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The Application of Virtual Reality in the Diagnosis, Rehabilitation, and Surgical Interventions of Neurological Disorders: A Brief Scoping Review

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Review Article

Abstract

Introduction: Technological advancements in the healthcare industry have introduced transformative opportunities to enhance patients' quality of life and optimize clinical services. As an emerging technology, Virtual Reality (VR) provides simulated three-dimensional environments with diverse interactive capabilities. In academic fields, the application of VR is expanding into various medical sciences, including neurological disorders. It plays a valuable role in cognitive assessments for diagnosis, rehabilitation, and medical education. Furthermore, it serves as an effective tool for training residents in preoperative planning and intraoperative procedures, as well as in interventional radiology. This study aims to review the scientific literature on the application of virtual reality in the diagnosis, rehabilitation, and surgery of neurological disorders.

Materials and Methods: In this review, a total of 30 articles were selected from an initial pool of English and Persian studies identified through PubMed and Magiran databases, accessed via Google Scholar and Science Direct. The search targeted publications indexed between 2010 and 2023 for English sources and between 2017 and 2024 for Persian sources using keywords such as “Virtual Reality”, “Rehabilitation”, “Neurological Disorders”, and “Neurosurgery”, and their Persian equivalents. In scoping studies, assessing the quality and risk of bias in articles is not mandatory; therefore, these evaluations were not performed in this study.

Results: It appears that following the application of virtual reality in disorders related to the central nervous system, a significant improvement has been observed in patients' cognitive-behavioral issues, such as attention, concentration, and stress. Based on the reviewed articles, this technology can be used to assess symptoms associated with the onset of neurological disorders. Additionally, it can be utilized in training residents both before and during surgical procedures.

Conclusion: Given the diverse applications of this technology in rehabilitation, diagnosis, and pre- and intra-surgical training, it is recommended that systematic review studies be conducted specifically within each domain, namely assessment, diagnosis, surgical treatment, and rehabilitation of neurological problems. Furthermore, such studies should explore the integration of artificial intelligence. If possible, the most optimal clinical approach for each domain should be identified.

Keywords: Virtual reality; Rehabilitation; Neurological disorders

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Introduction

Neurological disorders are considered one of the leading causes of health threats and mortality worldwide. Global reports states that one billion people are affected by these disorders (1). Alzheimer's disease, Parkinson's disease, Huntington's disease,

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dementia, brain tumors, spinal cord injuries, and stroke are examples of such conditions (3). In recent years, due to the high number of elderly individuals and factors such as gradual neuronal degeneration and necrosis, diseases like Alzheimer's, Parkinson's, amyotrophic lateral sclerosis, frontotemporal dementia, and spinocerebellar ataxia have become more prevalent (3). These disorders have diverse pathophysiologies; in some cases, they lead to memory and cognitive impairments, while in others, they affect an individual's motor ability and speech (2). Cognitive impairment is a common feature in the pathophysiology of these diseases. Given the aforementioned points, timely diagnosis of this type of cognitive deficit is essential, and effective treatment for these disorders depends on the precise causes and mechanisms of each (3). Neurosurgery is performed with the aim of treating disorders related to the central nervous system, such as brain tumors, trauma, neurovascular disorders, and progressive spinal column diseases. It is considered a complex branch of medicine, and acquiring proficiency in it necessitates completing lengthy training periods and obtaining extensive knowledge about the anatomy of the central nervous system (4). Learning through observation has been a part of surgical training for a hundred years. However, due to patient-related legal and ethical issues and the costs associated with observation in the operating room, this approach poses challenges for medical residents (5). The global coronavirus pandemic in 2019 introduced even more severe restrictions to this process. Consequently, the emergence of the field of surgical simulation and virtual training provided an opportunity for neurosurgery education and practice outside the operating room, aiming to develop the necessary skills for performing complex surgeries and enabling optimal management of intraoperative risks and the operating room environment (4, 5).

Virtual reality is rapidly expanding and refers to a computer that creates a three-dimensional graphical environment based on numerical data. By utilizing visual and auditory equipment, such as wearable displays or head-mounted displays, the user can experience an environment that could be part of reality (6). Virtual reality is divided into two categories: immersive and non-immersive. In the immersive type, the user interacts with an artificial, near-reality environment through head-mounted displays, perceiving that environment as the real world. In contrast, in the non-immersive type, the user is aware of and observes the real world while being able to enter the virtual world through graphical workstations (7). Head-mounted displays, which are the main component of virtual reality headsets, consist of two lenses to create stereoscopic three-dimensional images. To enhance the realism of the images, they provide a wide field of view ranging from 90 to 210 degrees with a frame rate of at least 90 frames per second (8).

This technology has been used to promote the reorganization of the cerebral cortex, improve the recovery of brain function, and activate various types of neural connections for the rehabilitation of functional skills across a wide range of central nervous system disorders in different age groups. Recent studies by Diz (2016) indicate that the use of this technology leads to significant improvement in the motor recovery of upper limbs in patients who have suffered from stroke (9). Calderone et al. (2023) demonstrated that this technology is a useful tool for improving cognitive deficits and motor function in individuals with traumatic brain injuries (10). Furthermore, the results of a study with a systematic review approach (2023) indicate that rehabilitation interventions based on virtual reality technology provide cognitive stimulation in patients with Parkinson's disease and are applicable in personalized rehabilitation and home-based treatment for patients (11). The use of this technology is compatible with functional magnetic resonance imaging and electroencephalography, and with user engagement, it enables the tracking of brain function within the environment (2). Additionally, by providing an individualized experience through increased engagement, offering insights that lead to improved learning, and reducing training hours, it is considered an innovative tool in medical education. It can be used to simulate educational programs and surgeries for medical residents (7).

By utilizing software such as Osirix and RadiAnt, two-dimensional MRI or CT images taken from patients can be converted into a three-dimensional virtual reality environment (12, 13). Furthermore, devices that use virtual reality for surgical training, such as expensive simulators like the Lap Mentor, are integrated with head-mounted displays, providing an effective experience for learners (14). This tool, combining head-mounted displays, gaming technology, and sensors that create interactive scenarios, is considered a novel diagnostic system and assesses human executive function and memory (15). The results of a review study by Parada et al. (2024) indicate the potential of emerging virtual reality technology for the early diagnosis of Alzheimer's disease before the onset of acute symptoms, through cognitive assessments conducted using this technology

(16). Also, according to a study with a systematic review approach (2022), fully immersive virtual reality simulators can be utilized in training for neurovascular surgeries and endovascular interventions in the treatment of intracranial aneurysms for resident education (17). Colombo (2023) showed that virtual reality, by converting MRI images into three-dimensional representations and displaying them, leads to a better understanding of cerebral aneurysms among residents (18). Considering the empirical studies indicating the effectiveness of virtual reality in the three areas of diagnosis, rehabilitation, and surgical training simulation for neurological disorders, this research was conducted with the aim of reviewing the research literature on the application of virtual reality in the diagnosis and rehabilitation of patients with central nervous system disorders, as well as in educational programs related to their surgeries.

Materials and Methods

The present study is a scoping review. The research population consisted of articles related to virtual reality in neurological disorders, conducted based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guideline (19).

A scoping review is used to provide a rapid overview of the key evidence in the background of a research field. It is utilized as an independent preliminary review project in cases where the study area is broad and has not been comprehensively studied in the past. In conducting such studies, after identifying and selecting studies relevant to the research topic, data charting is performed, and finally, the results are summarized and reported (20).

To extract the most recent articles, searches were conducted using combinations of the keywords "Virtual Reality" and "Rehabilitation" with other terms such as "Parkinson Disease", "Traumatic Brain Injury", "Dementia", "Cognitive Impairment", "Autism", "Epilepsy", "Multiple Sclerosis (MS)", "Acute Stroke"; the combination of keywords "Virtual Reality" and "Diagnosis" with "Neurological Diseases Diagnosis"; and the combination of keywords "Virtual Reality" with other terms such as "Awake Craniotomy", "Aneurysm Surgery", and "Brain Arteriovenous Malformations". Articles were included in the study if full access to the study was possible. The extracted articles included clinical trials, randomized clinical trials, case reports, and research studies published between 2010 and 2023 in English-language journals and between 2017 and 2023 in Persian-language journals, sourced from the PubMed and MagIran databases. In addition to searching the databases directly, English articles were also retrieved via the ScienceDirect and Google Scholar search engines. The reason for selecting this time frame was to access the most recent research. Exclusion criteria were review articles, duplicate articles, and lack of access to the full text of the article (despite repeated correspondence with the author teams). According to the 2020 PRISMA guideline and Chapter 11 of the JBI Manual for Evidence Synthesis on scoping reviews, assessing the quality and risk of bias in articles is not mandatory; therefore, these aspects were not addressed in this study (19, 21).

Results

A search in various databases initially yielded two hundred and four English articles and fourteen Persian articles. After removing duplicate articles, review articles, and those with inaccessible full texts, twenty-seven English research articles and clinical trials and three Persian articles were ultimately reviewed (Figure 1). Of the thirty articles obtained, twenty-two were in the field of rehabilitation, four in the field of diagnosis, and four were related to virtual reality-based simulators in central nervous system surgeries, which are compiled in Table 1.

Discussion

The reviewed literature can be examined within the following three categories:

Virtual Reality and its Application in the Rehabilitation of Neurological Disorders: Limited studies have been conducted with the aim of rehabilitating patients with Parkinson's disease (due to the loss of dopaminergic neurons in the substantia nigra). It appears that solving mathematical problems, computer-based treatments such as video games, and virtual reality technology can be used for patient rehabilitation, as they lead to improved function of the cerebral cortex and sensory cortex, facilitating patient treatment (22). The reception and processing of EEG signals from five brain regions, including the parietal lobe, temporal lobe, frontal lobe, central region, and occipital lobe, after playing the Sorting Cubes game, which is a type of immersive game, showed increased memory and motor activity (2). Adding training within a virtual reality system combined with a VR Gait Trainer to conventional exercises for six weeks improved motor symptoms (based on the Unified Parkinson's Disease Rating Scale motor section), balance (based on the Berg Balance Scale), and functional mobility (based on the Timed Up and Go test) in individuals with Parkinson's disease more than conventional exercises alone (23).

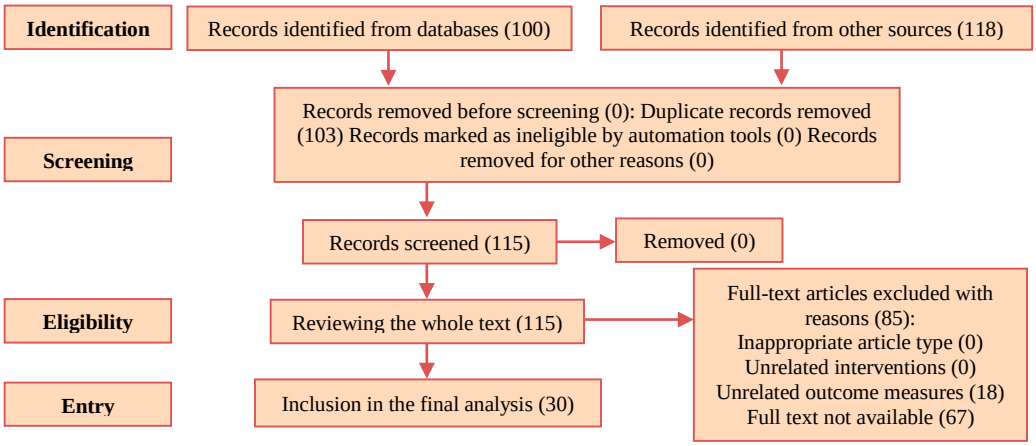

Figure 1. The process of choosing articles based on the PRISMA 2020 flow diagram (21)

Six months of training based on a combined treadmill and virtual reality method played a significant role in enhancing cognitive function in individuals with Parkinson's disease (24) (no comparison was made with another method). Treadmill and virtual reality-based treatment in individuals with traumatic brain injury played a significant role in improving patient balance and increasing their mobility after four weeks (25). Traumatic brain injury is the second leading cause of death and hospitalization in Iranian hospitals, and temporary or permanent cognitive impairment, motor and behavioral deficits, inability to problem-solve, decision-making difficulties, and reduced attention have been reported in fifty-seven percent of survivors of these incidents (26). It is said that the use of non-immersive virtual reality systems in these individuals is effective in attention, the recovery process, and mood, leading to improved cognition and behavior (27). Furthermore, in hospitalized individuals with traumatic brain injury, immersive virtual reality can reduce pain and alter parasympathetic activities such as heart rate (28). Pilot studies in four children with traumatic brain injury compared to ten healthy children showed that immersive virtual reality contributes to cognitive flexibility (mental adaptation to environmental changes) and, as a novel approach in the rehabilitation of executive function in children with traumatic brain injury, may have significant clinical value in improving memory and cognition (29).

Due to the lack of precise understanding of the mechanisms and risk factors for dementia, prescribing pharmacological treatments for this disease is challenging, and for any type of medication prescription, side effects such as cardiovascular risks must be considered (30). In one study, thirty-one middle-aged individuals with cognitive impairment due to dementia underwent training in memory, attention, executive function, and calculation abilities within a personalized virtual reality system designed to facilitate learning, for five weeks, three times per week. Improvements in cognitive function, memory, attention, and executive performance were reported in these individuals (30, 31).

Autism spectrum disorder is a neurodevelopmental disorder characterized by repetitive behaviors, communication difficulties, and impaired social interactions. Based on EEG signals recorded after utilizing virtual reality technology, significant improvement has been reported in children with autism, along with enhanced attention and reduced stress associated with changes in frontal lobe connectivity (32-34). MS is associated with the degeneration of axons in the central nervous system and can be exacerbated by vitamin D deficiency or Epstein-Barr virus infection (35). According to existing studies, utilizing Kinect-based virtual reality games alongside conventional balance exercises for six weeks is effective in reducing falls and enhancing cognitive-motor performance in these individuals (36).

Researchers have employed training interventions combined with virtual reality to develop appropriate exercise strategies for achieving balance in children with cerebral palsy. In this study, five children with spastic cerebral palsy (hemiplegia) were randomly selected and underwent eight weeks of training including aerobics, ball skills, balance exercises, and virtual reality using the Xbox Kinect system. One-way ANCOVA and Bonferroni post-hoc tests were used for statistical analysis. The results indicated a significant improvement in the children's balance, with virtual reality being effective as a superior training intervention for improving balance in children with cerebral palsy (37).

Table 1. Studies Related to the Application of Virtual Reality in Neurological Disorders

References	Type of Disorder and Sample Size	Study Type	Type of Virtual Reality	Objective	Conclusion
Muñoz et al. (2)	9 middle-aged patients with Parkinson's disease	Clinical Trial	Immersive	Investigating the application of virtual reality technology in the rehabilitation of Parkinson's patients	Significant increase in executive function and concentration in patients after being placed in an immersive virtual reality environment and playing computer games such as Sorting Cubes.
Gulcan et al. (23)	15 patients with Parkinson's disease	Clinical Trial	Non-Immersive	Investigating the effectiveness of the VR Gait Trainer in improving movement and balance in Parkinson's patients	Improvement in functional mobility, balance, and facilitation of motor learning following the use of the VR Gait Trainer, as assessed by functional balance tests in patients.
Pelosin et al. (24)	96 patients with Parkinson's disease	Randomized Controlled Trial	Non-Immersive	Investigating the effect of treadmill learning using virtual reality on reducing falls and enhancing cognitive function in Parkinson's patients	Improvement in cognitive functions such as executive performance, attention, visuospatial ability, and a significant reduction in falls following the use of virtual reality and treadmill learning.
Tefertiller et al. (22)	31 patients with traumatic brain injury	Randomized Controlled Trial	Non-Immersive	Investigating the efficacy of treadmill learning and virtual reality on balance and mobility in individuals with traumatic brain injury	Treadmill learning and virtual reality will be an effective method for improving balance and mobility in patients with traumatic brain injury.
De Luca et al. (27)	15 patients with traumatic brain injury	Clinical Trial	Non-Immersive	Investigating the enhancement of attention in patients with severe traumatic brain injury using non-immersive virtual reality	Non-immersive virtual reality can lead to the recovery of attention and improved cognition in patients who have suffered from traumatic brain injury.
Morris et al. (28)	48 patients with traumatic brain injury	Randomized Controlled Trial	Immersive	Evaluating the use of virtual reality in reducing pain in patients with brain injuries	Significant reduction in pain and changes in parasympathetic activities such as heart rate with the use of virtual reality, which could potentially replace narcotic pain medications.
Shen et al. (29)	4 children with traumatic brain injury	Clinical Trial	Immersive	Evaluating the use of virtual reality in the rehabilitation of executive function in children with traumatic brain injury	Utilizing virtual reality hardware and software in children with traumatic brain injury holds potential for the rehabilitation of executive functions such as memory and cognition.
Zhu et al. (30)	31 patients with dementia	Pilot Study	Immersive	Evaluating virtual reality in improving cognitive function, depression, and reducing stress in older adults with cognitive impairment and dementia	Virtual reality is a useful tool for enhancing cognitive function, memory, attention, and executive performance in patients. The study did not report outcomes on stress reduction or depression improvement with virtual reality.
De Luca et al. (31)	1 patient with frontotemporal dementia	Case Report	Non-Immersive	Investigating novel neurorehabilitation using virtual reality in a patient with dementia	Following the application of virtual reality-based neurorehabilitation, a reduction in anxiety, apathy, depression, and motor improvement was observed in the patient with dementia.
De Luca et al. (32)	20 patients with autism	Clinical Trial	Immersive	Evaluating the improvement of functional brain connectivity in individuals with autism using virtual reality	Significant improvement in behavioral-cognitive problems related to attention, spatial perception, and stress reduction was observed following the use of virtual reality in this study.
Zhao et al. (33)	22 children with autism	Clinical Trial	Immersive	Evaluating virtual reality technology on social communication and cognition in children with autism	The simultaneous application of conventional rehabilitation methods and virtual reality can be effective in improving communication and cognitive skills in children.

Table 1. Studies Related to the Application of Virtual Reality in Neurological Disorders (continue)

References	Type of Disorder and Sample Size	Study Type	Type of Virtual Reality	Objective	Conclusion
De Luca et al. (34)	1 patient with autism	Case Report	Immersive	Evaluating virtual reality technology on spatial cognition skills in a patient with autism	The combined use of immersive virtual reality and cognitive behavioral therapy led to improved attention processes and spatial cognition skills in the patient.
Molhemi et al. (36)	19 patients with MS	Randomized Controlled Trial	Non-Immersive	Effectiveness of using virtual reality and conventional balance training methods on balance and falls in patients with MS	Virtual reality-based training has high efficacy in enhancing cognitive-motor function and reducing falls compared to other methods.
Maggio et al. (58)	53 patients with secondary progressive MS	Clinical Trial	Semi-Immersive	Investigating the effect of virtual reality on upper limb ideomotor apraxia in patients with MS	The results of using semi-immersive virtual reality-based training showed significant improvement in cognitive function, neurological impairment, and ideomotor apraxia in patients with MS. Further studies are recommended for final confirmation.
Campo-Prieto et al. (35)	14 patients with MS	Randomized Controlled Trial	Immersive	Evaluating the application of virtual reality on the function of patients with MS	The use of virtual reality glasses and virtual games led to improved mobility and enhanced lower limb function in patients.
Taheri et al. (39)	20 patients with MS	Clinical Trial	Non-Immersive	Evaluating the effect of virtual reality on kinematic gait parameters, muscle strength, and balance in women with MS	Performing virtual reality-based game exercises with the Xbox system for eight weeks led to improved muscle strength, balance, and kinematic gait parameters in patients.
Gray et al. (59)	2 patients with epilepsy	Clinical Trial	Immersive	Evaluating the use of virtual reality in treating stress in patients with epilepsy	A reduction in stress related to epileptic seizures was reported following the use of virtual reality and exposure therapy in the studied samples. It could potentially be utilized as a novel therapeutic method in the future.
Movahedi et al. (38)	15 children with cerebral palsy	Clinical Trial	Non-Immersive	Investigating video games in a virtual reality environment on the motor function of children with cerebral palsy	Video games in a virtual reality environment led to improved motor skills in children with cerebral palsy and represent an efficient and dynamic tool in this field.
Ranjbar et al. (37)	15 children with hemiplegic cerebral palsy	Clinical Trial	Non-Immersive	Evaluating virtual reality on functional balance in children with spastic hemiplegic cerebral palsy	Performing virtual reality-based exercises using the Xbox system for eight weeks led to improved balance and physical condition in children with spastic hemiplegic cerebral palsy.
Peláez-Vélez et al. (43)	12 patients with stroke	Randomized Controlled Trial	Immersive	Investigating the impact of virtual reality and video games in physiotherapy treatment for patients who have suffered from stroke	The use of virtual reality and video games has high efficacy in improving balance, gait, and increasing motor ability in patients who have suffered from stroke.
Yun Hsu et al. (42)	52 patients with chronic stroke	Randomized Controlled Trial	Immersive	Evaluating the application of virtual reality-based therapy on the sensorimotor function of the upper limbs in individuals with chronic stroke	Virtual reality technology and its headset possess therapeutic potential for restoring motor abilities and improving upper limb function, and can be used for brain activation.
Lin et al. (40)	143 patients with acute ischemic stroke	Randomized Controlled Trial	Immersive	Evaluating virtual reality in the early rehabilitation of muscle strength, mood states, and function in patients with acute ischemic stroke	Results from patients in the experimental group, who were placed in a virtual reality environment for fifteen minutes twice daily for three days post-stroke, indicated increased muscle strength in upper and lower limbs, and reduced depression and anxiety.

Table 1. Studies Related to the Application of Virtual Reality in Neurological Disorders (continue)

References	Type of Disorder and Sample Size	Study Type	Type of Virtual Reality	Objective	Conclusion
Mannan et al. (41)	154 participants	Clinical Trial	Immersive	Applying an immersive virtual reality environment to assess cognitive function and automatically detect cognitive impairment	After placing participants in a virtual reality-based simulated store environment, analyzing spatiotemporal behaviors—such as error rates in task performance and item recognition, hesitation, and reaction time—can be utilized for the early diagnosis of various cognitive impairments, including Alzheimer's disease.
Mo et al. (44)	24 patients with cerebral aneurysms	Research Study	Immersive	Using virtual reality technology in the diagnosis of cerebral aneurysms	By utilizing virtual reality technology and digital subtraction angiography, the precise location, size, and shape of aneurysms, as well as their anatomical spatial relationships with the skull, were determined.
Cabinio et al. (47)	36 patients with mild cognitive impairment	Research Study	Non-Immersive	Employing a virtual reality platform to assess memory decline and hippocampal neuronal damage resulting from cognitive impairment	After using intelligent games on a virtual reality platform and obtaining magnetic resonance images from participants, hippocampal volume was assessed. Linear regression analysis showed that this technology was capable of detecting hippocampal neuronal degeneration.
Martins et al. (60)	1 patient with epilepsy	Research Study	Immersive	Evaluating the use of virtual reality in diagnosing photoparoxysmal response during seizure occurrence in epilepsy	In this study, after placing a wireless-connected virtual reality head-mounted display and an EEG cap on the patient, the EEG signals were analyzed using machine learning methods. An abnormality in the signals, indicating photosensitivity that could trigger a seizure in the epilepsy patient, was identified.
Gosal et al. (51)	6 patients with glioma brain tumors	Research Study	Immersive	Simulating glioma brain tumor surgery in a three-dimensional virtual reality environment	Virtual reality can be used in preoperative simulation for skin incision and craniotomy, virtual reconstruction of cortical surfaces, glioma tumor tracing, venous anatomy of superficial gliomas, and determining the precise location of glioma tumors.
Sprengel et al. (54)	3 patients with arteriovenous malformations	Research Study	Immersive	Simulating embolization in the treatment of cerebral arteriovenous malformations using virtual reality applications	After accessing angiographic images of three patients with arteriovenous malformations and converting them into a 3D model, feeders and a portion of the nidus were created. Blood flow interaction within the cerebral AVMs was visualized, enabling virtual embolization of feeders and analysis of subsequent blood flow changes.
Bernard et al. (56)	Patient with malignant glioma tumor undergoing awake craniotomy	Research Study	Immersive	Investigating the application of virtual reality in awake craniotomy surgeries	After using a virtual reality headset with eye-tracking capability in patients undergoing awake craniotomy, it enabled surgeons to map language and assess the patient's visual field intraoperatively. This will minimize postoperative neurological deficits in the patient.
Zawy Alsofy et al. (57)	116 patients with unruptured anterior cerebral artery aneurysms	Research Study	Non-Immersive	Diagnosing arterial anatomy in patients with unruptured anterior cerebral artery aneurysms using a virtual reality simulator	Patient digital images were converted into 3D virtual reality images, allowing visualization of the lateral skull view, superior view of the aneurysm, relevant vascular anatomy, and the skull base with aneurysm magnification capability. This can aid in selecting the surgical technique, such as pterional, supraorbital, or extended pterional craniotomy.

Stress is considered a psychological disturbance in patients due to seizures caused by epilepsy (40). In this regard, a clinical trial study utilized a 360-degree virtual reality camera to expose individuals to a video of a person experiencing a seizure at home, targeting fear of seizures. Interviews with participants suggested that in the not-too-distant future, virtual reality could potentially be used to reduce seizure-related stress in patients with epilepsy (41).

Motor, sensory, and cognitive disabilities, as well as impaired upper limb motor function, have been reported in individuals who have suffered from stroke (42). Accordingly, in a study, neurophysiotherapy combined with a virtual reality-based program in the rehabilitation of 24 stroke survivors demonstrated a positive effect of adding virtual reality to the rehabilitation process for these patients (43).

A review of the literature indicates the effectiveness of virtual reality technology in the rehabilitation of central nervous system disorders. Based on the conducted studies, it can be concluded that the use of virtual reality technology in improving the neurological function of patients is promising.

Virtual Reality and its Application in the Diagnosis of Neurological Disorders: The Dextroscope is a medical instrument that provides a virtual reality environment for surgeries and can be used in the diagnosis of cerebral aneurysms by focusing on image details. In a study, researchers used the Dextroscope to convert CT angiography images into three-dimensional virtual reality images to observe and measure aneurysms and adjacent blood vessels. The location, size, shape of the aneurysm, and the spatial relationship between the aneurysm and the skull were determined. Twenty-eight aneurysms were identified, of which twenty-five were located in the anterior circulation and three in the posterior circulation (44).

Given the lack of pharmacological treatments for patients with dementia, early diagnosis of this condition is essential for implementing preventive interventions (45). With the development of interactive virtual reality technology, researchers have utilized this technology for cognitive assessment (46). In a study conducted in 2020, virtual reality games were used to assess cognition and diagnose cognitive impairment in older adults (47).

In general, many neurological disorders are associated with cognitive deficits, and this cognitive impairment can progress to dementia. By simulating situations encountered in daily life, virtual reality assesses cognitive abilities such as memory, executive function, cognitive planning, and spatial memory, facilitating the early diagnosis of neurological disorders. For example, head-mounted virtual reality displays can be used to detect reduced stereopsis in patients with Parkinson's disease.

Despite the aforementioned points, this technology has been used to a limited extent in the diagnosis of neurological disorders or the assessment of cognitive ability, even though it offers advantages over other methods (48).

Furthermore, with the development of virtual reality applications, the anatomical structure of the skull and its pathologies can be reconstructed in three dimensions using MRI and CT scan images. This three-dimensional visualization can then be utilized for the diagnosis and better understanding of skull base conditions (49).

Virtual Reality and its Application in Brain Surgery: Training periods for neurosurgery residents are lengthy, and acquiring extensive knowledge to master the anatomy of the central nervous system is essential. Therefore, virtual reality-based applications can be used for training surgical skills, teaching neuroanatomy, and planning surgical procedures (50).

Access to a visualization method beyond the classic two-dimensional display found in books is necessary for neurosurgery residents to master the anatomy of the central nervous system. Furthermore, a three-dimensional display of the brain's anatomical structures is required for surgeons during orientation in surgical procedures (50). For this purpose, in one study, after collecting MRI images from six individuals with glioma tumors, three-dimensional virtual reality images were generated using RadiAnt software (surgical simulation). The cortical surfaces, venous anatomy related to the glioma tumors, and the precise location of the glioma tumors were reconstructed through virtual reality to facilitate maximal tumor resection (51).

Brain surgery is a precise and highly challenging procedure that is technically difficult to perform. Virtual reality technology can be a promising tool for planning related to brain surgery (52). For example, hyperbaric oxygen therapy, open surgery, and embolization are treatment methods for cerebral arteriovenous malformations (53). Ulrike Sprengel et al. implemented an immersive virtual reality program simulating blood flow with millions of particles. In this way, the surgeon can interactively identify occluded or non-occluded arteries that lead to tangles in the brain, analyze changes in blood flow, and make appropriate decisions regarding the type of treatment for intracranial arteriovenous malformations (54).

Glioblastoma multiforme is a type of malignant tumor in the central nervous system. Awake craniotomy

with brain mapping using electrical stimulation is a fundamental method for the safe resection of this tumor and for reducing the likelihood of neurological impairment in motor and language functions in patients after surgery (55). Researchers, utilizing a virtual reality headset along with an eye tracking device during an awake craniotomy on a patient with a glioblastoma tumor, assessed language, visual field, visuospatial cognition, and social cognition. The patient's ability to recognize images displayed through the virtual reality headset and name them during surgery was used to evaluate speech and language ability (56).

Unruptured anterior communicating artery aneurysms are among the most common types of intracranial aneurysms. Clipping and coiling are treatments for this condition, and the choice of each depends on the location and morphology, such as size, angle, and the presence of multiple lobes (Darsaut, T. et al.). Three-dimensional reconstruction of CT images and their display through virtual reality can lead to a better understanding of vascular anatomy and aid in therapeutic planning during surgery (57).

Limitations

This study is a scoping review that examined the evidence surrounding virtual reality in central nervous system disorders without conducting a qualitative assessment of the included studies. Furthermore, access to many relevant English articles was not available, leading to their exclusion from the review. Additionally, no Persian-language studies were found on topics related to the diagnosis of central nervous system disorders and the training of residents using this technology, which are considered limitations of this study.

Recommendations

For any generalization of the results regarding the application of virtual reality in neurological disorders, particularly in the field of patient rehabilitation, it is necessary to examine therapeutic studies with larger sample sizes over longer periods. Playing games on a virtual reality platform is an innovative tool for diagnosing executive function impairments associated with central nervous system disorders; however, further research is recommended before any routine clinical use of this technology in treatment centers. Implementing virtual reality-based applications in the field of neurosurgery resident training involves technical complexities in design, thus requiring engineers to acquire specific technical skills.

Conclusion

Virtual reality represents a novel approach in the rehabilitation of central nervous system disorders and motor function, and extensive clinical research has been published in this area. It appears that the use of this technology in stroke survivors leads to improved motor function, enhanced ability to use limbs, and increased balance. Improved cognitive function following the use of virtual reality after surgical treatments in individuals with traumatic brain injury is clinically valuable. Enhanced cognitive function and motor abilities in patients with multiple sclerosis, increased coordination and improved movement in Parkinson's patients, and better behavioral management in individuals with dementia are among the other clinical benefits of employing this technology. Therefore, based on a number of studies, it seems that this technology can be used as a useful tool for the early detection of cognitive deficits in individuals. Furthermore, this technology serves as a learning module that, by creating three-dimensional models of patients' heads from segmented MRI images, improves residents' conceptual understanding of the complex anatomy of the central nervous system and can be utilized for training residents in neurosurgery. Given the aforementioned points, this tool could be widely used in healthcare centers and hospitals in the future.

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References

1. Gitler A, Dhillon P, Shorter J. Neurodegenerative disease: models, mechanisms, and a new hope. Disease Models & Mechanisms 2017; 10(5): 499-502.
2. Muñoz D, Barria P, Cifuentes CA, Aguilar R, Baleta K, Azorín JM, Múnera M. EEG Evaluation in a Neuropsychological Intervention Program Based on Virtual Reality in Adults with Parkinson's Disease. Biosensors (Basel). 2022; 12(9): 751.
3. Wang Y, Chen R, Yang Z, Wen Q, Cao X, Zhao N, Yan J. Protective Effects of Polysaccharides in Neurodegenerative Diseases. Front Aging Neurosci. 2022; 14: 917629.
4. Vayssiere P, Constanthin P, Herbelin B, Blanke O, Schaller K, et al. Application of virtual reality in neurosurgery: Patient missing. A systematic review. clinical Neuroscience 2022; 95: 55-62
5. Alaraj A, Lemole MG, Finkle JH, Yudkowsky R, Wallace A, Luciano C, Banerjee PP, Rizzi SH, Charbel FT. Virtual reality training in neurosurgery: Review of current status and future applications. Surg Neurol Int. 2011; 2: 52.
6. Lasaponara S, Marson F, Doricchi F, Cavallo M. A Scoping Review of Cognitive Training in Neurodegenerative Diseases via Computerized and Virtual Reality Tools: What We Know So Far. Brain Sci. 2021; 11(5): 528.
7. Monaghesh E, Negahdari R, Samad-Soltani T. Application of virtual reality in dental implants: a systematic review. BMC Oral Health. 2023; 23(1): 603.
8. Venkatesan M, Mohan H, Ryan JR, Schürch CM, Nolan GP, Frakes DH, Coskun AF. Virtual and augmented reality for biomedical applications. Cell Rep Med. 2021; 2(7): 100348.
9. Viñas-Diz S, Sobrido-Prieto M. Realidad virtual con fines terapéuticos en pacientes con ictus: revisión sistemática [Virtual reality for therapeutic purposes in stroke: A systematic review]. Neurologia. 2016; 31(4): 255-77.
10. Calderone A, Carta D, Cardile D, Quartarone A, Rifici C, Calabrò RS, Corallo F. Use of Virtual Reality in Patients with Acquired Brain Injury: A Systematic Review. J Clin Med. 2023; 12(24): 7680.
11. Rodríguez-Mansilla J, Bedmar-Vargas C, Garrido-Ardila EM, Torres-Piles ST, González-Sánchez B, Rodríguez-Domínguez MT, Ramírez-Durán MV, Jiménez-Palomares M. Effects of Virtual Reality in the Rehabilitation of Parkinson's Disease: A Systematic Review. J Clin Med. 2023; 12(15): 4896.
12. Mazurek J, Kiper P, Cieślik B, Rutkowski S. Virtual reality in medicine: A brief overview and future research directions. Human Movement 2019; 20(3): 16-22.
13. Ali SG, Wang X, Li P, Jung Y, Bi L, Kim J, Chen Y, Feng DD, Magnenat Thalmann N, Wang J, Sheng B. A systematic review: Virtual-reality-based techniques for human exercises and health improvement. Front Public Health. 2023; 11: 1143947.
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; 13(2): 36-43.
15. Ching Yeh sh, Chin Chen Yu, Tsai ch, Rizzo A. An innovative virtual reality system for mild cognitive impairment: Diagnosis and evaluation. IEEE-EMBS Conference on Biomedical Engineering and Sciences.2012 Dec 17-19; Langkawi, Malaysia [Abstract].
16. Scribano Parada MDLP, González Palau F, Valladares Rodríguez S, Rincon M, Rico Barroeta MJ, García Rodriguez M, Bueno Aguado Y, Herrero Blanco A, Díaz-López E, Bachiller Mayoral M, Losada Durán R Preclinical Cognitive Markers of Alzheimer Disease and Early Diagnosis Using Virtual Reality and Artificial Intelligence: Literature Review JMIR Med Inform 2024; 13: e62914.
17. Colombo E, Lutters B, Kos T, van Doormaal T. Application of virtual and mixed reality for 3D visualization in intracranial aneurysm surgery planning: a systematic review. Front Surg. 2023; 10: 1227510.
18. Zaed I, Chibbaro S, Ganau M, et al. Simulation and virtual reality in intracranial aneurysms neurosurgical training: a systematic review. Journal of Neurosurgical Sciences. 2022; 66(6): 494-500.
19. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021: 372: n71.
20. Arksey H. Malley O. Scoping studies: Towards a methodological framework,International Journal of Social Research Methodology: Theory and Practice, 8(1): 19-32.
21. Peters MDJ, Godfrey C, McInerney P, Munn Z, Tricco AC, Khalil, H. Scoping Reviews (2020). Aromataris E, Lockwood C, Porritt K, Pilla B, Jordan Z, editors. JBI Manual for Evidence Synthesis. JBI; 2024. Available from: https://synthesismanual.jbi.global.
22. Tefertiller C, Ketchum JM, Bartelt P, Peckham M, Hays K. Feasibility of virtual reality and treadmill training in traumatic brain injury: a randomized controlled pilot trial. Brain Inj. 2022; 36(7): 898-908.
23. Gulcan K, Guclu-Gunduz A, Yasar E, Ar U, Sucullu Karadag Y, Saygili F. The effects of augmented and virtual reality gait

training on balance and gait in patients with Parkinson's disease. Acta Neurol Belg. 2023; 123(5): 1917-25.
24. Pelosin E, Ponte C, Putzolu M, Lagravinese G, Hausdorff JM, Nieuwboer A, Ginis P, Rochester L, Alcock L, Bloem BR, Nieuwhof F, Cereatti A, Della Croce U, Mirelman A, Avanzino L. Motor-Cognitive Treadmill Training With Virtual Reality in Parkinson's Disease: The Effect of Training Duration. Front Aging Neurosci. 2022; 13: 753381.
25. Shen J, Xiang H, Luna J, Grishchenko A, Patterson J, Strouse RV, Roland M, Lundine JP, Koterba CH, Lever K, Groner JI, Huang Y, Lin ED. Virtual Reality-Based Executive Function Rehabilitation System for Children With Traumatic Brain Injury: Design and Usability Study. JMIR Serious Games. 2020; 8(3): e16947.
26. Ebrahimi-Nejad F, Oraee-Yazdani S, Vahedi M, Peyravi Dehsorkhi M, Hosseinzadeh S. Relationship between CT-Scan Findings and Longitudinal Blood Markers with the Occurrence of Death among Comatose Patients Due to Traumatic Brain Injury: Retrospective Longitudinal Study. Advances in Medical and Biomedical Research 2023; 31(147): 330-41
27. De Luca R, Bonanno M, Rifici C, Pollicino P, Caminiti A, Morone G, Calabrò RS. Does Non-Immersive Virtual Reality Improve Attention Processes in Severe Traumatic Brain Injury? Encouraging Data from a Pilot Study. Brain Sci. 2022; 12(9): 1211.
28. Morris NA, Wang Y, Felix RB, Rao A, Arnold S, Khalid M, Armahizer MJ, Murthi SB, Colloca L. Adjunctive virtual reality pain relief after traumatic injury: a proof-of-concept within-person randomized trial. Pain. 2023; 164(9): 2122-9.
29. Shen J, Xiang H, Luna J, Grishchenko A, Patterson J, Strouse RV, Roland M, Lundine JP, Koterba CH, Lever K, Groner JI, Huang Y, Lin ED. Virtual Reality-Based Executive Function Rehabilitation System for Children With Traumatic Brain Injury: Design and Usability Study. JMIR Serious Games. 2020; 8(3): e16947.
30. Zhu K, Zhang Q, He B, Huang M, Lin R, Li H. Immersive Virtual Reality-Based Cognitive Intervention for the Improvement of Cognitive Function, Depression, and Perceived Stress in Older Adults With Mild Cognitive Impairment and Mild Dementia: Pilot Pre-Post Study. JMIR Serious Games. 2022; 10(1): e32117.
31. De Luca R, Marra A, Pollicino P, Buda M, Mucari M, Bonanno M, Torregrossa W, Caminiti A, Rifici C, Calabrò RS. Advances in neuroRehabilitation of TREM2-related dementia: A case report on a novel multimodal approach using virtual reality. Medicine (Baltimore). 2022; 101(21): e29470.
32. De Luca R, Naro A, Colucci PV, Pranio F, Tardiolo G, et al. Improvement of brain functional connectivity in autism spectrum disorders: an exploratory study on the potential use of virtual reality.Neural Transmission. J Neural Transm (Vienna) 2021; 128(3): 371-80.
33. Zhao J, Zhang X, Lu Y, Wu X, Zhou F, Yang S, Wang L, Wu X, Fei F. Virtual reality technology enhances the cognitive and social communication of children with autism spectrum disorder. Front Public Health. 2022; 10: 1029392.
34. De Luca R, Leonardi S, Portaro S, Le Cause M, De Domenico C, Colucci PV, Pranio F, Bramanti P, Calabrò RS. Innovative use of virtual reality in autism spectrum disorder: A case-study. Appl Neuropsychol Child. 2021; 10(1): 90-100.
35. Campo-Prieto P, Cancela-Carral J, Rodríguez-Fuentes G. Immersive virtual reality to improve functional capacities in people with multiple sclerosis: study protocol. Sclerosis 2023; 1(2): 68-75.
36. Molhemi F, Monjezi S, Mehravar M, Shaterzadeh-Yazdi M, Salehi R, et al. Effects of Virtual Reality vs Conventional Balance Training on Balance and Falls in People with Multiple Sclerosis: A Randomized Controlled Trial. Arch Phys Med Rehabil 2021; 102(2): 290-9.
37. Ranjbar Z, Molanorouzi K, Arab Ameri E, Shojaei M, Daneshfar A. The Effect of Physical Activity and Virtual Reality on Functional Balance in Spastic Hemiplegic Cerebral Palsy. Motor Behavior 2024; 16(57): 17-36. [In Persian].
38. Movahedi Y, Pakzad S. The Effect of Video Games Virtual Reality Environment on Motor Function of Children with Cerebral Palsy. Community Health journal 2020; 14(1): 1-10.
39. Taheri S, Parvinpour S, Balali M. The effect of eight weeks of virtual reality-based physical training on kinematic indicators of gait, muscle strength, and balance in women with Multiple Sclerosis. Advances in Cognitive Sciences 2022; 24(3): 1-16
40. Lin RC, Chiang SL, Heitkemper MM, Weng SM, Lin CF, Yang FC, Lin CH. Effectiveness of Early Rehabilitation Combined With Virtual Reality Training on Muscle Strength, Mood State, and Functional Status in Patients With Acute Stroke: A Randomized Controlled Trial. Worldviews Evid Based Nurs. 2020; 17(2): 158-67.
41. Mannan FA, Porffy LA, Joyce DW, Shergill SS, Celiktutan O. Automatic Detection of Cognitive Impairment with Virtual Reality. Sensors (Basel). 2023; 23(2): 1026.
42. Yun Hsu H, Kuo L, Ching Lin Y, Chin Su F, Hua Yang T, et al. Effects of a Virtual Reality-Based Mirror Therapy Program on Improving Sensorimotor Function of Hands in Chronic Stroke Patients: A Randomized Controlled Trial. Neurorehabil Neural Repair 2022; 36(6): 335-45.
43. Peláez-Vélez FJ, Eckert M, Gacto-Sánchez M, Martínez-Carrasco Á. Use of Virtual Reality and Videogames in the Physiotherapy Treatment of Stroke Patients: A Pilot Randomized Controlled Trial. Int J Environ Res Public Health. 2023; 20(6): 4747.
44. Mo DP, Bao SD, Li L, Yi ZQ, Zhang JY, Zhang Y. Virtual reality system for diagnosis and therapeutic planning of cerebral aneurysms. Chin Med J (Engl). 2010; 123(16): 2206-10.
45. Fabbri L, Mosca IE, Gerli F, Martini L, Pancani S, Lucidi G, Savazzi F, Baglio F, Vannetti F, Macchi C. Goal working group the games for older adults active life (GOAL) project for people with mild cognitive impairment and vascular cognitive impairment: A study protocol for a randomized controlled trial. Front. Neurol 2019; 9: 1040.
46. Realdon O, Serino S, Savazzi F, Rossetto F, Cipresso P, Parsons TD, Cappellini G, Mantovani F, Mendozzi L, Nemni R, et al. An ecological measure to screen executive functioning in MS: The Picture interpretation test (PIT) 360 degrees. Sci. Rep 2019;

9: 1-8.
47. Cabinio M, Rossetto F, Isernia S, Saibene FL, Di Cesare M, Borgnis F, Pazzi S, Migliazza T, Alberoni M, Blasi V, Baglio F. The Use of a Virtual Reality Platform for the Assessment of the Memory Decline and the Hippocampal Neural Injury in Subjects with Mild Cognitive Impairment: The Validity of Smart Aging Serious Game (SASG). J Clin Med. 2020; 9(5): 1355
48. Hyuk-June Moon, Sungmin Han (2022). Perspective: Present and Future of Virtual Reality for Neurological Disorders Brain Sci. 2022; 12(12): 1692.
49. Ferroli P, Tringali G, Acerbi F, Schiariti M, Broggi M, Aquino D, Broggi G. Advanced 3-dimensional planning in neurosurgery. Neurosurgery. 2013; 72 Suppl 1: 54-62.
50. Vayssiere P, Constanthin PE, Herbelin B, Blanke O, Schaller K, Bijlenga P. Application of virtual reality in neurosurgery: Patient missing. A systematic review. J Clin Neurosci. 2022; 95: 55-62.
51. Gosal JS, Tiwari S, Sharma T, Agrawal M, Garg M, Mahal S, Bhaskar S, Sharma RK, Janu V, Jha DK. Simulation of surgery for supratentorial gliomas in virtual reality using a 3D volume rendering technique: a poor man's neuronavigation. Neurosurg Focus. 2021; 51(2): E23.
52. Shao X, Yuan Q, Qian D, et al. Virtual reality technology for teaching neurosurgery of skull base tumor. BMC Med Educ 20, 3(2020).
53. Hajikarimloo B, Kavousi S, Jahromi GG, Mehmandoost M, Oraee-Yazdani S, Fahim F. Hyperbaric Oxygen Therapy as an Alternative Therapeutic Option for Radiation-Induced Necrosis Following Radiotherapy for Intracranial Pathologies. World Neurosurg. 2024; 186: 51-61.
54. Sprengel U, Saalfeld P, Stahl J, Mittenentzwei S, Drittel M, Behrendt B, Kaneko N, Behme D, Berg P, Preim B, Saalfeld S. Virtual embolization for treatment support of intracranial AVMs using an interactive desktop and VR application. Int J Comput Assist Radiol Surg. 2021; 16(12): 2119-27.
55. Hajikarimloo B, Fahim F, Sabbagh Alvani M, Oveisi S, Zali A, Anvari H, Oraee-Yazdani S. Management of Glioblastoma Multiforme During the Severe Acute Respiratory Syndrome Coronavirus 2 Pandemic: A Review of the Literature. World Neurosurg. 2023; 178: 87-92.
56. Bernard F, Clavreul A, Casanova M, Besnard J, Lemée JM, Soulard G, Séguier R, Menei P. Virtual Reality-Assisted Awake Craniotomy: A Retrospective Study. Cancers (Basel). 2023; 15(3): 949.
57. Zawy Alsofy S, Sakellaropoulou I, Nakamura M, Ewelt C, Salma A, Lewitz M, Welzel Saravia H, Sarkis HM, Fortmann T, Stroop R. Impact of Virtual Reality in Arterial Anatomy Detection and Surgical Planning in Patients with Unruptured Anterior Communicating Artery Aneurysms. Brain Sci. 2020; 10(12): 963.
58. Grazia Maggio M, Stagnitti M, Rizzo E, Andaloro A, Manuli A, et al. Limb apraxia in individuals with multiple sclerosis: is there a role of semi-immersive virtual reality in treating the Cinderella of neuropsychology? Multiple Sclerosis and Related Disorders 2023; 69: 104405.
59. Gabrielle Gray H, Tchao D, Lewis-Fung S, Pardini S, Harris LR, et al. Virtual Reality therapy for people with Epilepsy and related anxiety: protocol for a 3-phase pilot clinical trial. JMIR research protocols 2023; 12(1): e41523.
60. Moncada Martins F, Martín S, González V, Alvarez V. Virtual reality and machine learning in the automatic photoparoxysmal response detection. Neural Computing and Applications 2023; 35(8): 5659-5843.