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TRAINING METHODS IN NEUROSURGERY - WHAT SOLUTIONS XXI CENTURY CAN OFFER?

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ABSTRACT

Neurosurgical training has evolved in recent years, influenced by technological innovations, an increasing complexity of neurosurgical procedures, and growing patients' expectations. While highly effective, traditional methods of learning in neurosurgery require the support of modern technologies to address the intricacy of the field. By synthesizing recent findings and trends, this article aims to provide valuable perspectives on improving neurosurgical training programs to prepare the next generation of neurosurgeons for the demands of a rapidly advancing field. This review explores innovations in neurosurgical education, highlighting 3D printing, virtual reality, augmented reality, and artificial intelligence. New technologies support traditional neurosurgical education, providing reusability, limitless repetitions, relevant feedback, and increased procedure comprehension, but with partial realism. Hence, high-technology solutions remain a valuable complement to traditional training.

KEYWORDS

Surgical Education, Deliberate Practice, Simulation, Mixed Reality

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Introduction

As a specialization neurosurgery is undoubtedly one of the most challenging surgical branches of medicine. The fragility of nervous tissue, the necessity of careful operation and the possibility of serious complications or even death in case of the slightest mistake are features that demand extensive knowledge and practical experience from a surgeon. Comparing mortality and postoperative complications morbidity in neurosurgical procedures performed by specialists with and without resident involvement, higher rates are observed in the first group [1,2]. For this reason, it is crucial to focus on the quality of new surgeons' training. It is assessed that to obtain neurosurgical proficiency the resident has to operate annually about 100-125 times meanwhile the maintenance of specialist skills can require even more cases in relation to only one procedure [3]. Aside from commonly occurring cases, it is impossible to meet these requirements due to a lack of patients suffering from rare conditions. Consequently, nowadays, one can observe a progressive trend of dividing specializations into subspecialties, also concerning neurosurgery. This solution allows specialists to focus on mastering a limited number of procedures to provide their best quality. On the other hand, the idea of subspecialties may lead to a loss of knowledge and operating abilities in remaining neurosurgery fields contributing to more difficult access to adequate specialists and a paradoxical decrease in care quality [4,5]. Regarding those unsatisfying effects rather than reducing the specialist range of responsibilities, the healthcare should ‘increase’ the number of patients. It can be achieved by ensuring an opportunity for appropriate training in neurosurgical procedures as a part of residents’ learning and specialists’ skills maintenance. Besides well-known equipment facilitating the training of single activities like pads for surgical suturing, the XXI century offers high technology solutions such as virtual reality (VR) and augmented reality (AR). The aim of this study is a review of currently available training methods in neurosurgery.

Material and methods

The search was conducted by two independent researchers in databases such as PubMed and Google Scholar. The aim of the search was to find publications covering the topic of neurosurgical training, with particular emphasis on modern methods involving online resources and advanced technologies such as VR, AR, and AI. Among the works related to this topic, studies aimed at evaluating the impact of a given training method on the learning outcomes of practical neurosurgical skills were initially included. The final inclusion of each study was determined by the unanimous decision of both researchers, and in cases of differing opinions, the decision was made by a third researcher

Results and discussion

Traditional methods of learning neurosurgery supported by modern ideas

The traditional method of training surgical skills relies on the 'see one, do one, teach one' approach. That means the knowledge is handed down personally from master to apprentice in the operating room (OR). This approach requires adequate commitment and time from specialists, who devote time to younger colleagues. Concerning improving the education process, modern methods that complement the traditional ones are being introduced more and more often [6]. Moreover, the COVID-19 pandemic highlighted the importance of developing online learning tools [7].

Morbidity and mortality conferences (MMCs)

The implementation of MMCs is one of the methods to increase the operational effectiveness of young doctors. These meetings make it possible to find repetitive mistakes, so-called system-based errors, to avoid them in the future [8]. Kashiwazaki et al. reported that the implementation of the MMCs significantly reduces the number of "avoidable" cases. This study applies to both residents and experienced surgeons [9].

Webinars

Live online educational presentations, called webinars, allow participants from different locations to study and discuss a specific topic, and submit questions and comments. A survey of Saudi Association of Neurological Surgery (SANS) trainees showed high satisfaction with neurosurgical webinars and was considered as one possible educational method to enrich traditional learning [10]. Similar results were obtained by Tzerefos et al. The vast majority of survey participants found online education to be an effective tool for further training, but not a substitute for face-to-face learning [11].

Online video libraries

Online videos in the field of neurosurgery rank prominently among various online educational platforms. Residents see such videos as an additional opportunity to improve their surgical skills and express the need for more such substantive videos to be available online [12]. Knopf et al. analyzed 5 sources of neurosurgical operative videos: YouTube channels of the NEUROSURGERY Journal and the American Association of Neurological Surgeons Neurosurgery, the Neurosurgical Atlas Operative Video Cases, Operative Neurosurgery and Neurosurgical Focus: Video. These sources contain over 1,000 videos, mainly concerning such subspecialties as vascular, tumor, and skull base surgery. The vast majority of the videos originated in the United States [13]. In addition to the sources listed, there are also video libraries featuring cadaveric dissections (e.g. the Rhoton Collection). Rhoton's book and its online collection are recommended as sources for the study of neuroanatomy by professionals around the globe [14].

Microsurgical skills

Microsurgical techniques such as dissection, drilling, suturing, and cutting can be practiced on superficial surfaces and later on various models [15]. Specific models allow residents to acquire microsurgical skills at a defined level. Basic synthetic ones are designed for simple tasks such as simple microsurgical suturing. Learning correct tissue handling and practicing vessel anastomosis demands models like a cadaveric animal or human tissue. Live animal ones are the gold standard for microsurgical simulations. However, for ethical reasons and high cost, such models are intended only for practicing advanced microsurgical skills [16]. Three-dimensional (3D) models can additionally be used as an effective method of learning the spatial relationships of the brain anatomy [17].

Cadaver workshops

Cadaver workshops have become an integral component of surgical training around the world. The lack of pressure on time enables trainees to improve surgical skills in stress-free conditions, as well as to obtain detailed feedback from trainers. These workshops are very well appreciated by the participants, but the question of an objective assessment of the translation of lab skills to the operating theater has to be investigated [18]. Cadaver courses can also contribute significantly to scientific advancement. Participants of the longest-running annual skull-base cadaver microsurgical course, '*Annual Al-Mefty Skull Base Approaches Course*' published more than 1500 articles in peer-reviewed journals after participation in the course [19]. Over the years, cadaver workshops have been developed more and more. Advances like the use of Stratathane resin ST-504 polymer (SRSP) enable a simulation of tumors in the cadaver brain. The dissection experience can be strongly enhanced by a virtual surgery simulation system as well as post-dissection analysis and quantification of data [20,21]. Despite advancements, Bohl et al. reported that high-fidelity synthetic surgical models are subjectively perceived as a better material for training neurosurgical skills than cadavers, except for improving knowledge of surgical anatomy [22].

Novel directions in neurosurgical education

The relentless development of technology not only improves our daily lives but also the possibilities of providing the finest healthcare. Neurosurgery is a medical discipline that especially takes advantage of creating new solutions due to limitations of surgeon's sight and hand precision in confrontation with errors disallowed by nervous tissue. Articles published in recent years approve a wide range of opportunities for advanced technology implementation in neurosurgery such as neurosurgical training, preoperative planning, neuronavigation, robotic surgery, diagnostics, rehabilitation, pain management, and patients' education [23]. This part is focused on a summary of modern technologies' utility in neurosurgeons' training.

3D printing

On account of lower costs and customization of product design to our demands, 3D printing is nowadays widespread in the industry. Its application in neurosurgery is probably the most recognizable in the creation of patient-specific bone implants efficiently used in cranioplasty [24]. Regarding neurosurgical training 3D printing is exploited to prepare anatomical models of diseases in order to simulate procedures performed in the OR. Their development is usually based on the patient's neuroimaging data providing even over 99% accuracy of the finished simulator [25]. Besides printing material, other compounds such as agar, silicone, or animal tissues are commonly added for adequate haptic sensation [26,27]. Moreover, supplementation of special pomp can imitate the blood circulation or cerebrospinal fluid increasing model realism [28]. The results of validation suggest satisfying anatomy reflection however, opinions about tactile feedback are divided. Nevertheless, simulators are confirmed to ensure faithful simulation of neurosurgical procedures consequently becoming a valuable training complement [27,29,30]. Current studies establish 3D printed models' utility in vascular neurosurgery, neuro-oncology, cranium base surgery, spine surgery, and pediatric neurosurgery [31-33].

Virtual reality

The concept of VR assumes an arranged situation display that involves the operator's visual and tactile senses. The world of VR is shown simultaneously on a computer screen or special headset while one can affect its present view via manual controllers. The first method of VR use in training is 360° 3D video recording demonstrating a technique of procedure performance. One can choose from a large variety of topics for instance: tumor resection, aneurysm clipping, endoscopic ventriculoscopy and cranial approaches. This form of education residents have found as a chance for better operation understanding, thereby a helpful tool in learning and preoperative preparation [34-36]. The more interactive solutions are VR models. Three-dimensional presentation of neuroanatomy and intracranial pathologies facilitates comprehension of their structure and conversion from 2D neuroimaging pictures to 3D thinking. Students and residents experienced in VR models are able to detect issues faster and have a superior association with clinical manifestation [37,38]. The above-described systems are undoubtedly a source of precious knowledge nevertheless, they do not ensure the possibility of acquiring practical skills. VR simulators have been designed to imitate the chosen procedure's surgical field, allowing operators to simulate operation performance with virtual surgical instruments controlled by manual devices. The implementation of simulators is related to increased procedure understanding [39]. Regular training leads to on average 32,5% improvement in all simulated actions which can be objectively measured via a selection of appropriate automated performance metrics [40-42]. Current studies establish VR training methods' utility in vascular neurosurgery, neuro-oncology, microsurgery, spine surgery and pediatric neurosurgery [34].

Augmented reality

The AR allows the inclusion of virtually programmed structures in the operator's objective view. Aside from ambient reality by wearing a special headset, one can see designed 3D virtual objects as if they are a part of surroundings. Furthermore, via hand movements, the operator is capable of controlling object properties such as situation, size or transparency. Regarding the utility of AR in neurosurgery, research is mostly directed at use in the operating room as a neuronavigation substitute. The results of those works suggest elevated distance to target accuracy together with convenience due to lack of sight distraction from the operating field [43,44]. Moreover, AR addition in tumor resection procedure can almost double the chance for total resection [45]. The reports about AR application in neurosurgical training are unfortunately very limited. One of the interesting solutions is a hybrid combination of a 3D printed simulator with AR visualization. By using a phone application operators obtain an AR presentation of the cranial approach which may be then tested in a practical way on a dedicated model. This idea has been assessed by residents as easy to use, facilitating procedure comprehension, and helpful in routine operations training [46]. Another described approach is similar to VR simulators. In this case, tumor removal is also performed with manual controllers however, the operation is displayed in AR. In the study participants' evaluation, both visual and haptic experiences have been rated as realistic indicating usefulness in training [47]. Current works establish AR utility in vascular neurosurgery, neuro-oncology, spine surgery, and stereotactic procedures [48].

Artificial intelligence (AI)

At the present time, AI is one of the most intriguing directions of technology development. It works on the principle of complex algorithms, which determine the answer for a given issue or task. What is more, implemented mechanisms of learning allow AI self-improvement with each solved problem and collected data. Until now, AI has found applications in a vast array of medical areas such as diagnostics, treatment, the drug industry, hospital management, students' education, and COVID-19 research [49]. According to neurosurgical training, AI cannot be directly used nevertheless, it is likely to be a beneficial supplement. The VR simulations, assisted with AI using automated performance metrics, enable a comparison between individual cases and their unbiased appraisal. Afterwards, AI may be used to distinguish a level of neurosurgeon's experience reaching up to 97,6% accuracy [50-52]. In consequence, AI opinions can provide relevant feedback to surgeons, especially residents about what they ought to work on and monitor progress in following approaches.

Conclusions

Proficiency in neurosurgery requires the operator to obtain a wide range of activities and procedures regarding each branch of this specialty. Hands-on training in the operating room under the supervision of a more experienced surgeon is undoubtedly the best form of skills improvement. Unfortunately, its accessibility is restricted due to a limited number of patients. The novel training methods offer visual and haptic realism, reusability, and objective feedback providing a valuable complement to standard education. Due to a harmless character, stress-free environment, and possibility of unlimited task repetition, they significantly facilitate residents to gain experience and specialists to prepare before challenging or rarely performed procedures.

List of abbreviations:

AI – artificial intelligence
AR – augmented reality
VR – virtual reality

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