**DIGITAL ESCAPADES: JOURNEY OF MEDICINE IN VIRTUAL WORLD**

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**1.0 INTRODUCTION AND TYPES OF VR EXPERIENCES**

Jaron Lanier in 1987coined 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*

**2.0 VR APPLICATIONS IN MEDICAL TRAINING AND EDUCATION**

 **2.1 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). The students' feedback of the VR experience indicated that it was mentally demanding and needs a high degree of presence, indicating VR as a promising innovative technology 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

 **2.2 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 knowledge 19 and understanding capabilities.23

 **2.3 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. 24Single-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

 **2.4 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.

**3.0 VR IN PAIN MANAGEMENT AND REHABILITATION**

 **3.1 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 studies 3 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

 **3.2 VR FOR PSYCHOLOGICAL PAIN MANAGEMENT**

VR acts as a non-pharmacological form of analgesia by exerting an array of emotional affective, emotion-based cognitive and attentional process on the body’s pain modulation system. 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

 **3.3 REHABILITATION AND PHYSICAL THERAPY USING VR**

VR rehabilitation is noted to have a positive impact on cognitive impairment 45–47 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 functional ability, muscular strength, range of motion, quality of life, 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.

 **3.4 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

**4.0 ENHANCING PATIENT CARE AND EXPERIENCES WITH VR**

 **4.1 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

 **4.2 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 phobias, 60,61 and post-traumatic stress disorder (PTSD).62,63 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

 **4.3 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

 **4.4 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

**5.0 TELEMEDICINE AND REMOTE HEALTHCARE WITH VR**

 **5.1 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

 **5.2 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

 **5.3 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

**6.0 RESEARCH AND DEVELOPMENT IN MEDICAL VR**

 **6.1 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.

 **6.2 INNOVATIONS IN VR HARDWARE AND SOFTWARE FOR MEDICAL USE**

Remarkable advancements in VR hardware include High-Resolution Displays with a wider field of view, allows 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.

 **6.3 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. 76Hoogens *et al.* in 2018 conducted a randomized comparison study using robotic simulators and stated that it effectively improved surgical skill acquisition among trainees. 21Artificial 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

 **6.4 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

**6.5** **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.

**7.0 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.

**8.0 REFERENCES**

1. R. Riener, M. Harders. Introduction to virtual reality in medicine. In: Virtual Reality in Medicine. Springer London, London, UK, 2012. 2012. p. 1–12.

2. Gendia A, Rehman M, Cota A, Gilbert J, Clark J. Can virtual reality technology be considered as a part of the surgical care pathway? Ann R Coll Surg Engl. 2023 Jan;105(1):2–6.

3. Vlake JH, Van Bommel J, Riva G, Wiederhold BK, Cipresso P, Rizzo AS, et al. Reporting the early stage clinical evaluation of virtual-reality-based intervention trials: RATE-VR. Nat Med. 2023 Jan;29(1):12–3.

4. Bridget Taylor, Glenda McLean, Jenny Sim. Immersive virtual reality for pre-registration computed tomography education of radiographers: A narrative review. J Med Radiat Sci. 2023;70:171–82.

5. Ha Ni Lee, Joong Wan Park, Soyun Hwang, Jae Yun Jung, Do Kyun Kim, Young Ho Kwak, et al. Effect of a Virtual Reality Environment Using a Domed Ceiling Screen on Procedural Pain During Intravenous Placement in Young Children: A Randomized Clinical Trial. AMA Pediatr. 2023 Jan 1;177(1):25–31.

6. Kumar A, Srinivasan B, Saudagar AKJ, AlTameem A, Alkhathami M, Alsamani B, et al. Next-Gen Mulsemedia: Virtual Reality Haptic Simulator’s Impact on Medical Practitioner for Higher Education Institutions. Electronics. 2023 Jan 10;12(2):356.

7. Mahling M, Wunderlich R, Steiner D, Gorgati E, Festl-Wietek T, Herrmann-Werner A. Virtual Reality for Emergency Medicine Training in Medical School: Prospective, Large-Cohort Implementation Study. J Med Internet Res. 2023 Mar 3;25:e43649.

8. Munawar A, Li Z, Nagururu N, Trakimas D, Kazanzides P, Taylor RH, et al. Fully Immersive Virtual Reality for Skull-base Surgery: Surgical Training and Beyond [Internet]. arXiv; 2023 [cited 2023 Jul 18]. Available from: http://arxiv.org/abs/2302.13878

9. Selin Unsaler, Ayşenur Meriç Hafız, Ozan Gökler, Yasemin Sila Ozkaya. Virtual reality simulation-based training in otolaryngology. Virtual Real [Internet]. 2023 Jul 6; Available from: https://doi.org/10.1007/s10055-023-00828-6

10. Cate G, Barnes J, Cherney S, Stambough J, Bumpass D, Barnes CL, et al. Current status of virtual reality simulation education for orthopedic residents: the need for a change in focus. Glob Surg Educ - J Assoc Surg Educ. 2023 Mar 22;2(1):46.

11. Knudsen MH, Breindahl N, Dalsgaard T, Isbye D, Mølbak AG, Tiwald G, et al. Using Virtual Reality Head-Mounted Displays to Assess Skills in Emergency Medicine: Validity Study. J Med Internet Res. 2023;25:e45210.

12. Ba-Hattab R, Helvacioglu-Yigit D, Anweigi L, Alhadeethi T, Raja M, Atique S, et al. Impact of Virtual Reality Simulation in Endodontics on the Learning Experiences of Undergraduate Dental Students. Appl Sci. 2023 Jan 11;13(2):981.

13. Mühling T, Späth I, Backhaus J, Milke N, Oberdörfer S, Meining A, et al. Virtual reality in medical emergencies training: benefits, perceived stress, and learning success. Multimed Syst. 2023 Aug;29(4):2239–52.

14. Ntakakis G, Plomariti C, Frantzidis C, Antoniou PE, Bamidis PD, Tsoulfas G. Exploring the use of virtual reality in surgical education. World J Transplant. 2023 Feb 18;13(2):36–43.

15. Huang Y, Hu Y, Chan U, Lai P, Sun Y, Dai J, et al. Student perceptions toward virtual reality training in dental implant education. PeerJ. 2023 May 5;11:e14857.

16. Chang AH, Lin PC, Lin PC, Lin YC, Kabasawa Y, Lin CY, et al. Effectiveness of Virtual Reality-Based Training on Oral Healthcare for Disabled Elderly Persons: A Randomized Controlled Trial. J Pers Med. 2022 Feb 4;12(2):218.

17. Hood RJ, Maltby S, Keynes A, Kluge MG, Nalivaiko E, Ryan A, et al. Development and Pilot Implementation of TACTICS VR: A Virtual Reality-Based Stroke Management Workflow Training Application and Training Framework. Front Neurol. 2021 Nov 11;12:665808.

18. Gunn T, Jones L, Bridge P, Rowntree P, Nissen L. The use of virtual reality simulation to improve technical skill in the undergraduate medical imaging student. Interact Learn Environ. 2018 Jul 4;26(5):613–20.

19. Chiang DH, Huang CC, Cheng SC, Cheng JC, Wu CH, Huang SS, et al. Immersive virtual reality (VR) training increases the self-efficacy of in-hospital healthcare providers and patient families regarding tracheostomy-related knowledge and care skills: A prospective pre–post study. Medicine (Baltimore). 2022 Jan 14;101(2):e28570.

20. Andersen NL, Jensen RO, Posth S, Laursen CB, Jørgensen R, Graumann O. Teaching ultrasound-guided peripheral venous catheter placement through immersive virtual reality: An explorative pilot study. Medicine (Baltimore). 2021 Jul 9;100(27):e26394.

21. Hoogenes J, Wong N, Al-Harbi B, Kim KS, Vij S, Bolognone E, et al. A Randomized Comparison of 2 Robotic Virtual Reality Simulators and Evaluation of Trainees’ Skills Transfer to a Simulated Robotic Urethrovesical Anastomosis Task. Urology. 2018 Jan;111:110–5.

22. Banerjee S, Pham T, Eastaway A, Auffermann WF, Quigley EP. The Use of Virtual Reality in Teaching Three-Dimensional Anatomy and Pathology on CT. J Digit Imaging. 2023 Jan 30;36(3):1279–84.

23. Adhikari R, Kydonaki C, Lawrie J, O’Reilly M, Ballantyne B, Whitehorn J, et al. A mixed-methods feasibility study to assess the acceptability and applicability of immersive virtual reality sepsis game as an adjunct to nursing education. Nurse Educ Today. 2021 Aug;103:104944.

24. Marvin Mergen, Anna Junga, Benjamin Risse, Dimitar Valkov, Norbert Graf, Bernhard Marschall. Immersive training of clinical decision making with AI driven virtual patients – a new VR platform called medical tr.AI.ning. GMS J Med Educ. 2023 Apr 17;40(2):1–12.

25. Mergen M, Meyerheim M, Graf N. Towards Integrating Virtual Reality into Medical Curricula: A Single Center Student Survey. Educ Sci. 2023 May 8;13(5):477.

26. Gan W, Mok TN, Chen J, She G, Zha Z, Wang H, et al. Researching the application of virtual reality in medical education: one-year follow-up of a randomized trial. BMC Med Educ. 2023 Jan 3;23(1):3.

27. Mallik R, Patel M, Atkinson B, Kar P. Exploring the Role of Virtual Reality to Support Clinical Diabetes Training—A Pilot Study. J Diabetes Sci Technol. 2022 Jul;16(4):844–51.

28. Alcázar Artero PM, Pardo Rios M, Greif R, Ocampo Cervantes AB, Gijón-Nogueron G, Barcala-Furelos R, et al. Efficiency of virtual reality for cardiopulmonary resuscitation training of adult laypersons: A systematic review. Medicine (Baltimore). 2023 Jan 27;102(4):e32736.

29. Kim HY, Kim EY. Effects of Medical Education Program Using Virtual Reality: A Systematic Review and Meta-Analysis. Int J Environ Res Public Health. 2023 Feb 22;20(5):3895.

30. Sinha S, DeYoung V, Nehru A, Brewer-Deluce D, Wainman BC. Determinants of Learning Anatomy in an Immersive Virtual Reality Environment — A Scoping Review. Med Sci Educ. 2022 Dec 22;33(1):287–97.

31. Dhar E, Upadhyay U, Huang Y, Uddin M, Manias G, Kyriazis D, et al. A scoping review to assess the effects of virtual reality in medical education and clinical care. Digit Health. 2023 Jan;9:205520762311580.

32. Gudadappanavar AM, Hombal P, Benni JM, Patel S, Tubaki BR. Evaluation of Virtual Reality High-Fidelity Adult Mannequin-based Simulation of Real-Life Clinical Scenarios in Teaching Clinical Pharmacology to Medical Students. J Pharmacol Pharmacother. 2023 Mar 15;0976500X2311594.

33. Hitching R, Hoffman HG, Garcia-Palacios A, Adamson MM, Madrigal E, Alhalabi W, et al. The Emerging Role of Virtual Reality as an Adjunct to Procedural Sedation and Anesthesia: A Narrative Review. J Clin Med. 2023 Jan 20;12(3):843.

34. Constantini Leopardi A, Adanero Velasco A, Espí Mayor M, Miegimolle Herrero M. Effectiveness of Virtual Reality Goggles as Distraction for Children in Dental Care—A Narrative Review. Appl Sci. 2023 Jan 18;13(3):1307.

35. Koo CH, Park JW, Ryu JH, Han SH. The effect of virtual reality on preoperative anxiety: a meta-analysis of randomized controlled trials. J Clin Med. 2020;9:3151.

36. Austin PD. The Analgesic Effects of Virtual Reality for People with Chronic Pain: A Scoping Review. Pain Med. 2022 Jan 3;23(1):105–21.

37. Naseem Ahmadpour, Melanie Keep, Anna Janssen, Anika Saiyara Rouf, Michael Marthick. Design Strategies for Virtual Reality Interventions for Managing Pain and Anxiety in Children and Adolescents: Scoping Review. JMIR Serious Games. 2020 Jan 31;8(1):e14565.

38. Beverly E, Hommema L, Coates K, Duncan G, Gable B, Gutman T, et al. A tranquil virtual reality experience to reduce subjective stress among COVID-19 frontline healthcare workers. Afrashtehfar KI, editor. PLOS ONE. 2022 Feb 9;17(2):e0262703.

39. Ryu JH, Park JW, Nahm FS, Jeon YT, Oh AY, Lee HJ, et al. The Effect of Gamification through a Virtual Reality on Preoperative Anxiety in Pediatric Patients Undergoing General Anesthesia: A Prospective, Randomized, and Controlled Trial. 2018;284:7.

40. Bouraghi H, Mohammadpour A, Khodaveisi T, Ghazisaeedi M, Saeedi S, Familgarosian S. Virtual Reality and Cardiac Diseases: A Systematic Review of Applications and Effects. Lakshmanna K, editor. J Healthc Eng. 2023 May 30;2023:1–20.

41. Wong CL, Choi KC. Effects of an Immersive Virtual Reality Intervention on Pain and Anxiety Among Pediatric Patients Undergoing Venipuncture: A Randomized Clinical Trial. JAMA Netw Open. 2023 Feb 16;6(2):e230001.

42. Orr E, Arbel T, Levy M, Sela Y, Weissberger O, Liran O, et al. Virtual reality in the management of stress and anxiety disorders: A retrospective analysis of 61 people treated in the metaverse. Heliyon. 2023 Jul;9(7):e17870.

43. Li A, Montaño Z, Chen VJ, Gold JI. Virtual reality and pain management: current trends and future directions. Pain Manag. 2011 Mar;1(2):147–57.

44. Zavarmousavi M, Eslamdoust-Siahestalkhi F, Feizkhah A, Mobayen M, Fazeli Masouleh SA, Badrikoohi M, et al. Gamification-based Virtual Reality and post-burn rehabilitation: How promising is that? Bull Emerg Trauma [Internet]. 2023 Apr [cited 2023 Jul 18];11(2). Available from: https://doi.org/10.30476/beat.2023.97911.1416

45. Thapa N, Park HJ, Yang JG, Son H, Jang M, Lee J, et al. The Effect of a Virtual Reality-Based Intervention Program on Cognition in Older Adults with Mild Cognitive Impairment: A Randomized Control Trial. J Clin Med. 2020 Apr 29;9(5):1283.

46. De Luca R, Russo M, Naro A, Tomasello P, Leonardi S, Santamaria F, et al. Effects of virtual reality-based training with BTs-Nirvana on functional recovery in stroke patients: preliminary considerations. Int J Neurosci. 2018 Sep 2;128(9):791–6.

47. Jonsdottir J, Baglio F, Gindri P, Isernia S, Castiglioni C, Gramigna C, et al. Virtual Reality for Motor and Cognitive Rehabilitation From Clinic to Home: A Pilot Feasibility and Efficacy Study for Persons With Chronic Stroke. Front Neurol. 2021 Apr 7;12:601131.

48. Mubin O, Alnajjar F, Al Mahmud A, Jishtu N, Alsinglawi B. Exploring serious games for stroke rehabilitation: a scoping review. Disabil Rehabil Assist Technol. 2022 Feb 17;17(2):159–65.

49. Bergmann J, Krewer C, Bauer P, Koenig A, Riener R, Müller F. Virtual reality to augment robot-assisted gait training in non-ambulatory patients with a subacute stroke: a pilot randomized controlled trial. Eur J Phys Rehabil Med [Internet]. 2018 Jun [cited 2023 Jul 19];54(3). Available from: https://www.minervamedica.it/index2.php?show=R33Y2018N03A0397

50. Yeh SC, Lee SH, Chan RC, Wu Y, Zheng LR, Flynn S. The Efficacy of a Haptic-Enhanced Virtual Reality System for Precision Grasp Acquisition in Stroke Rehabilitation. J Healthc Eng. 2017;2017:1–9.

51. Mekbib DB, Debeli DK, Zhang L, Fang S, Shao Y, Yang W, et al. A novel fully immersive virtual reality environment for upper extremity rehabilitation in patients with stroke. Ann N Y Acad Sci. 2021 Jun;1493(1):75–89.

52. Tricco AC, Lillie E, Zarin W, O’Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. Ann Intern Med. 2018 Oct 2;169(7):467–73.

53. Al‐Sharman A, Khalil H, El‐Salem K, Alghwiri AA, Khazaaleh S, Khraim M. Motor performance improvement through virtual reality task is related to fatigue and cognition in people with multiple sclerosis. Physiother Res Int [Internet]. 2019 Oct [cited 2023 Jul 19];24(4). Available from: https://onlinelibrary.wiley.com/doi/10.1002/pri.1782

54. Asadzadeh A, Samad-Soltani T, Salahzadeh Z, Rezaei-Hachesu P. Effectiveness of virtual reality-based exercise therapy in rehabilitation: A scoping review. Inform Med Unlocked. 2021;24:100562.

55. Orgil Z, Johnson L, Karthic A, Williams SE, Ding L, Kashikar-Zuck S, et al. Feasibility and acceptability of perioperative application of biofeedback-based virtual reality versus active control for pain and anxiety in children and adolescents undergoing surgery: protocol for a pilot randomised controlled trial. BMJ Open. 2023 Jan;13(1):e071274.

56. Dang VA, Vu Khanh Q, Nguyen VH, Nguyen T, Nguyen DC. Intelligent Healthcare: Integration of Emerging Technologies and Internet of Things for Humanity. Sensors. 2023 Apr 22;23(9):4200.

57. Morina N, Kampmann I, Emmelkamp P, Barbui C, Hoppen TH. Meta-analysis of virtual reality exposure therapy for social anxiety disorder. Psychol Med. 2023 Apr;53(5):2176–8.

58. Pot-Kolder RMCA, Geraets CNW, Veling W, Van Beilen M, Staring ABP, Gijsman HJ, et al. Virtual-reality-based cognitive behavioural therapy versus waiting list control for paranoid ideation and social avoidance in patients with psychotic disorders: a single-blind randomised controlled trial. Lancet Psychiatry. 2018 Mar;5(3):217–26.

59. Kandalaft MR, Didehbani N, Krawczyk DC, Allen TT, Chapman SB. Virtual Reality Social Cognition Training for Young Adults with High-Functioning Autism. J Autism Dev Disord. 2013 Jan;43(1):34–44.

60. Botella C, Fernández-Álvarez J, Guillén V, García-Palacios A, Baños R. Recent Progress in Virtual Reality Exposure Therapy for Phobias: A Systematic Review. Curr Psychiatry Rep. 2017 Jul;19(7):42.

61. Rothbaum BO, Hodges LF, Kooper R, Opdyke D. Effectiveness of computer-generated (virtual reality) graded exposure in the treatment of acrophobia. Am J Psychiatry. 1995 Apr;152(4):626–8.

62. Jonathan NT, Bachri MR, Wijaya E, Ramdhan D, Chowanda A. The efficacy of virtual reality exposure therapy (VRET) with extra intervention for treating PTSD symptoms. Procedia Comput Sci. 2023;216:252–9.

63. Rothbaum BO, Rizzo A “Skip”, Difede J. Virtual reality exposure therapy for combat-related posttraumatic stress disorder: Virtual reality exposure therapy for PTSD. Ann N Y Acad Sci. 2010 Oct;1208(1):126–32.

64. Ruívo M, Frontini R, Pernencar C. Virtual Reality in Depressive and Anxiety Symptomatology – Contributions to REVIDA project from a mobile app mapping. Procedia Comput Sci. 2023;219:1185–92.

65. Lee CH, Kim YS, Jung JH. Effectiveness of Virtual Reality Based Cognitive Rehabilitation on Cognitive Function, Motivation and Depression in Stroke Patients.

66. Riches S, Taylor L, Jeyarajaguru P, Veling W, Valmaggia L. Virtual reality and immersive technologies to promote workplace wellbeing: a systematic review. J Ment Health. 2023 Mar 15;1–21.

67. Omori K, Shigemoto N, Kitagawa H, Nomura T, Kaiki Y, Miyaji K, et al. Virtual reality as a learning tool for improving infection control procedures. Am J Infect Control. 2023 Feb;51(2):129–34.

68. Tanaka N, Takagi H. Virtual Reality Environment Design of Managing Both Presence and Virtual Reality Sickness. J Physiol Anthropol Appl Human Sci. 2004;23(6):313–7.

69. Sugimoto M, Sueyoshi T. Development of Holoeyes Holographic Image-Guided Surgery and Telemedicine System: Clinical Benefits of Extended Reality (Virtual Reality, Augmented Reality, Mixed Reality), The Metaverse, and Artificial Intelligence in Surgery with a Systematic Review. Med Res Arch [Internet]. 2023 [cited 2023 Jul 21];11(7.1). Available from: https://esmed.org/MRA/mra/article/view/4045

70. Kuznetsov M, Elor A, Kurniawan S, Bosworth C, Rosen Y, Heyer N, et al. The Immersive Graph Genome Explorer: Navigating Genomics in Immersive Virtual Reality. In: 2021 IEEE 9th International Conference on Serious Games and Applications for Health(SeGAH) [Internet]. Dubai, United Arab Emirates: IEEE; 2021 [cited 2023 Jul 19]. p. 1–8. Available from: https://ieeexplore.ieee.org/document/9551857/

71. Li H, Yang Y, Hong W, Huang M, Wu M, Zhao X. Applications of genome editing technology in the targeted therapy of human diseases: mechanisms, advances and prospects. Signal Transduct Target Ther. 2020 Jan 3;5(1):1.

72. Stolk B, Abdoelrahman F, Koning A, Wielinga P, Neefs JM, Stubbs A, et al. Mining the Human Genome using Virtual Reality.

73. Persky S, Kistler WD, Klein WMP, Ferrer RA. Internet Versus Virtual Reality Settings for Genomics Information Provision. Cyberpsychology Behav Soc Netw. 2019 Jan;22(1):7–14.

74. Brown CE, Alrmuny D, Williams MK, Whaley B, Hyslop RM. Visualizing molecular structures and shapes: a comparison of virtual reality, computer simulation, and traditional modeling. Chem Teach Int. 2021 Mar 19;3(1):69–80.

75. Slater P, Hasson F, Gillen P, Gallen A, Parlour R. Virtual simulation training: Imaged experience of dementia. Int J Older People Nurs [Internet]. 2019 Sep [cited 2023 Jul 19];14(3). Available from: https://onlinelibrary.wiley.com/doi/10.1111/opn.12243

76. Thai Hua, Ramsey Kinney, Sang-Eun Song. Computer Assisted and Virtual Reality Based Robotic Knee Arthroscopy: A Systematic Review,. IEEE Trans Med Robot Bionics. 2023 Jul 5;1–1.

77. Adnan K, Fahimullah, Farrukh U, Askari H, Siddiqui S, Jameel RA. AI-enabled virtual reality systems for dental education. Int J Health Sci. 2023 Jun 11;7(S1):1378–92.

78. Moztarzadeh O, Jamshidi M (Behdad), Sargolzaei S, Jamshidi A, Baghalipour N, Malekzadeh Moghani M, et al. Metaverse and Healthcare: Machine Learning-Enabled Digital Twins of Cancer. Bioengineering. 2023 Apr 7;10(4):455.

79. Sun T, He X, Li Z. Digital twin in healthcare: Recent updates and challenges. Digit Health. 2023 Jan;9:205520762211496.

80. Tolga Erol, Arif Furkan Mendi, Dilara Doğan. The Digital Twin Revolution in Healthcare. 4th Int Symp Multidiscip Stud Innov Technol ISMSIT. 2020 Oct;1–7.

81. Ford TJ, Buchanan DM, Azeez A, Benrimoh DA, Kaloiani I, Bandeira ID, et al. Taking modern psychiatry into the metaverse: Integrating augmented, virtual, and mixed reality technologies into psychiatric care. Front Digit Health. 2023 Mar 24;5:1146806.

82. Suh I, McKinney T, Siu KC. Current Perspective of Metaverse Application in Medical Education, Research and Patient Care. Virtual Worlds. 2023 Apr 18;2(2):115–28.

83. Ahuja AS, Polascik BW, Doddapaneni D, Byrnes ES, Sridhar J. The digital metaverse: Applications in artificial intelligence, medical education, and integrative health. Integr Med Res. 2023 Mar;12(1):100917.

84. Massetti M, Chiariello GA. The metaverse in medicine. Eur Heart J Suppl. 2023 Apr 21;25(Supplement\_B):B104–7.

85. Ozkan J. Taking cardiology to the metaverse: how augmented and virtual reality are broadening our horizons. Eur Heart J. 2023 Apr 15;ehad156.

86. Skalidis I, Fournier S, Skalidis E, Maurizi N. Virtual hospitals and digital doctors: how far are we from the CardioVerse? Eur Heart J. 2023 Jan 1;44(1):7–9.

87. Kumar A, Saudagar AKJ, Alkhathami M, Alsamani B, Khan MB, Hasanat MHA, et al. Gamified Learning and Assessment Using ARCS with Next-Generation AIoMT Integrated 3D Animation and Virtual Reality Simulation. Electronics. 2023 Feb 7;12(4):835.

88. Martirosov S, Kopecek P. Cyber Sickness in Virtual Reality - Literature Review. In: Katalinic B, editor. DAAAM Proceedings [Internet]. 1st ed. DAAAM International Vienna; 2017 [cited 2023 Jul 19]. p. 0718–26. Available from: http://www.daaam.info/Downloads/Pdfs/proceedings/proceedings\_2017/101.pdf

89. Guna J, Geršak G, Humar I, Krebl M, Orel M, Lu H, et al. Virtual Reality Sickness and Challenges Behind Different Technology and Content Settings. Mob Netw Appl. 2020 Aug;25(4):1436–45.

90. Saredakis D, Szpak A, Birckhead B, Keage HAD, Rizzo A, Loetscher T. Factors Associated With Virtual Reality Sickness in Head-Mounted Displays: A Systematic Review and Meta-Analysis. Front Hum Neurosci. 2020 Mar 31;14:96.

91. Cobb SVG, Nichols S, Ramsey A, Wilson JR. Virtual Reality-Induced Symptoms and Effects (VRISE). Presence Teleoperators Virtual Environ. 1999 Apr;8(2):169–86.