

DIGITAL ESCAPADES: JOURNEY OF MEDICINE IN VIRTUAL WORLD

Abstract

Embarking on digital escapades, medicine journeys into the virtual realm. The convergence of technology and healthcare unfolds immersive experiences, revolutionizing medical training, therapy, and patient engagement. Virtual platforms simulate surgeries, amplifying skill acquisition. Telemedicine leverages virtual spaces, bridging distances for consultations. Patients find solace in therapeutic virtual environments, augmenting healing. Moreover, drug discovery and disease modeling flourish through computational simulations. This odyssey reshapes healthcare delivery, fostering innovation and patient-centric care. As medicine navigates the digital expanse, the virtual voyage propels the field toward unprecedented horizons, where health and technology intertwine for a brighter future.

Keywords: Virtual Reality, VR rehabilitation, VR telemedicine

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I. INTRODUCTION AND TYPES OF VR EXPERIENCES

Jaron Lanier in 1987 coined the term ‘Virtual Reality’ (VR)¹, is one of the impactful revolutionizing technologies in healthcare.¹⁻³ It immerses users in a simulated,⁴ computer-generated environment,⁵ allowing interactive and immersive experiences.^{6,7}

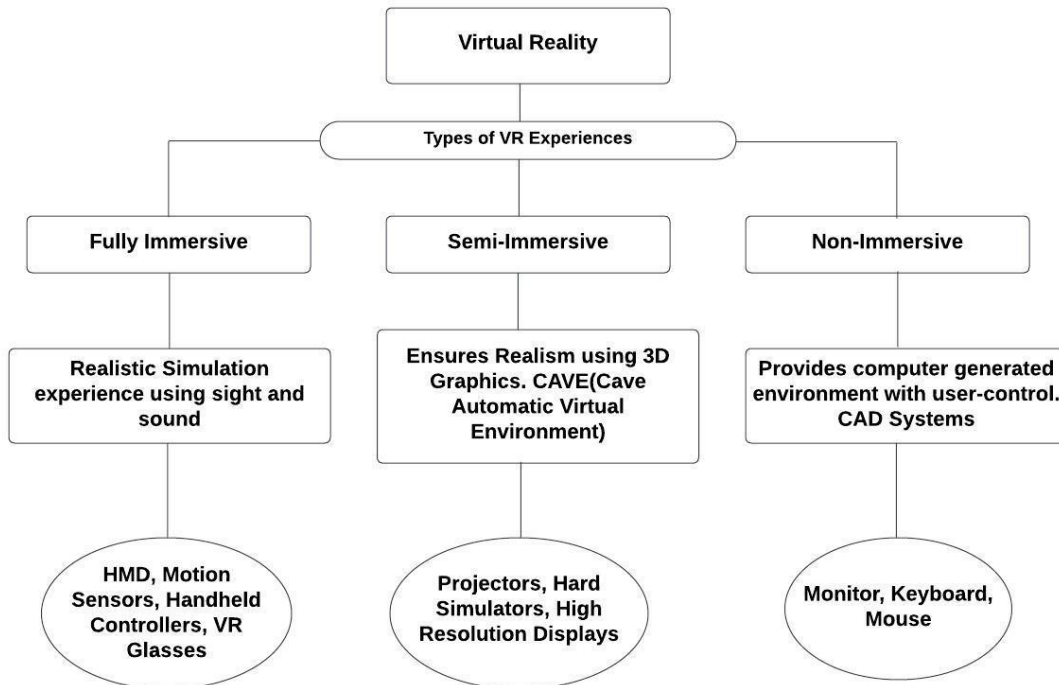


Figure 1: Types of VR Experiences

II. VR APPLICATIONS IN MEDICAL TRAINING AND EDUCATION

1. Simulation-Based Training For Medical Procedures: VR provides realistic and immersive surgical simulations, allowing surgeons to practice complex procedures in a virtual environment.⁸ According to Unsaler *et al.* in 2023, Otology simulators had shown in improving trainee performance. The effectiveness of simulators has been compared in previous studies to cadaveric bone dissections, and trainees stated that VR simulators were exceptionally beneficial in accelerating their learning curves.⁹ It aids Surgeons hone their skills,¹⁰ refine techniques, and gain expertise in diverse medical situations with varying degrees of intricacies.

A study conducted by Knudsen *et al.* in 2023 evaluated the validity of emergency medicine skills among medical students using a 360-degree VR scenario generator played in a Head-Mounted Display (HMD). Students’ feedback of VR experience indicated that it was mentally demanding and needs a high degree of conscience, indicating VR as a potential innovative technique in evaluating emergency medicine skills.¹¹

In addition, VR aids in surgical planning by creating virtual 3D models of patient anatomy, enabling surgeons to visualize and strategize surgical approaches before the

actual operative procedure. Dentists can utilize VR to plan and visualize complex dental treatments. Virtual Reality Dental Stimulators (VRDS) are used along with conventional mannequins to increase the efficiency of preclinical training.¹²

- 2. Surgical Training And Virtual Anatomy:** VR simulations can provide medical students with a realistic, hands-on training experience.¹³ They can practice various complex procedures, such as 3D reconstruction of internal organs in a virtual environment that mirrors real-life scenarios.¹⁴ This enables students to acquire valuable practical skills in a protected and controlled setting.^{7,15-21} According to a study conducted by Banerjee *et al.* in 2023, the use of VR is an essential tool for improving the comprehension of three-dimensional anatomy or pathology among radiology trainees.²²

VR facilitates the learning process of students to explore complex, detailed and interactive virtual models of anatomical structures in 3D that enhances their knowledge¹⁹ and understanding capabilities.²³

- 3. VR for Improving Clinical Decision-Making Skills:** By creating virtual 3D models of a patient using digital algorithms, surgeons can virtually manipulate and analyse the teeth and its surrounding structures to develop precise treatment plans and evaluate various treatment options.²⁴ Single-centred student survey conducted by Mergen *et al.* in 2023 states that the enhancement of clinical competencies of prospective doctors', particularly in practical knowledge and decision-making, improves public health care.²⁵
- 4. VR in Medical Education and Knowledge Retention:** Due to its intrinsic potential as an effective teaching tool, VR has transformed medical education. It exerts a beneficial positive impact on self-efficacy,¹⁵ perceptions of confidence,^{17,18,23,26,27} and competence.^{25,28,29} Medical students and professionals can study virtual anatomical models,³⁰ practice diagnostic skills,²⁶ and interact with virtual patients in realistic clinical scenarios.

Kim *et al.* conducted a systematic-review and meta-analysis in 2023 suggested that the VR group's skill and satisfaction levels were shown significant improvement. In addition, maximization of VR's benefits shall expand learning chances and supplements scant clinical experience resulting in enhanced medical services. It also states that a systematic and efficient VR medical educational programme shall considerably improve the key competencies of the learners.²⁹ Thus, VR technology enhances knowledge retention,³¹ skill development,^{16-21,32} and teamwork among medical students and healthcare providers.

III. VR IN PAIN MANAGEMENT AND REHABILITATION

- 1. Virtual Environments for Distraction During Painful Procedures:** VR creates immersive and calming virtual environments to help patients manage anxiety during medical or dental intervention.³³ According to a Narrative review by Leopardi *et al.* in 2023, it is evident that VR goggles significantly reduce paediatric dental patients' anxiety. These results were at par with the previous studies³ having similar outcomes with a significant decrease in anxiety.³⁴ By wearing VR goggles and headsets, patients are transported to relaxing virtual environments that provides distraction from the clinical

setting, further improves behavioural patterns,⁵ reduces anxiety and stress during painful procedures.³⁵⁻³⁹

2. **VR for Psychological Pain Management:** VR affects the pain modulatory system in patient's through a variety of emotion-based cognitive, emotional affective, and attentional processes, acting as a non-pharmacological form of analgesia.⁴⁰⁻⁴² Rutter *et al.* in 2009 conducted a study where 28 participants were assessed over an eight-week period using once-weekly VR distractions while experiencing cold pressor pain. The results showed that VR distraction increased pain tolerance and threshold while significantly lowering pain intensity, pain thinking time, and self-reported anxiety.⁴³ In addition, VR gamification is majorly used in post-burn rehabilitation in alleviating pain, anxiety and depression.⁴⁴
3. **Rehabilitation And Physical Therapy Using VR:** VR rehabilitation is noted to have a positive impact on cognitive impairment⁴⁵⁻⁴⁷ and motor function.⁴⁵⁻⁵³ Evidence from the study conducted by Asadzadeh *et al.* in 2021 supports the claim that VR interventions during rehabilitation improved quality of life, range of motion, functional ability, muscular strength, and particularly in management of pain.⁵⁴ In the field of dentistry, VR aids in the design of dental prosthesis, such as crowns or dentures. VR tools create and refine digital models of the prosthetics, ensuring proper fit, aesthetics, and functionality before fabrication.
4. **Neurorehabilitation and Motor Function Recovery with VR:** VR-based rehabilitation programs have the potential to transform the field of physical therapy.² Patients recovering from injuries or neurological conditions can engage in interactive exercises and simulations in a virtual environment, improving their motivation and compliance with the therapy.⁵⁴ VR can provide real-time biofeedback,⁵⁵ track progress, and adapt exercises as per individual needs, leading to more effective rehabilitation outcomes.^{48,51}

IV. ENHANCING PATIENT CARE AND EXPERIENCES WITH VR

1. **Patient Education Using VR:** VR enhances patient education by allowing patients to virtually explore health topics, treatment procedures, and post-operative care instructions in a visually appealing and easily understandable manner, promoting better patient comprehension and engagement.⁵⁶ It enhances communication and enables a more informed decision-making.²³
2. **VR-Based Therapies for Psychological Conditions:** VR has impeccable applications in the treatment of psychological conditions such as anxiety disorders,^{35,57,58} autism,⁵⁹ post-traumatic stress disorder (PTSD)^{62,63} and phobias^{60,61}. This exposure therapy significantly helps individuals to gradually overcome anxiety, fear, depression^{64,65} and phobias that reduce emotional tension and stress thereby improving the overall mental well-being.^{38,40,66}
3. **VR for Reducing Anxiety and Stress in Patients:** VR can offer interactive experiences that guide patients through relaxation techniques and controlled breathing exercises. Ryu *et al.* in 2018 conducted a prospective, randomized controlled trial among children undergoing elective surgical procedures and general anaesthesia. This study revealed that

VR experiences preoperatively reduced anxiety and increased patients' compliance.³⁹ These immersive exercises can help patients to achieve a state of calmness thereby reducing anxiety pre-operatively and during operational procedures.⁵⁸

- 4. Pain Reduction and Comfort In Palliative Care Through VR:** VR has shown promising effects in pain management by distracting patients from discomfort or providing relaxation experiences.⁵ Immersive environments aids patients to divert attention away from painful interventional procedures,³³ thereby reducing the need for analgesics or sedatives.³⁶ VR in conjunction with cognitive behavioural techniques are employed to alleviate chronic pain and improve overall well-being.^{37,58}

VI. TELEMEDICINE AND REMOTE HEALTHCARE WITH VR

- 1. VR Applications in Telemedicine and Remote Consultations:** Jonsdottir *et al.* in 2021 stated that VR enhances telemedicine wherein patients had virtual visits with healthcare professionals;⁴⁷ They interact with avatars or realistic representations of medical practitioners in a virtual clinical setting that contain physical parameters of patient. This technology bridges geographical distances, making healthcare more accessible to remote populations residing in underserved areas and plays a significant role in infection control.⁶⁷
- 2. Virtual Clinics and Remote Monitoring Using VR:** Shared virtual consultations between medical professionals and patients through VR technology can be utilized to present treatment plans, demonstrate procedures remotely,⁶⁷ and address patient concerns in a virtually monitored environment.^{30,51,68}
- 3. Tele-Surgery and Remote Medical Interventions with VR:** Telesurgery and remote medical interventions employ cutting-edge technology and telecommunications to perform intricate surgeries and provide top-notch medical care to patients in remote areas.⁶⁹ Surgeons control robotic systems through real-time visual and audio communication, enabling precise and prompt interventions.²¹ It expands access to healthcare, improves patient outcomes, satisfaction and fosters global medical collaboration.⁶⁹

VI. RESEARCH AND DEVELOPMENT IN MEDICAL VR

- 1. Current Advancements and Ongoing Research in Medical VR:** VR enables researchers to visualize complex medical data, such as genomic information,⁷⁰⁻⁷³ molecular structures,⁷⁴ or medical imaging,^{4,17,18,18,22,26,75} in three dimensions. This immersive visualization aids in the understanding of complex relationships, identification of patterns, and generation of new hypotheses. VR-based data exploration tools facilitate an abundant of collaborative opportunities to accelerate scientific discoveries.
- 2. Innovations in VR Hardware and Software for Medical Use:** Remarkable advancements in VR hardware include High-Resolution Displays with a wider field of view, allowing users to visualize a more immersive and encompassing experience. In addition, development of comfortable, lightweight VR headsets with untethered VR systems provides a freedom of movement and flexibility during medical procedures or simulations.¹² On the other hand, innovations in VR Software include visualization and

analysis of large datasets such as medical imaging and patient records in virtual 3D spaces. This promotes better insights and decision-making skills.

- 3. Integration of VR with Advent Technologies:** Integration of VR technologies with latest technological advancements are utilized to create ground-breaking revolution in the field of medicine.⁷⁶ Hoogens *et al.* in 2018 conducted a randomized comparison study using robotic simulators and stated that it effectively improved surgical skill acquisition among trainees.²¹ Artificial Intelligence (AI) integrated with VR increases the efficiency of medical and dental education programs.⁷⁷ Digital Twin technology is an amalgamation of VR technology with 3D graphics and Big data processing.^{78,79} It is utilized to create digital models of individuals in a virtual environment to deliver customized precision diagnosis and personalized treatment in reality.⁸⁰

Metaverse is a recent technology involving the integration of AI, Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR) and Extended Reality (XR) with the Internet of Things (IoT).⁸¹⁻⁸⁴ A conceptualized contemporary model, 'CardioVerse' is the combination of Diagnostic Cardiology with Metaverse that helps in the virtual real-time diagnosis of heart ailments.^{85,86} Kumar *et al.* in 2023 proposed a novel model called 'Integrated 3D Animation and Virtual Reality Simulations in Next-Generation AIoMT' by combining a 3D software with AIoMT.⁸⁷ Newer integrations such as the combination of AI with 'Internet of Medical Things (AIoMT) and Intelligent healthcare (IoHT) systems have opened up frontiers in the era of future medicine.⁵⁶

- 4. Challenges:** Current challenges include weak internet connectivity due to low bandwidth, lack of tactile feedback and data security concerns. VR technology, especially high-end VR headsets, goggles are expensive, making it less accessible and affordable to general population.²⁵ Kumar *et al.* in 2023 stated that the total expenditure involved in the implementation of VR technologies may be much higher than an estimated expenditure due to insufficient financing at the school-level.⁸⁷ Apart from conventional accessories, VR requires powerful hardware to run all applications. Prolonged duration of VR usage causes Cybersickness that includes eye strain, discomfort, dizziness and visually induced motion sickness.^{68,88-91}
- 5. Overcoming Barriers to Widespread Adoption of Medical VR:** Overcoming the perception that VR tools are only used for gaming purposes among general population is the need-of -the-hour. Addressing privacy concerns and ensuring data security is crucial for building trust among users. Making virtual interactions seamless and natural is required to improve the overall user experience.

VII. CONCLUSION

Virtual Reality in today's world plays a vital role in the field of medicine and dentistry. The wide range of advanced applications deliver a highly standardized medical education via simulations enabling medical, dental students and practitioners to ramp up their diagnostic and surgical skills. VR is used in the treatment of complex diseases that enhances patients' satisfaction and treatment outcomes. In addition, rehabilitation and pain management using VR technologies alleviates anxiety, depression and pain. Telemedicine using VR technology delivers advanced medical care to the general population residing in

underserved remote areas. This thereby allows patients to access expert diagnoses and treatment plans through virtual environments. Furthermore, the integration of VR with novel paradigm-shifting technologies such as AI, Digital Twin, IoMT, and Metaverse in the medical domain shall enhance the futuristic trends and allow patients to experience a new era of virtual medicine.

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