand technique, which is a standard method in most of the ORs.[14] Implementation of AR visualization followed by utilizing a surgical microscope and O-arm for complicated keyhole spine cases on Transvertebral Anterior Cervical Foraminotomy and Posterior Foraminotomy (TVACF and PCLF). Authors claimed that keyhole procedure maybe widely utilized, even by the surgeons with minimal experience, if they use AR visualization as a guide for these particular cases. A complex spine surgical case coupled with available neurosurgical AR visualization brings a greater confidence in procedure.[15]

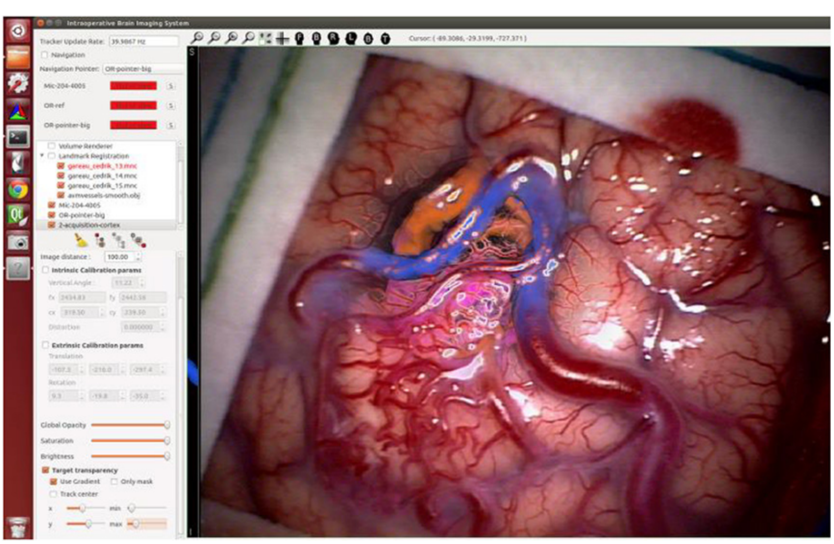

Figure 2.[6] Visualization of operative field with direct AR guidance on anatomical structures of the brain

Cost efficiency of AR technology

The latest improvements in mobile technology, allowed Chinese neurosurgeons to implement AR technology by utilizing an iPhone, simple computer software and CT navigation. They Integrated a low-cost image based iPhone specific AR solution for identifying shallow supratentorial intracranial lesions of moderate size. The simple implementation of sagittal photographs of the patients' heads with iPhone was performed; and by utilizing mentioned above iOS application - MR images and sagittal photo of the patient's head was applied on top of each other, in order to co-register mid-sagittal MR image with the sagittal photograph of the patient. Co-registration was confirmed according to anatomical landmarks and further with guided intraoperative navigation system for accuracy. As a result CT markers confirmation displayed a high accuracy levels (D ≤ 5mm).[16]

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Limitations of virtual and augmented reality

Most of the reviewed research publications suggest that limitations within the scope of implementation of VR/AR do exist, particularly in deep lesions of the brain and operational distractions within identification of anatomical structures. Extra-axial tumors and aneurysms are particularly vulnerable to misguide a surgeon by using AR, as the actual lesion could be located deeper. Therefore, surgeon's intuition must be vigilant and always at the forefront of procedure.[13]

What concerns of VR limitations, most neurosurgeons should be able to get accustomed to transfer their skills from virtual reality that they practiced before the procedure, to the real patient scenario. Although brain shift/movement of vessels can potentially provide inaccurate image to the operator while employing AR/VR technology, it is imperative to always reconfirm a current status of lesion throughout the length of surgery.

CONCLUSION

From the given summary on augmented and virtual reality, it is evident that this technology could be easily utilized in the pre and during operational stages of neurological surgery. Both systems are easily integrated in the flow of operational structure and even provide a very cost-effective method of teaching residents and fellows. Additionally, it is a great educational tool for neurosurgical patient education, as it was mentioned earlier. Further clinical investigation on efficacy and efficiency of both devices in neurosurgical field is needed, as technological progress in the haptic and artificial intelligence (AI) environment is being majorly upgraded throughout upcoming years.

CONSENT FOR PUBLICATION

The consent for publication is not applicable for this review article.

CONFLICT OF INTERESTS

Authors declared no competing interests to declare.

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AUTHORS CONTRIBUTIONS

Study conception and acquisition of data were done by Zhalmukhamedov E. Interpretation of data and critical revision were done by Urakov T.

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