The Use of Virtual Reality and 3D Models in Medicine and in the Training of Medical Students and Physicians

Wykorzystanie wirtualnej rzeczywistości i modeli 3D w kształceniu studentów medycyny i lekarzy

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Abstract: This article aims to show the role and potential of virtual reality (VR) technology and 3D models in medicine, with a special focus on their application in medical education and patient rehabilitation. Research is based on a review of the scientific literature and an analysis of a series of case studies, which encompasses the application of VR in various aspects of healthcare, from geriatric and oncological rehabilitation to surgical training for medical students and practising physicians. The findings indicate significant benefits of VR in medicine, such as improved coordination in the elderly, reduced pain and anxiety in paediatric and oncological patients, and improved efficiency and safety in surgical training. These effects are amplified by the ability to personalise exercises and the increased accessibility and affordability of these technologies. Furthermore, virtual reality offers a unique environment for simulating complex medical and surgical procedures, contributing to better preparation of medical students and young doctors for future clinical practice. In light of these findings, VR emerges as an innovative educational and therapeutic tool, with the potential to significantly improve medical practices and quality of healthcare.

Streszczenie: Artykuł ma na celu przedstawienie roli i potencjału technologii wirtualnej rzeczywistości (VR) oraz modeli 3D w medycynie, ze szczególnym uwzględnieniem ich zastosowania w edukacji medycznej i rehabilitacji pacjentów. Badanie opiera się na przeglądzie literatury naukowej oraz analizie serii studiów przypadków, które obejmują zastosowanie VR w różnych aspektach opieki zdrowotnej – od rehabilitacji geriatrycznej i onkologicznej po szkolenia chirurgiczne dla studentów medycyny i praktykujących lekarzy. Wyniki wskazują na znaczące korzyści płynące z zastosowania VR w medycynie, takie jak poprawa koordynacji u osób starszych, redukcja bólu i lęku u pacjentów pediatrycznych i onkologicznych, a także

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wzrost efektywności i bezpieczeństwa w szkoleniach chirurgicznych. Efekty te są potęgowane przez możliwość personalizacji ćwiczeń oraz zwiększenie dostępności i przystępności tych technologii. Dodatkowo, wirtualna rzeczywistość oferuje unikalne środowisko do symulacji skomplikowanych procedur medycznych i chirurgicznych, co przyczynia się do lepszego przygotowania studentów medycyny i młodych lekarzy do przyszłej praktyki klinicznej. W świetle tych wyników, VR ujawnia się jako innowacyjne narzędzie edukacyjne i terapeutyczne, które ma potencjał do znacznego ulepszenia praktyk medycznych i jakości opieki zdrowotnej.

Keywords: virtual reality, 3D models, medical education, patient rehabilitation, surgical simulation, healthcare technology, medical training, interactive learning, digital innovation, clinical practice

Słowa kluczowe: wirtualna rzeczywistość, modele 3D, edukacja medyczna, rehabilitacja pacjentów, symulacja chirurgiczna, technologia w ochronie zdrowia, szkolenie medyczne, interaktywne uczenie się, innowacje cyfrowe, praktyka kliniczna

1. Introduction

The last decade has witnessed relentless progress in technology, with the advancement of Industry 4.0 and investments in new technologies significantly contributing to the revolutionization of social, economic and scientific spheres. The application of new technological advances in medicine was an obvious step, enabling the improvement of numerous medical procedures and paving the way for new methods of diagnosis, treatment, and patient care. It should be noted especially the use of virtual reality (VR) and 3D models for their potential benefits in the diagnosis, therapy, and more realistic training of medical personnel. Virtual reality allows the creation of immersive environments where patients and medical staff can participate in ways that transcend traditional methods. This article aims to outline the history of virtual reality and provide examples of its application in various branches of medicine and in the training of medical students and doctors, proving its immense usefulness in these areas.

2. Definitions

Virtual reality (VR) technology is an interactive, computer-generated environment that simulates the real world or creates entirely new realms. Users use specialised devices such as VR goggles, gloves, or controllers to immerse themselves in a three-dimensional environment. The primary objective of this technology is to provide the participant with a realistic feeling of presence in a virtual world, allowing interaction with the environment using various senses, such as sight, hearing, and touch. Through the use of virtual reality, medical students have the opportunity to practice and refine their skills in a realistic virtual environment, which can contribute to better preparation for clinical work. In addition, VR allows for the simulation of complex medical procedures, potentially increasing the confidence and competence of future medical professionals.

3D models represent three-dimensional objects or scenes generated computationally. They consist of three-dimensional coordinates (x, y, z) that define points in space. These models are created using various techniques, such as manual modelling, 3D scanning, mathematical methods (e.g., Bézier curves), or through 3D modelling software. Once created, they can be rendered (generating 2D images) for use in animations, video games, simulations, or other fields where three-dimensional representation is beneficial. In medicine, these models enable physicians, students, and researchers to gain a better understanding of anatomical structures, diseases, pathological processes, and interactions within biological systems. Generated 3D models can be viewed on traditional monitors, but their integration with virtual reality technology can offer students and doctors the most extensive opportunities to familiarise themselves with research material.

3. History

Although the term “virtual reality” was coined only in 1987, the concept of virtual reality traces its roots back to the early decades of the 20th century. During this time, the American mathematician and inventor, Edwin Albert Link, created flight simulators known as the *Blue Box* and *Link Trainer*[2]. Although not directly related to today's understanding of virtual reality, Link managed to create an environment that simulated the appropriate conditions and isolated the participant from their surroundings, thereby providing a safe training environment for future pilots. This example illustrates that the desire to immerse people in different environments was

[2] *The National Centre of Simulation*, https://www.simulationinformation.com/hall-of-fame/members/edwin-albert-link/ (on-line 23.11.2023)

not exclusive to artists and the entertainment industry, who sought to elevate the experience of their audience to a new level.

The post-war years brought further development to virtual reality. In 1968, Ivan Sutherland and his team created a device named the *Sword of Damocles*. It was an early virtual reality project using head-mounted displays (HMD)[3]. These were attached to an apparatus mounted on the ceiling and displayed simple images. Although this design did not allow movement within the virtual environment, it was a pioneering step in the development of virtual reality technology and inspired further research in the field.

The development of virtual reality technology was also linked in its later stages to the defence and aviation industries. In the 1960s, General Electric created the first flight simulator with a built-in generator of real-time virtual images, initially for the Apollo program, and later in 1972 for the United States Navy[4]. Subsequently, other companies, such as McDonnell Douglas Corporation, developed helmets and other tools to train pilots.

The advancement of virtual reality technology in these sectors also led to its implementation in other fields, including medicine. Thanks to researchers who sought innovative solutions and technological progress, virtual reality became more widely accessible, enabling its application in medicine.

4. The use of virtual reality technology in medicine

Initially, researchers endeavoured to implement new technologies that were not directly related to the medical industry, but rather to the entertainment sector. In response to the ageing population in many countries, researchers are looking for new solutions to improve the lives of the elderly. They investigated whether the use of virtual reality and console games could improve the coordination of older people. For this study, the Nintendo Wii® console and the Wii Balance BoardTM were used[5]. Although the console and module do not provide full immersion using goggles, the combination of the images displayed on the screen, sound effects, and complex gameplay mechanics makes the experience of the game world more engaging. The

[3] I. Shuterland, *A head-mounted three dimensional display*, "Proceedings of the AFIPS Fall Joint Computer Conference", Washington 1968, pp. 757–759.
[4] *Brittanica.com, Virtual Reality – Education and training*,
https://www.britannica.com/technology/virtual-reality/Education-and-training (on-line 23.11.2023)
[5] M. Żak *et al.*, *Wykorzystanie wirtualnej rzeczywistości i gier konsolowych w profilaktyce upadków osób starszych,* "Gerontologia Polska" 2014 (1), pp. 9–10.

study involved seniors over the age of 65 practising balance using the devices mentioned above. Research confirmed that the use of such solutions should be part of programmes aimed at improving the condition of older patients. Furthermore, it appears that the use of console games and devices that train balance is a good strategy to prevent falls, to which this age group is particularly susceptible. The results of the study also indicate that the combination of conventional kinesiotherapy and virtual reality should be used jointly to achieve the best effects in patient treatment[6]. The above example excellently demonstrates how virtual reality can be used in patient rehabilitation. An additional advantage of incorporating console games into patient rehabilitation is the relatively low cost of such devices compared to specialised equipment. This also allows patients to continue their prescribed exercises at home, due to the popularity of consoles for personal use.

Thanks to immersion in a virtual environment, patients can also perform exercises in a more engaging manner, increasing their motivation to participate in the rehabilitation process. In studies aimed at evaluating the effectiveness of vestibular rehabilitation in patients with vestibular dysfunction, it was shown that „patients reported greater improvement after training with VR"[7]. This indicates that competition-based exercises, tracking progress, and thus more actively engaging the patient, are perceived by them as more effective. The use of virtual reality in the rehabilitation sector can lead to greater patient participation and willingness to cooperate in the pursuit of regaining or improving their physical abilities, especially thanks to the simulation of everyday situations, which supports the training of life functions for those in need.

Rehabilitation of patients using virtual reality also offers the possibility of customising exercises to the needs of the individual patient, by adjusting the level of difficulty, the number of repetitions, or the pace of rehabilitation. Furthermore, it is worth mentioning again that as virtual reality technology develops, its cost will decrease, allowing an increasing number of patients to afford such a set-up and continue exercises at home. Patients could receive personalised exercise programmes and perform them at home, bringing benefits not only in terms of time savings, but also in increasing the regularity of exercise execution.

Virtual reality can help physicians treat pain and anxiety in patients. Cases are known where psychiatrists work with patients struggling with anxiety disorders or posttraumatic stress disorder (PTSD). The use of controlled simulations allows gradual adaptation to stress-inducing

[6] *Ibidem*, p. 12.
[7] O. Rosiak *et al*., *Ocena skuteczności rehabilitacji przedsionkowej u pacjentów z dysfunkcją błędnika,* "Medycyna Pracy" 2019 (5), p. 550.

situations. Another example showing that the virtual reality environment can be used to treat anxiety and pain involves studies with paediatric patients on pain reduction. These patients are particularly sensitive to this discomfort, which during painful medical procedures can discourage the continuation due to negative associations. Furthermore, fear of medical visits and procedures negatively affects patient convalescence[8]. Scientific research on pain reduction in children has confirmed its alleviation through the use of distractions such as television, music, interactive toys, or electronic games; however, the possibilities offered by virtual reality are much greater[9]. The use of virtual reality does not interrupt pain signals but, directly and indirectly, through its impact on emotions, senses, concentration, and attention, affects the perception of pain and its signaling due to immersion. Immersion, which means deep involvement and engagement of the user in a virtual environment, combines both visualisation and sound, as well as the possibility of interaction within virtual reality. This tool in working with children can also be a form of play, positively influencing their development and association with medical procedures. Studies also show that the use of VR to reduce preoperative anxiety is an effective method. Virtual reality technology offers various possibilities for its use and adaptation to the age of the patient. Among the tested methods, it can include familiarising the child with the operating room before a planned procedure. Thanks to this, both the child and the accompanying parent can watch a film displayed in VR that presents the operating room, and then discuss their reflections. Another method involves watching your favourite animated film in VR glasses and repeating this on the day of the procedure while waiting for anaesthesia[10]. Among the medical procedures and treatments that cause stress and anxiety, needle procedures should be mentioned, with particular emphasis on vaccinations. These procedures are necessary for the protection of children's health, but negative stimuli can cause avoidance of vaccinations due to them. The use of VR technology can reduce experienced fear and pain by focussing attention on another activity and isolating the child's mind from the unpleasant environment[11]. The examples shown above demonstrate how virtual reality technology can be an effective tool in reducing stress, anxiety, and pain, especially among paediatric patients. These patients are particularly sensitive to these factors,

[8] U. Fussek-Styga *et al.*, *Wykorzystanie wirtualnej rzeczywistości jako metody redukcji bólu i lęku u pacjentów pediatrycznych – praca przeglądowa*, "Journal of Education, Health and Sport" 2023 (1), p. 83.
[9] *Ibidem*, p. 84.
[10] *Ibidem*, pp. 84–85.
[11] *Ibidem*, p. 86.

which can have a negative impact that can influence their future relationships with the medical sector. They are also more open to testing such devices because of their innate curiosity about the world.

Another group studied for pain reduction is cancer patients. According to the American Cancer Society, cancer-related disorders include mood decline, irritability, and side effects of treatment methods such as nausea[12]. These difficulties do not support treatment, during which patient attitude is extremely important. The prolonged experience of the negative effects of the disease, as well as its treatment, can significantly reduce the quality of life of patients. To counteract side effects and improve the overall well-being of patients, researchers from the University of Wrocław and Wrocław University of Technology conducted studies to verify whether virtual reality can reduce stress and increase patient comfort during treatment. The study involved patients who destroyed cancer cells in a virtual environment using VR weaponry[13]. As mentioned above, virtual reality technology is an engaging medium that affects multiple senses. Individuals who have a lower ability to create vivid mental images, and hence for whom visualisation techniques are not effective, can benefit from virtual reality technology, achieving better results and progress, including an increased subjective sense of control over pain. The cancer patients studied indicated that the VR game arranged had a significant impact on their experiences during chemotherapy sessions, greatly contributing to an increased subjective sense of control over the treatment process. It should be noted that the patients' reactions to the VR game experience were positive and rated the game as fascinating and generally conducive to relaxation[14]. The virtual experience of destroying cancer cells with drug particles shows that potentially modern therapeutic methods can revolutionise cancer treatment, minimising side effects and increasing the effectiveness of therapy. These studies also indicate that, in addition to fighting/treating the disease, an important aspect is the patient's well-being and the regaining of control.

5. Using virtual reality with 3D models for training students and physicians

One of the key areas of virtual reality application is surgical simulation, where physicians can perfect their skills in a realistic virtual environment, minimising risk to patients. A prime example of this type of VR implementation in medical staff training is Eyesi, a German VR

[12] J. Piskorz *et al*., *Virtual Reality Use for Stress Reduction and Patient Comfort During Chemotherapy*, "Polish Psychological Bulletin" 2023 (2), p. 136.
[13] *Ibidem*, p. 144.
[14] *Ibidem*, p. 136.

simulator that allows virtual cataract surgery simulation. This equipment enables training at four levels (A–D) and, by accumulating points from previous simulations, allows one to compare the results[15]. With these characteristics, it is a tool that allows the training of a physician from the beginning of their education to achieving masterful precision, but it also offers the possibility of use by more experienced physicians who feel the need for further education. The ability to track one's results is a valuable source of information on personal progress. The Eyesi simulator has been used among residents of the Royal College of Ophthalmologists, Botucatu Medical School, Miller School of Medicine, as well as among surgeons in Denmark. Studies in these centres confirm that training in the virtual reality environment improved the work of residents and practising surgeons. Training with the Eyesi simulator contributes to a reduction in complications, especially among young physicians, who are at the highest risk of making errors[16]. In addition to improving patient safety, this also leads to reduced costs of treating complications, allowing the saved funds to be invested, for example, in further training for physicians.

Another example of training future physicians using virtual reality technology is a study conducted with students from Jinan University (China). The students participated in a one-year internship during which they used virtual reality technology (apart from the control group) as part of their learning. The study showed that medical students who had access to virtual reality teaching methods exhibited greater perseverance in their careers. In addition, they showed a tendency to active learning and achieved higher instructional grades during the clinical practice stage of surgery. Furthermore, it was noted that the VR teaching mode could contribute to improving the performance of medical students on physical examinations as part of the Final Practice Examination (OBWE). The study also demonstrated that by shaping a learning model based on non-linear dynamics, the VR teaching mode has the potential to become an effective and stable initial element for medical students[17].

Compared to conventional teaching methods or a hybrid approach using 3D technology, the immersive learning method provided by VR technology can effectively engage students,

[15] P. Łajczak *et al.*, *Zastosowanie symulatora VR Eyesi w szkoleniach operacji zaćmy* [in:] *Innowacje w medycynie przegląd wybranych technologii XXI w*., J. Kufel, P. Lewandowski (eds.), v. 10, Łódź 2023, pp. 274–275.
[16] *Ibidem*, p. 283.
[17] W. Gan *et al.*, *Researching the application of virtual reality in medical education: one-year follow-up of a randomized trial,* "BMC Medical Education" 2023 (3), pp. 9–10.

stimulate their motivation for active learning, and create a personalised system of accumulated medical knowledge. From a didactic objectives perspective, it can be stated that virtual reality simulation improves the quality and efficiency of the educational process, serving as a complement to traditional forms of teaching rather than replacing it. According to the data, when asked about strengthening the determination to become a doctor after the internship, 28 students (52.8%) from the VR group gave a positive response, compared to 17 students (30.9%) from the control group[18]. The role of medical education, in which VR enables realistic simulations of clinical cases, integrating theoretical knowledge with practice, should also be emphasised. Medical students have access to interactive scenarios, increasing their readiness to work under real clinical conditions.

In the context of the recent pandemic, teaching with the use of virtual reality seems extremely useful. As indicated by a meta-analysis conducted by Hyeon-Young Kim and Eun-Young Kim, access to medical education programmes using VR through immersive experiences can be particularly valuable in circumstances where the safety of students and educators cannot be guaranteed due to the spread of infectious diseases or in the event of other natural disasters[19]. The authors also note that students can improve clinical skills in a safe environment through repeated learning, appropriately modifying interventions that ended in failure. This is an effective way to improve skills, which can also reduce student stress. This method is not only effective but also positive for the general well-being and motivation of students. Systematic practice of skills can build confidence and increase competence, positively impacting the management of stress associated with educational demands. Additionally, creating a friendly environment for learning and skill development can result in a better understanding of the material and promote a positive attitude towards education. The research confirms that medical education based on virtual reality technology effectively improves students' skills and satisfaction levels[20]. These indicators are also significant due to demographic changes and other requirements for today's students and future medical doctors.

Furthermore, virtual reality technology not only allows entry into a created world, but also facilitates connection with others, even if they are in different parts of the world. A study conducted in the USA using such an environment involved testing a virtual anatomy

[18] *Ibidem*, p. 7.
[19] H. Kim, E. Kim, *Effects of Medical Education Program Using Virtual Reality: A Systematic Review and Meta-Analysis*, "International Journal of Environmental Research and Public Health" 2023 (5), p. 12.
[20] *Ibidem*, p. 12–13.

laboratory[21]. Using images from medical databases, 3D anatomical models were developed and then evaluated by neurosurgeons and neurosurgery residents in virtual space. The study created 10 immersive anatomical environments in which physicians and residents viewed, evaluated and discussed 3D models. Each researcher who participated in the session had their own virtual avatar and controllers, which allowed them to rotate, move, zoom in and out of the designed models. The camera and microphone setup allowed for free exchange of opinions among the participants[22]. Study participants unanimously stated that incorporating such virtual educational experiences into the traditional programme could improve the learning of anatomy by surgical interns. In addition, virtual reality technology would be useful during surgical simulations and in gaining knowledge about surgical approaches. Furthermore, the students also noted that the immersive environment creates a more engaging setting, which improves learning, and that this technology could have a significant impact on international neurosurgeon training.

Anatomical 3D models can also be used on a smaller scale in specific specialisations. An example is the application of a photorealistic virtual ear in otological education, particularly in surgical procedures. The greater realism of the external and middle ear model enabled a more immersive interaction among the training participants. In addition to improving the understanding of human ear anatomy, this technology may change the way otology is taught, confirming the universality of virtual reality technology in medical training and the possibility of its personalization to individual fields through appropriate development of anatomical 3D models.

6. Conclusions

As the examples above illustrate, the use of virtual reality in medicine is becoming increasingly popular. The advancement of digitisation in the healthcare sector serves as an impetus for the implementation of innovative solutions, including virtual reality technology. As a result, patients can benefit from more advanced forms of therapy, and medical personnel can refine their skills under simulated conditions, improving the effectiveness of training. This positive impact accelerates the adoption of modern technologies and raises healthcare standards. This technology not only allows, as repeatedly emphasised in this article, training in a safe

[21] N. Gonzalez-Romo *et al.*, *Virtual neurosurgery anatomy laboratory: A collaborative and remote education experience in the metaverse*, "Surgical Neurology International" 2023 (14), pp. 2–3.
[22] *Ibidem*, p. 6–8.

environment, but also has a range of other advantages. Firstly, it enables multiple people to connect in one session, allowing a group of students to be trained simultaneously, and medical databases provide materials that make it possible to create highly detailed anatomical 3D models. Increasingly extensive medical databases will contribute to the creation of even more detailed and refined 3D anatomical images, which, when implemented in virtual reality, will become excellent training material. Such models vividly illustrate anatomy, allowing students to delve deeper into it, and once prepared, a model can be used for many years. Another positive aspect of using virtual reality technology in student training is its positive reception among the target group. Students are eager to use such tools, they are well acquainted with technology, have a positive attitude towards it, and learn to operate it easily. The ability to practice difficult procedures in a safe environment improves learning comfort, and training software that continuously tracks student progress provides the opportunity to monitor one's own development, which can be associated with greater willingness to continue learning. Virtual reality represents a promising training tool in the field of medicine, offering innovative and effective methods of education.

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