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IMPACT OF AUGMENTED REALITY-BASED NEURONAVIGATION ON NEUROSURGICAL EDUCATION AND TRAINING

ARTIRILMIŞ GERÇEKLİK TABANLI NÖRONAVİGASYON SİSTEMİNİN NÖROŞİRÜRJİ EĞİTİMİNE ETKİSİ

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ABSTRACT

Objective: Integrating technology into surgical training enhances learning experiences. Affordable extended reality (XR) equipment, like the Illumetry XR screen with ArSurgeon software, allows segmentation of preoperative MRI and CT scans in a digital environment, presenting 3D visualisations of tumours and surrounding anatomy. This improves the spatial orientation and understanding of surgical cases, benefiting neurosurgery residents.

Material and Methods: This study utilized preoperative MRI and CT scans of two patients, one with a right frontal mass and the other with a pituitary adenoma. The scans were segmented to isolate the brain, mass, and vascular structures. The 3D models were integrated with MRI and CT data and examined on the Illumetry XR screen with ArSurgeon software. Surgical procedures were recorded and edited into 5-minute videos. Forty neurosurgery residents, split into two groups based on the training year, were provided with the scans and 3D models. After viewing the surgical video, the participants completed a 20-item survey. The survey results were analysed using IBM SPSS Statistics version 29.0.

Result: Among the 40 participants (28 male, 12 female), half were in the first three years of training, and half had 3-5 years of experience. The AR-based neuronavigation system received an average motivation score of 8.4/10, an ease of use rating of 7.6/10, and an ergonomic design rating of 7.9/10. Participants also rated the system's contribution to anatomical understanding and mastery at 8.3/10.

Conclusion: The study showed that AR-based neuronavigation systems effectively enhance surgical education by motivating

ÖZET

Amaç: Teknolojiyi cerrahi eğitime entegre etmek öğrenme deneyimlerini geliştirir. ArSurgeon yazılımına sahip Illumetry XR ekranı gibi uygun fiyatlı genişletilmiş gerçeklik (XR) ekipmanı, ameliyat öncesi MR ve BT taramalarının dijital bir ortamda segmentasyonuna olanak tanıyarak tümörlerin ve çevresindeki anatominin 3D görselleştirmelerini sunar. Bu, uzamsal oryantasyonu ve cerrahi vakaların anlaşılmasını geliştirerek nöroşirürji asistanlarına fayda sağlar.

Gereç ve Yöntem: Bu çalışmada sağ frontal kitle ve hipofiz adenomu olan iki hastanın preoperatif MR ve BT taramaları kullanıldı. Taramalar beyin, kitle ve vasküler yapıları izole etmek için segmentlere ayrıldı. 3D modeller MR ve BT verileriyle entegre edildi ve ArSurgeon yazılımı ile Illumetry XR ekranında incelendi. Cerrahi prosedürler kaydedildi ve beş dakikalık videolar halinde düzenlendi. Eğitim yılına göre iki gruba ayrılan 40 beyin cerrahisi asistanına taramalar ve 3D modeller verildi. Cerrahi videoyu izledikten sonra katılımcılar 20 maddelik bir anket doldurdu. Anket sonuçları IBM SPSS Statistics version 29.0. kullanılarak analiz edilmiştir.

Bulgular: Kırk katılımcının (28 erkek, 12 kadın) yarısı eğitimlerinin ilk üç yılında, yarısı ise 3-5 yıllık deneyime sahipti. AR tabanlı nöronavigasyon sistemi ortalama 8,4/10 motivasyon puanı, 7,6/10 kullanım kolaylığı puanı ve 7,9/10 ergonomik tasarım puanı almıştır. Katılımcılar ayrıca sistemin anatomik anlayış ve ustalığa katkısını 8,3/10 olarak değerlendirmiştir.

Sonuç: Çalışma, AR tabanlı nöronavigasyon sistemlerinin öğrencileri motive ederek ve anatomik bilgiyi geliştirerek cerrahi eğitimi etkili bir şekilde geliştirdiğini göstermektedir. Bununla

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learners and improving anatomical knowledge. However, further improvements in ergonomics and design could enhance their utility in medical training.

Keywords: Augmented reality, neurosurgery, neuronavigation, education

birlikte, ergonomi ve tasarımdaki daha fazla iyileştirme, tıp eğitimindeki faydalarını artırabilir.

Anahtar Kelimeler: Artırılmış gerçeklik, beyin cerrahisi, nöronavigasyon, eğitim

INTRODUCTION

Conventional navigation and imaging technologies have advanced considerably in recent years, offering crucial three-dimensional (3D) images that have played a pivotal role in training and guiding specialised surgeons worldwide. The integration of preoperative and intraoperative imaging, such as magnetic resonance imaging (MRI), computed tomography (CT), tractography, and angiography, into an augmented reality (AR) environment allows surgeons to visualise diverse data in 3D formats. Research has shown that 3D visualisations improve surgeons' spatial understanding and orientation and reduce operation time (1).

AR technology superimposes computer-generated images onto the user's real-world view, enhancing or modifying the visual experience. In neurosurgery, AR combines preoperative and intraoperative imaging data to optimise the surgical process. It improves surgical planning, enhance neuronavigation, and decrease operative time. Moreover, AR offers significant potential as an educational tool for neurosurgeons, reducing complication risks while providing a comprehensive training platform (2).

The advantages of AR technology have led to its successful adoption in various medical applications, which can be categorised into two main areas. The first category includes treatment programs that support patients or healthcare providers in clinical or hospital environments, such as therapies, rehabilitation, or surgical procedures. The second category focuses on educational programs aimed at improving teaching and learning outcomes in academic settings (3).

Before the introduction of computers in medical education, training primarily relied on textbooks, lectures, cadavers, anatomical models, and live patients. However, the integration of computers into medical education has significantly reduced the reliance on these traditional tools. Computer-based education programs have made information more accessible and improved learning methods. These programs enhance visualisation, making information easier to retain for extended periods. Basic computer-based education programs first emerged in the early 1990s, marking the beginning of a trend that has continued to evolve to the present day (4).

In response to increasing budgetary constraints and the need for standardisation, extended reality (XR) has emerged as a cost-effective alternative to traditional simulation methods. XR is a broad term that includes immersive technologies such as virtual reality (VR), AR, augmented virtuality (AV), mixed reality, and other computer-generated environments using head-mounted displays (5). The introduction of XR has created new opportunities for immersive learning, particularly in mastering complex medical concepts. These technologies address the financial, ethical, and regulatory challenges associated with traditional training resources, such as cadavers and specialised laboratory equipment, used for skill development (6).

Training in neurosurgery requires substantial investment due to the extensive theoretical and procedural knowledge and practical skills that residents must acquire. This learning process continues throughout a neurosurgeon's career. However, the complexity of the neurosurgical procedures and the sensitivity of the anatomical regions involved limit the training opportunities, further prolonging the learning curve. Similar to the field of aviation, simulation in neurosurgery offers a trial-and-error learning approach without risking patient safety (7).

The complexity of neurosurgery largely stems from the intricate anatomy, making a deep understanding of neuroanatomy crucial for neurosurgeons. Research has shown that studying anatomy in a virtual environment improves the retention and recall of both topographic and operative anatomy (7-9). This study aimed to assess the effect of using 3D images, generated from preoperative MRI and CT scans, displayed in an XR environment, on surgeons' surgical orientation.

MATERIAL AND METHODS

The study was approved by the Ethics Committee of İstanbul Faculty of Medicine (Date: 12.07.2024, No:13). All patients provided written informed consent to participate in this study. Preoperative MRI and CT scans were obtained from two patients, one with a right frontal mass and the other with a pituitary adenoma, who both underwent surgery at the İstanbul Faculty of Medicine. These images were used to segment the brain, masses, and vascular structures separately using the Illumetry XR screen integrated with the ArSurgeon software developed by SimBT. Surgical procedures were recorded and edited by two surgeons into a 5-min video. The study included 40 neurosurgical residents. Participants were first presented with the preoperative MRI and CT images of the patient. They were then shown the segmented 3D images displayed in the XR environment, along with the edited video of the surgical procedure (Figure 1, 2). Following this, the participants completed a 20-item questionnaire (Figure 3). The survey responses were analysed descriptively using IBM SPSS Statistics version 29.0 (IBM SPSS Corp., Armonk, NY, USA).

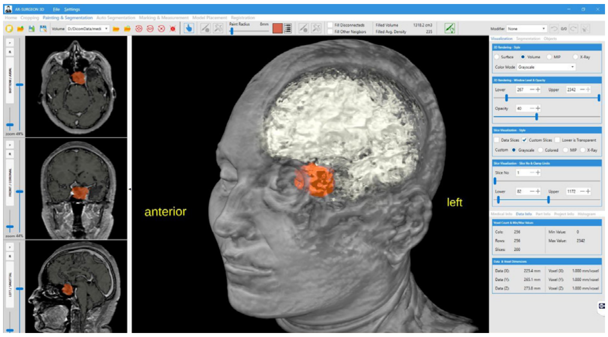

Figure 1: 3D image of preoperative MR and CT images of a patient with pituitary adenoma segmented on an Illumetry XR screen integrated with ArSurgeon software developed by SimBT

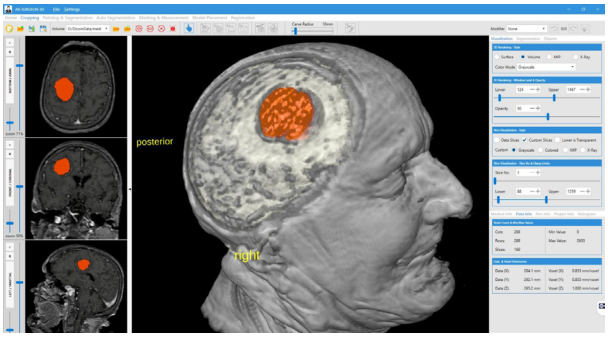

Figure 2: 3D image of preoperative MR and CT images of a right frontal mass patient segmented on the Illumetry XR screen integrated with the ArSurgeon software developed by SimBT

RESULTS

Forty neurosurgery residents participated in the study, evaluating the contribution of an AR-based neuronavigation system to their training. Among the participants, 28 were male and 12 were female. Half of the residents were in the first three years of their neurosurgical residency, while the other half had completed 3–5 years of training.

Participants rated the system's impact on their motivation to learn with an average score of 8.4/10, indicating a positive influence on their engagement in surgical education. The system's overall ease of use received a rating of 7.6/10, and its ergonomic design was rated at 7.9/10. Additionally, the system was found to enhance the understanding of anatomical structures and improve anatomical mastery, earning an average score of 8.3/10.

Name-Surname:

Age:

Sex:

Educational background:

Please rate the following questions between 1 and 10

1. How would you evaluate the overall user-friendliness of the augmented reality-based neuronavigation system?
2. Did using the augmented reality-based neuronavigation system enhance your mastery of anatomy?
3. How effective was the augmented reality-based neuronavigation system in improving the understanding of anatomical structures?
4. Would you recommend this system to others?
5. Do you believe that using this system in education is beneficial?
6. Are you satisfied with the visual and technical features of the augmented reality-based neuronavigation system?
7. How motivating do you think it would be to work with the augmented reality-based neuronavigation system?
8. Does the augmented reality-based neuronavigation system have any advantages over other educational materials?
9. Were you satisfied with the graphical interfaces of the augmented reality-based neuronavigation system?
10. How helpful do you think the augmented reality-based neuronavigation system would be in your learning process?
11. Were you satisfied with the accuracy of the information provided by the augmented reality-based neuronavigation system?
12. How comfortable does it feel to use the augmented reality-based neuronavigation system?
13. How suitable is the integration of the augmented reality-based neuronavigation system with educational materials?
14. What are your thoughts on the ergonomic design of the augmented reality-based neuronavigation system?
15. How would you rate the quality of the visual materials provided by the augmented reality-based neuronavigation system?
16. To what extent does the augmented reality-based neuronavigation system enhance your learning motivation?

Figure 3: Questions of the 20-question questionnaire asked neurosurgeons

Biostatistical analyses revealed that gender did not significantly influence the ease of use or anatomical mastery of the AR-based neuronavigation system. Analysis of variance (ANOVA) test results showed no significant gender differences in ease of use ($F=1.50$; $p=0.23$) or anatomical mastery ($F=0.46$; $p=0.50$). Similarly, a chi-square test examining the relationship between educational level and ease of use found no significant association ($\chi^2=1.30$; $p=0.86$). The educational level did not significantly impact the participants' evaluations of the system's usability.

These findings indicate that AR-based systems positively influence residents regardless of gender or education level. Nonetheless, the need for improvements in ergonomics and the quality of visual materials was highlighted to further enhance the user experience.

DISCUSSION

Neurosurgery is a challenging field that demands several skills and qualities from its practitioners. To succeed, neurosurgeons must undergo extensive training, develop strong manual dexterity and hand–eye coordination, and make sound decisions (10, 11). Technological tools are essential in this educational process. The 3D visualisation of segmented MRI or CT images provides a clearer understanding of the surrounding anatomical structures, aiding in the selection of the best approach for treating the tumoral tissue (2, 12).

The findings of this study emphasise the positive effect of XR-based neuronavigation systems on medical education, particularly in boosting residents' motivation to learn and enhancing their understanding of anatomy. The high average scores for motivation (8.4/10) and anatomical mastery (8.3/10) show that AR-based systems are valuable tools in neurosurgical training, helping residents better visualise and understand complex anatomical structures. This supports existing research that highlights the benefits of 3D visualisation technologies in improving cognitive retention and practical skills in surgical education (12, 13).

Despite the clear advantages, the ergonomic design and ease of use of the system received moderate scores (7.6/10 for ease of use and 7.9/10 for ergonomics), indicating areas for improvement. Some participants raised concerns about the visual quality and comfort while using the system, that improving these aspects could enhance the overall educational experience. These results align with previous studies emphasising the importance of user-centred design in medical technologies, where both functionality and user comfort are crucial for optimal learning outcomes.

The biostatistical analysis revealed no significant gender differences in the system's ease of use or its contribution to anatomical understanding. This that XR-based systems are equally effective across different demographic groups, making them versatile tools in various educational environments. The ANOVA test showed no significant differences in ease of use (F=1.50; p=0.23) or anatomical mastery (F=0.46; p=0.50) between male and female participants, indicating that the system's benefits apply broadly.

In recent years, technology has become an increasingly significant factor in medicine, particularly with the rise of artificial intelligence applications. These systems support doctors by aiding in the interpretation of diagnostic images, such as identifying bleeding in a CT scan from the emergency room or detecting acute ischaemia in a diffusion MRI (14, 15). Furthermore, advancements in medical education have gained attention, with traditional fresh cadavers in anatomy laboratories being replaced by virtual cadavers in VR environments. Studies have shown that these 3D virtual environments improve the understanding of anatomical structures, reduce the reliance on cadavers, and lower costs due to their accessibility from any location (16-18). Technological advancements are expected to continue expanding, particularly in resident and medical education.

Although the present study is methodologically thorough, it has some limitations. The survey methodology is prone to inherent bias, particularly with the use of Likert scales, which may increase the risk of non-response and consent bias, potentially leading to inaccurate responses. These biases could affect the validity of the data, so caution is needed when interpreting the results.

CONCLUSION

In recent years, technology has become increasingly integrated into surgical assistant and postgraduate training. It has been demonstrated that 3D simulation of complex pathologies, using devices like the cost-effective Illumetry XR screen with ArSurgeon software developed by SimBT greatly enhances resident training by improving case orientation. This allows for better visualisation of tumours or pathological structures in relation to the surrounding anatomy, offering a more thorough understanding of the case.

In conclusion, while XR-based neuronavigation systems show great potential for enhancing surgical education, especially in terms of motivation and anatomical understanding, there are areas that still need improvement, particularly in ergonomics and visual design. Addressing these issues could further strengthen AR's role as a key educational tool in medical training. Future research should investigate the long-term impact of AR on learning retention and practical skill development, as well as its broader clinical applications.

Ethics Committee Approval: Ethics committee approval was received for this study from the İstanbul Faculty of Medicine (Date: 12.07.2024, No:13).

Informed Consent: Written informed consent was obtained from all patients who participated in this study.

Peer Review: Externally peer-reviewed.

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