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Editorial

Opinion: Navigating the integration and impact of extended reality in neurosurgery

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The integration of extended reality (XR) systems into neurosurgical practice reflects the field's longstanding enthusiasm for embracing cutting-edge technologies.[9] Current XR systems, with their accurate 3D, dynamic, and interactive imaging capabilities, hold promise for planning and executing surgeries. Evidence from various surgical subspecialties suggests XR's potential to enhance surgical precision, patient outcomes, and overall procedural efficacy.[1,3,11,18] However, quantifying the clinical impact of these innovative tools for neurosurgical use remains a formidable challenge given the broad and difficult-to-measure potential benefits and the variability in applications across institutions and surgeons.

Fortunately, the introduction of XR in neurosurgery parallels historical technological advancements that underscore the value of such innovations. The transition from traditional maps to global positioning system (GPS) technology serves as a relevant example, transforming navigation by replacing static maps with a dynamic, real-time, and multi-layered system.[6] The accuracy and utility of GPS made comparing it to map-based navigation unnecessary. It was simply superior.

Similarly, XR in neurosurgery provides a dynamic visualization of both normal and abnormal anatomy, improving intraoperative decision-making with crucial information overlays that augment the surgeon's field of view.[10] These advancements facilitate an unparalleled understanding of complex anatomical structures, even though their superiority over traditional methods are challenging to prove directly. The undeniable superiority of GPS over maps hints at XR's transformative potential over conventional imaging techniques in neurosurgery. As Korzybski famously said, "the map is not the territory,"[8] yet advances in XR technologies are bringing us closer than ever to replicating the real thing.

Quantifying the benefits of GPS over maps extends beyond measuring accuracy – it includes evaluating efficiency, safety, and user confidence. Similarly, the benefits of XR in neurosurgery extend beyond improved surgical outcomes to include improved performance and learning experiences for surgical trainees, enhanced cognitive and spatial awareness for surgeons, reduced operative times, and potentially fewer complications.[3,7,16,17] Digital XR technologies also offer new possibilities for patient engagement and education.[2] Nevertheless, the challenge of quantifying these benefits is compounded by the diverse metrics required and the subjective experiences of surgeons, trainees, and patients.

The evolution from typewriters to computers, which revolutionized information processing, communication, and creation, serves as another pertinent analogy.[14] XR in neurosurgery represents a similar advancement, providing an unprecedented level of data interaction and integration. However, its full impact is challenging to measure using conventional metrics. Furthermore, XR technology's potential for connectivity and upgradability suggests a future where real-time, multi-layered information sharing and enhancement and AI-enhanced algorithms can continually improve the standard of care.

Measuring XR's impact in neurosurgery is complicated by its variable application across different procedures, patient anatomies, and surgeon experiences. While some aspects, such as the accuracy of pedicle screw placement in spine surgery,[5] may be more straightforward to assess, evaluating the nuanced benefits of visualizing complex anatomical and functional relationships at the tumor-brain interface during tumor surgery is inherently challenging. Understanding how XR might address global disparities in surgical education and democratize access to surgical training, especially in resource-limited settings, is even more difficult to describe.[4,12] Furthermore, the rapid evolution of XR technology complicates longitudinal studies, as the tools and software may significantly change over time.

The landmark introduction of the operative microscope and the advent of the endoscope in neurosurgery, which significantly reduced patient morbidity and recovery times, illustrate the field's capacity for rapid evolution and adaptation.[13,15] These milestones in neurosurgery, which were initially met with skepticism, have fundamentally altered surgical techniques and outcomes. The potential merger of these technologies with digital camera exoscope systems to permit augmented digital overlays illustrates the futuristic possibilities of integrating XR in neurosurgery.

Despite its advantages, XR's full integration into neurosurgical practice is hindered not just by its novelty but significantly by integration challenges with existing navigation systems and intraoperative technologies. This is further complicated by the disproportionate cost relative to the perceived value of these systems. This echoes a broader issue in medical technology adoption, where initial investments and learning curves can obscure long-term benefits.

To overcome these obstacles, a multidisciplinary research approach is essential. By capturing both quantitative data (e.g., operative times and complication rates) and qualitative insights (e.g., surgeon satisfaction and cognitive workload), we can begin to uncover the nuanced impacts of XR in neurosurgery. Collaboration with industry partners is critical to integrating XR into the existing technological landscape and justifying investments without immediate financial returns despite the promise of significant long-term benefits in education and patient safety.

In conclusion, our personal experience suggests that dynamically interacting with an XR representation of complex anatomy or surgical procedures, both preoperatively and intraoperatively, enhances our surgical capabilities. However, empirically proving this enhancement remains a challenge. As we embark on a new era of XR in neurosurgery, we are reminded of technology's transformative potential. Just as GPS and computers revolutionized their fields in initially intangible ways, understanding and quantifying XR's impact is like exploring uncharted territory that promises to advance neurosurgery significantly. Embracing the complexity of this endeavor, along with the multidisciplinary effort and shared insights it requires, is not just a challenge but an opportunity to embrace and adapt these revolutionary technologies.

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