

Effects of Hyperbaric Oxygen Combined Rehabilitation Therapy on Patients with Stroke: A-Ten-Year Systematic Review

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Abstract: Hyperbaric oxygen therapy (HBOT) shows promise in stroke rehabilitation. This review explores the impact of combining HBOT with other treatments on functional recovery. A comprehensive search was conducted in CNKI, Wanfang, PubMed and Web of Science up to January 1, 2026. After screening, 1867 patients from 18 studies were included. Common HBOT combinations were with exercise therapy (42.1%), magnetic stimulation (15.7%), and intelligent rehabilitation training (10.5%). The mean age was 55.02 years in the HBOT group (male-to-female ratio:1.43) and 55.86 years in the control group (ratio:1.24). The most used assessment scales were the Fugl-Meyer Assessment (78.9%), the Modified Barthel Index (63.2%), and the NIHSS Stroke Scale (36.8%). Compared to the control group, combined HBOT showed significant benefits in neurological and motor function, cognitive ability, and daily living activities. Future research should integrate hyperbaric oxygen therapy with other treatment modalities to more comprehensively evaluate its efficacy. Attention should also be paid to the safety and feasibility of the therapy, assessing the impact of different treatment protocols on patient health, particularly in terms of side effects and long-term dependency. Furthermore, more multicenter, large-sample clinical trials should be conducted, and the integration with intelligent rehabilitation technology should be explored to further enhance therapeutic outcomes.

Keywords: stroke, hyperbaric oxygen therapy, combination therapy

1. Introduction

Hyperbaric oxygen therapy (HBOT) has been recognized as a potential treatment for stroke [1]. This therapy involves placing patients in a hyperbaric oxygen chamber at pressures exceeding one standard atmosphere, where they inhale pure oxygen, thereby eliciting a range of mechanical and physiological effects in the body. From the late 19th to early 20th century, the rise of diving operations and underwater engineering led to an increased incidence of decompression sickness among divers due to rapid ascent. During this period, the medical community gradually discovered that exposure to a hyperbaric oxygen environment could accelerate the elimination of dissolved nitrogen from the body, effectively alleviating the clinical symptoms of decompression sickness [2].

Currently, HBOT has been applied across multiple medical disciplines. Evidence suggests that it may improve cognitive function, alleviate depressive symptoms, enhance the recovery of motor function, and aid in the treatment of conditions such as COVID-19 [3] and carbon monoxide poisoning. Nevertheless, the efficacy of HBOT in stroke treatment remains a subject of debate. Some clinical trials have reported beneficial effects of HBOT in patients with ischemic stroke [4], whereas others have found no significant improvement or even worse outcomes. One possible explanation for these discrepancies is the increased fatigue experienced by patients during HBOT sessions [5].

To address the discrepancy between the two clinical trials, the medical community has actively explored various combination therapies. The efficacy of combined acupuncture and HBOT therapy in the treatment and rehabilitation of stroke has been clinically validated [6]. Multiple randomized controlled trials have investigated HBOT-based combination therapies for stroke; however, the results remain inconsistent. This review aims to summarize research findings on HBOT combined with other therapies for treatment of stroke over the past decade, assess the current state of research, and explore potential directions for future studies.

Stroke is a cerebrovascular disease categorized into ischemic and hemorrhagic types. It can cause interruption or abnormalities in the brain's blood supply, leading to localized brain dysfunction and

significant neurological deficits. Stroke ranks among the primary causes of disability worldwide^[7]. The American Heart Association (AHA) reports that as the population ages and risk factors such as chronic diseases increase, the incidence of stroke is also rising year by year. Common sequelae of stroke include motor dysfunction, sensory impairment, and emotional or psychological disorders^[8]. The impact of stroke extends beyond the patient to encompass families, caregivers, and society as a whole. The disability status and long-term care needs of stroke survivors subject their families to multiple pressures—emotional, financial, and related to daily caregiving^[9, 10]. Therefore, actively seeking highly effective treatments for stroke is an urgent priority.

2. Method

2.1 Data Source, Search Strategy

This review follows the PRISMA guidelines for writing^[11]. Articles published between 2016 and 2026 were retrieved by searching multiple databases including China National Knowledge Infrastructure (CNKI), Wanfang Data, PubMed and Web of Science. Reference lists of included studies were manually searched to identify additional references.

PubMed was searched using the following search terms:

("Hyperbaric Oxygenation"[MeSH Terms] OR "hyperbaric oxygen therapy"[All Fields] OR "hyperbaric oxygen"[All Fields] OR HBOT[All Fields])

AND

("Stroke"[MeSH Terms] OR "stroke"[All Fields] OR "cerebrovascular accident"[All Fields] OR "cerebral infarction"[All Fields] OR "ischemic stroke"[All Fields] OR "haemorrhagic stroke"[All Fields])

AND

("Rehabilitation"[MeSH Terms] OR "Rehabilitation Therapy"[MeSH Terms] OR "rehabilitation"[All Fields] OR "physical therapy"[All Fields] OR "physiotherapy"[All Fields] OR "occupational therapy"[All Fields] OR "neurorehabilitation"[All Fields])

Web of Science was searched using the following search terms:

TS = ("hyperbaric oxygen therapy" OR "hyperbaric oxygenation" OR "hyperbaric oxygen" OR HBOT)

AND

TS = (stroke OR strokes OR "cerebrovascular accident" OR "cerebral infarction" OR "ischemic stroke" OR "haemorrhagic stroke")

AND

TS = (rehabilitation OR "rehabilitation therapy" OR "physical therapy" OR physiotherapy OR "occupational therapy" OR neurorehabilitation)

China National Knowledge Infrastructure (CNKI) and Wanfang Data was searched using Chinese keywords related to hyperbaric oxygen therapy, stroke, and rehabilitation.

2.2 Study Selection and Eligibility Criteria

Through systematic retrieval of multiple Chinese and English databases, a total of 825 relevant literature sources were identified. Following the search, duplicate entries were first removed, eliminating 276 redundant documents. Subsequently, automated tools were employed for preliminary screening, excluding 544 documents that failed to meet predetermined criteria such as publication year. An additional 5 documents, including conference abstracts and other non-compliant materials, were further excluded. Following the above procedures, a total of 73 documents advanced to the title and abstract screening phase. Subsequently, 37 documents unrelated to the research topic were excluded after reviewing the titles and abstracts. Thereafter, the full texts of the 26 documents meeting the initial screening criteria were evaluated to determine their compliance with the inclusion and exclusion criteria.

Inclusion Criteria:

- 1) All included literatures are from database
- 2) Study design was randomized controlled trials (RCTs) with treatment regimens combining hyperbaric oxygen therapy with various rehabilitation modalities.
- 3) Study subjects were patients diagnosed with stroke, including ischemic stroke (acute and chronic phases) and hemorrhagic stroke.
- 4) Studies must have included any quantitative or standardized clinical assessment scales (e.g.,

evaluations of neurological function, motor recovery, cognitive abilities, etc.).

5) Research methodology is clearly defined, with sufficient data provided for both control and treatment groups.

Exclusion Criteria:

- 1) Articles published before January 1, 2015
- 2) Non-clinical intervention studies, such as animal experiments, literature reviews, systematic reviews, meta-analyses, case reports, experience summaries, parameter studies, prospective or retrospective clinical observations, commentaries, letters, and conference reports.
- 3) Studies involving subjects other than stroke patients, such as patients with other neurological disorders or healthy individuals.
- 4) Studies using hyperbaric oxygen therapy as the sole treatment or non-combination therapy regimens.
- 5) The treatment methods include acupuncture therapy.
- 6) Studies in which both the control group and the experimental group are exposed to hyperbaric oxygen therapy.

During the full-text evaluation process, 2 studies were excluded due to the unavailability of full-text access, and 6 studies were excluded because both the experimental and control groups received hyperbaric oxygen therapy. Ultimately, 18 studies were included in this review. The review process is summarized in Figure 1. The search results for the systematic literature review are presented in the discussion section.

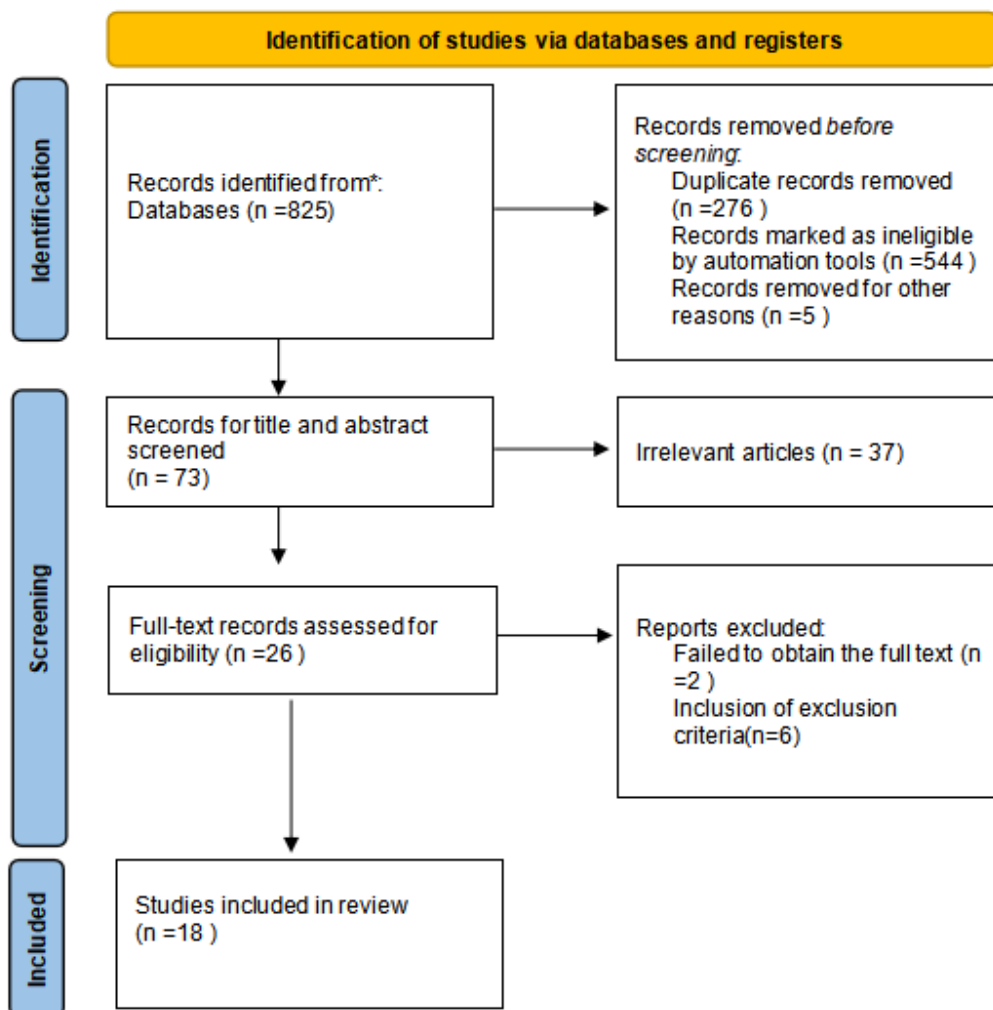


Figure 1. Flowchart of Study Selection Process for Systematic Review.

3. Results and Discussion

3.1 HBOT Combined with Magnetic Stimulation

Hyperbaric oxygen therapy combined with magnetic stimulation has been widely applied in recent years to promote neural repair and functional recovery in patients. Magnetic stimulation represents a novel non-invasive neuromodulation technique that utilizes time-varying magnetic fields to induce induced currents within the body. This approach painlessly and non-invasively stimulates specific brain regions or neural pathways, directly modulating neuronal excitability. Currently, the primary combined therapeutic modalities in clinical practice include repetitive transcranial magnetic stimulation (rTMS) and repetitive peripheral magnetic stimulation (rPMS).

3.1.1 HBOT Combined with rTMS

Repetitive Transcranial Magnetic Stimulation (rTMS) is a noninvasive, painless neuromodulation technique that uses pulsed magnetic fields to stimulate specific functional regions of the cerebral cortex. Its mechanism of action involves placing a coil on the scalp to generate rapidly changing magnetic fields, which induce induced currents in the cerebral cortex. This causes depolarization or hyperpolarization of target neurons, thereby modulating cortical excitability. The study by Lü Mingxin et al. utilized 10Hz high-frequency rTMS combined with hyperbaric oxygen therapy to assess the effects of this combination on cognitive function (MoCA, LOTCA), brain metabolites (NAA/Cr, Cho/Cr), and clinical overall efficacy in stroke patients^[12]. The results indicated that the combined treatment group significantly outperformed the groups receiving only hyperbaric oxygen or basic treatment in all of the aforementioned measures^[12].

3.1.2 HBOT Combined with rPMS

Repetitive Peripheral Magnetic Stimulation (rPMS) is a safe, non-invasive neuromodulation technique. It can target deeper neural and muscular tissues, effectively inducing neural plasticity changes, thereby promoting improvements in patients' motor and daily living activity abilities. Due to its painless nature and high comfort level, this therapy has good clinical acceptability. The study by Sun Tengfang et al. combined repetitive peripheral magnetic stimulation (rPMS) with hyperbaric oxygen therapy to evaluate the effects of this combination on motor function (ankle dorsiflexion range of motion) and gait stability (Berg Balance Scale scores) in stroke patients^[13]. The study found that the combined treatment group significantly outperformed the single treatment groups in terms of gait, balance ability, and the proportion of weight-bearing on the affected side^[13].

These two studies hold significant complementary value. They each focus on different aspects, namely "cognitive function of the brain" and "motor function of the limbs," and together provide evidence for the superiority of hyperbaric oxygen combined with magnetic stimulation treatment. However, both studies suffer from a lack of representative sample sizes and the absence of long-term efficacy follow-up. Future research should focus on multi-center, large-sample longitudinal studies, and explore personalized parameters such as stimulation frequency and treatment duration to promote the development of this combined therapy into a more mature and optimized clinical application phase. Table 1 shows the effects of HBOT combined with magnetic stimulation on stroke patients.

Table 1. Effect of HBOT combined with magnetic stimulation on stroke

Author	Sample	Treatment	Outcome Measures	Conclusion
Sun et al.	96	Control: Conventional rehabilitation training; rPMS group: Conventional rehabilitation + rPMS; Combined group: Conventional rehabilitation + rPMS + HBOT	Affected side plantar load-bearing ratio, BBS, Active ankle dorsiflexion ROM of the affected side, iEMG of tibialis anterior and gastrocnemius muscles	More significant improvement in combined group
Lv et al.	138	Combined: 10Hz high-frequency rTMS + HBOT + Basic treatment; HBOT group: HBOT + Basic treatment; Control: Basic treatment	MoCA, LOTCA, RBMT, a, Brain metabolites (NAA/Cr, Cho/Cr), Total clinical effective rate	More significant improvement in combined group

ROM: Range of Motion, BBS: Berg Balance Scale, iEMG: Integrated Electromyography, MoCA: Montreal Cognitive Assessment, LOTCA: Loewenstein Occupational Therapy Cognitive Assessment, RBMT: Rivermead Behavioural Memory Test, NAA/Cr:N-acetylaspartate to Creatine Ratio, Cho/Cr:Choline to Creatine Ratio

3.2 HBOT Combined with functional exercise training

Hyperbaric oxygen combined with task-oriented training has become an increasingly recognized treatment approach in the field of stroke rehabilitation in recent years. By integrating the oxygenation effects of hyperbaric oxygen with various exercise training methods, this therapy aims to promote comprehensive improvements in stroke patients' motor function, cognitive abilities, and overall quality of life. This review summarizes eight studies that explore the effects of different exercise training methods combined with hyperbaric oxygen therapy.

3.2.1 HBOT combined with dual task training

Dual task training is a rehabilitation method that requires patients to perform both cognitive and motor tasks simultaneously. Yang Hua's study found that dual-task training combined with hyperbaric oxygen therapy significantly improved patients' motor function (UL-FMA, FMA-L), cognitive function (MMSE, MoCA), and activities of daily living (MBI) compared to dual-task training alone^[14]. Yang Hua believes that this therapy increases oxygen supply to brain cells, alleviates local brain hypoxia and ischemia, and improves oxidative stress in brain cells, thereby promoting self-repair of neural functions^[14]. As a result, it works synergistically with dual-task training to significantly enhance patient recovery^[14]. However, the study did not include long-term follow-up, and it was a single-center study. Future research could consider multi-center studies to further validate the effectiveness of this approach^[14].

3.2.2 HBOT Combined with roller operation training

Roller operation training is a repetitive exercise training method aimed at improving the coordination of the upper and lower limbs. Shen Xinyi's study combined roller task training with hyperbaric oxygen therapy, demonstrating significant improvements in motor function (FMA, MSS, BBS), gait, and activities of daily living (BI)^[15]. The study also observed the patients' gait after two months of treatment and found that, compared to before treatment, both groups showed increased step frequency, step length, affected side step length, and gait cycle. Moreover, the observed group had significantly better results than the control group ($P < 0.05$)^[15]. The reason for this improvement is that gait abnormalities in hemiplegic stroke patients are primarily caused by neurological damage. Hyperbaric oxygen therapy promotes angiogenesis, improves cerebral blood flow, and provides a foundation for neural repair. Roller training, on the other hand, helps optimize motor control. The combination of these two therapies works synergistically at different levels to promote functional recovery and improve gait.

3.2.3 HBOT combined with mirror neuron rehabilitation training

Mirror neuron training helps patients "imitate" the movements of the unaffected side through visual feedback, activating the motor areas in the brain, while hyperbaric oxygen increases brain oxygen supply, promoting nerve repair and neuroplasticity. Li Hui's research shows that the combination of mirror neuron rehabilitation training and hyperbaric oxygen therapy can significantly improve patients' motor function and levels of neurotrophic factors (BDNF, NGF)^[16].

3.2.4 HBOT combined with restraint-induced exercise therapy

Restraint-induced exercise therapy works by restricting the unaffected limb, forcing the patient to use the affected limb for functional training. Guo Yuna's study found that constraint-induced movement therapy combined with hyperbaric oxygen therapy significantly improved patients' motor function (FMA), cognitive function (MMSE), gait stability, and levels of nerve growth factor^[17]. The study focused on middle-aged and young stroke hemiplegic patients; however, the sample size was relatively limited, and the observation period was short. Future research should extend the rehabilitation intervention period in a broader population to conduct more in-depth and systematic exploration.

3.2.5 HBOT combined with trunk control training

Trunk control training aims to enhance motor function by improving trunk stability in patients. Guo Zhenghui's study compared the effects of early simultaneous intervention with delayed intervention, showing that the treatment combining hyperbaric oxygen therapy with trunk control training had significantly better outcomes than the delayed intervention group^[18]. When combined with hyperbaric oxygen therapy, this approach effectively promotes neural function recovery, especially for ischemic stroke patients, yielding more prominent rehabilitation effects. The study emphasizes the importance of early intervention in stroke rehabilitation, particularly in enhancing patients' motor function and gait stability.

3.2.6 HBOT combined with muscle energy technology

Muscle energy technique primarily works by stretching the myofascial tissues, enhancing muscle strength, and increasing the range of joint motion to correct rigid abnormal movement patterns. When

combined with hyperbaric oxygen therapy, it helps oxygen pass through the blood-brain barrier, reducing hypoxic damage to brain tissue, thereby creating more favorable physiological conditions for the patient's functional recovery. Liu Haoyi's study explored the effects of combined muscle energy technique and hyperbaric oxygen therapy. The study found that this combined treatment significantly improved patients' upper limb motor function (FMA), activities of daily living (MBI), and muscle strength^[19].

3.2.7 HBOT combined with constraint-induced movement therapy

Constraint-induced movement therapy is a method that involves forcing the use of the affected limb for functional training. Fan Liubo et al. divided 69 patients into three groups to compare the effects of CIMT alone, HBOT alone, and their combination^[20]. The evaluation indicators included muscle tone, neurological function, motor ability, balance ability, and activities of daily living. The results confirmed that the combined treatment approach was the most effective^[20].

3.2.8 HBOT combined with early precision exercise rehabilitation

Precision exercise rehabilitation targets specific functional training, such as limb control and balance coordination, to directly stimulate neural remodeling and cortical reorganization, thereby activating the compensatory ability of unaffected brain regions and promoting motor function recovery. Zheng Hebin et al. explored the effects of early precision exercise rehabilitation combined with hyperbaric oxygen therapy. The results showed that the combined treatment group had significantly better recovery in neurological function (FMA, NIHSS) and cognitive function (MMSE) compared to the exercise rehabilitation-only group^[21]. The combination of precision exercise rehabilitation and hyperbaric oxygen therapy can more accurately address the specific needs of patients, promoting the recovery of both neural and motor functions, with particularly remarkable rehabilitation effects in patients with acute ischemic stroke.

In conclusion, the combination of hyperbaric oxygen therapy and exercise training has shown significant effects in the rehabilitation of stroke patients. The integration of different exercise training methods with hyperbaric oxygen not only significantly improves patients' motor function and cognitive abilities, but also enhances their activities of daily living and overall quality of life. However, most studies have limitations such as small sample sizes and lack of long-term follow-up data. To further validate the effectiveness of this treatment method, future research should focus on expanding the sample size, conducting multi-center studies, and carrying out long-term follow-up evaluations to obtain more comprehensive and reliable conclusions. Additionally, exploring the optimal parameters for combining different exercise training methods with hyperbaric oxygen therapy will further optimize clinical treatment protocols. Table 2 summarizes the effects of various functional training programs combined with hyperbaric oxygen therapy on stroke patients.

Table 2. Effect of HBOT Combined with Functional Exercise Training on stroke

Author	Sample	Treatment	Outcome Measures	Conclusion
Yang et al.	198	Combined group: Dual-task training + HBOT; Control: Dual-task training	FMA,MMSE, MoCA,MBI SS-QOL	More significant improvement in combined group
Sheng et al.	116	Observation: Cylinder task training + HBOT; Control: Cylinder task training	NIHSS,BI,FMA,MSS, BBS, 10m MWS, cadence,step length, stride length, gait cycle, double support phase	More significant improvement in observation group
Li et al.	118	Research: HBOT + Mirror neuron rehabilitation training + Conventional treatment; Control: Mirror neuron rehabilitation training + Conventional treatment	Clinical efficacy, Serum BDNF/NGF, Hemorheology indicators, FMA-UE/L, Gait parameters	More significant improvement in research group
Guo et al.	108	Combined: HBOT + CIMT + Conventional treatment; HBOT group: HBOT + Conventional treatment; Movement group: CIMT + Conventional treatment	MMSE, BI, FMA, iEMG, Serum BDNF/NGF, SEP (P40/N20 latency & amplitude), Gait stability	More significant improvement in combined group
Guo et al.	116	Observation: HBOT + Trunk control training;	MMSE, NIHSS, BBS, Sheikh score, FMA, FIM, Serum	More significant improvement in

		Control: HBOT for 4 weeks, followed by trunk control training for 4 weeks	nerve growth factor, Neuron-specific enolase, Myelin basic protein	observation group
Liu et al.	80	Observation: Conventional rehabilitation + Muscle energy technique + HBOT; Control: Conventional rehabilitation	Clinical efficacy, Upper limb FMA, MBI, MAS, Upper limb muscle SWE value, Serum GABA/glutamate, Vs, Vm, RI	More significant improvement in observation group
Fan et al.	69	CIMT group: CIMT; HBO group: HBOT; CIMT+HBO group: CIMT combined with HBOT	MAS, Neurological deficit score, FMA, BBS, BI	More significant improvement in combined group
Zheng et al.	76	Combined therapy group: Early precise motor rehabilitation + HBOT; Motor rehabilitation group: Early precise motor rehabilitation	NIHSS, FMA, MMSE, Clinical efficacy	More significant improvement in motor rehabilitation group

FMA: Fugl-Meyer Assessment, MMSE: Mini-Mental State Examination, MBI: Modified Barthel Index, SS-QOL: Stroke-Specific Quality of Life Scale, NIHSS: National Institutes of Health Stroke Scale, BI: Barthel Index, MSS: Motor Status Score, 10m WWS: 10-Meter Maximal Walking Speed, BDNF: Brain-Derived Neurotrophic Factor, NGF: Nerve Growth Factor, FMA-UE/L: Fugl-Meyer Assessment for Upper Extremity / Lower extremity, SEP: Somatosensory Evoked Potential, CIMT: Constraint-induced movement therapy, Sheikh: Sheikh Trunk Control Test, FIM: Functional Independence Measure, MAS: Modified Ashworth Scale, SWE: Shear Wave Elastography, Vs: Systolic Peak Velocity, Vm: Mean Velocity, RI: Resistive Index

3.3 HBOT combined with Cognitive Training

A study by Zhong Yufei et al. compared the therapeutic effects of conventional rehabilitation therapy, conventional rehabilitation combined with hyperbaric oxygen therapy, and conventional rehabilitation combined with hyperbaric oxygen therapy plus cognitive training^[22]. The results indicated that the hyperbaric oxygen therapy combined with cognitive training group demonstrated significantly superior improvements in cognitive function compared to both the hyperbaric oxygen therapy alone group and the control group^[22]. Cognitive training effectively enhances cognitive abilities such as attention, memory, and executive function. When supplemented with hyperbaric oxygen therapy, it significantly amplifies therapeutic outcomes. This synergistic effect stems from neural plasticity: hyperbaric oxygen improves cerebral oxygenation, promoting neural repair and plasticity, thereby creating an optimal brain environment for cognitive training. Concurrently, cognitive training reinforces neural pathways and facilitates the formation of new neural connections, accelerating the rehabilitation process. Table 3 shows the effects of hyperbaric oxygen therapy combined with cognitive training on the rehabilitation of stroke patients.

Table 3. Effect of HBOT Combined with Cognitive Training on stroke

Author	Sample	Treatment	Outcome Measures	Conclusion
Zhong et al.	90	Control group: Conventional rehabilitation; HBOT group: Conventional rehabilitation+HBOT Combined therapy group: Conventional:rehabilitation+HBOT+ Cognitive training	MMSE, MoCA	More significant improvement in research group

3.4 HBOT combined with Psychological Intervention

Post-stroke depression (PSD) is a common complication in stroke patients. Sun Hongmin's research compared the effects of oral paroxetine and hyperbaric oxygen therapy combined with psychological intervention in the treatment of post-stroke depression^[23]. The results showed that the group receiving hyperbaric oxygen combined with psychological intervention significantly outperformed the pure medication therapy group in several evaluation indicators, and the combined treatment group demonstrated better therapeutic effects and safety^[23]. Additionally, the study found that the combined treatment group had a higher total effectiveness rate and improved daily living activities^[23]. Compared to the pure medication therapy group, hyperbaric oxygen therapy combined with psychological intervention

not only enhanced the therapeutic effect but also avoided the potential side effects associated with single drug therapy. Particularly when compared to oral paroxetine treatment, the combined therapy's safety was more prominent, minimizing adverse drug reactions and enhancing the sustainability of the treatment. Therefore, this combined therapy can not only improve the patient's emotional symptoms and cognitive function but also promote the recovery of the patient's quality of life, which is especially important for those patients who are unable to undergo other rehabilitation treatments due to depression. Table 4 shows the effects of HBOT combined with psychological intervention on post-stroke depression.

Table 4. Effect of HBOT Combined with Psychological Intervention on stroke

Author	Sample	Treatment	Outcome Measures	Conclusion
Sun et al.	136	Control: Oral paroxetine; Observation: HBOT+Psychological intervention	HAMD, MMSE, MESSS, MBI, Total effective rate	The Observation group was significantly effective and safe.

HAMD: Hamilton Depression Rating Scale, MESSS: Modified Edinburgh-Scandinavian Stroke Scale

3.5 HBOT combined with comprehensive rehabilitation

Over the past decade, multiple studies have examined the efficacy of hyperbaric oxygen therapy combined with comprehensive rehabilitation training for stroke patients, covering aspects such as neurological recovery, muscle strength improvement, cognitive function enhancement, and emotional relief. This systematic review analyzes relevant research findings to summarize the application outcomes of hyperbaric oxygen therapy combined with comprehensive rehabilitation training in stroke patient recovery.

3.5.1 Functional Recovery and Improvement in neurological and motor functions

The combination of HBOT and rehabilitation treatment shows significant advantages in promoting the recovery of neurological and motor functions in stroke patients. In terms of neurological function, the combined treatment is more effective in reducing neurological deficit scores. Chen Yanli's study demonstrated that the experimental group had significantly lower neurological deficit scores after treatment compared to the control group ($P < 0.00$)^[24]. Li Dan et al. further confirmed that the combined treatment group showed a significantly greater reduction in NIHSS scores and improvement in Fugl-Meyer scores than the control group ($P < 0.05$)^[25]. Regarding motor function, the combined treatment clearly enhanced muscle strength. Tursungul Abdurahman et al. found that the combined treatment group had significantly better muscle strength in hip extension and knee extension compared to the control group^[26]. Studies by Li Dan et al. and Guan Xiaobo et al. both reported more significant improvements in Lovett muscle strength grading in the combined treatment group ($P < 0.05$)^{[25][27]}. Additionally, the Barthel index, which reflects activities of daily living, also showed a more positive trend of improvement in the combined treatment group.

3.5.2 Improvement in Emotional and Psychological State

Post-stroke depression and anxiety are important complications that affect the rehabilitation process and quality of life. Studies consistently show that hyperbaric oxygen combined with rehabilitation therapy can effectively alleviate patients' negative emotions. Research by Guan Xiaobo and colleagues indicates that the combined treatment group showed significant reductions in both the Health Questionnaire-9 (PHQ-9) and Generalized Anxiety Disorder-7 (GAD-7) scores^[27]. Furthermore, improvements in depressive symptoms were significantly negatively correlated with the recovery of upper and lower limb muscle strength, while improvements in anxiety symptoms were also negatively correlated with enhanced daily living activity capacity ($P < 0.05$). This suggests that there is a synergistic relationship where emotional improvement and physical function recovery mutually promote each other.

3.5.3 Improvements in Hemorheology and Physiological Biochemical Indicators

Combined treatment also demonstrates positive effects on multiple physiological indicators across various systems. In terms of blood rheology, a study by Guan Xiaobo and colleagues found that the combined treatment significantly reduced whole blood viscosity and plasma viscosity ($P < 0.01$), helping to improve cerebral microcirculation^[27]. Regarding neuroprotection and repair-related factors, research by Tursungul Abdurahman and colleagues showed that the serum levels of brain-derived neurotrophic factor (BDNF) in the combined treatment group were significantly higher than those in the control group on both the 7th and 15th days after treatment^[26]. This factor plays a key role in neuronal survival, differentiation, and synaptic plasticity. In terms of oxidative stress regulation, research by Li Dan and colleagues indicated that the combined treatment significantly reduced serum reactive oxygen species (ROS) levels while enhancing the activities of catalase and superoxide dismutase. This suggests that the treatment can effectively alleviate oxidative damage, providing a more favorable cellular environment

for nerve repair^[25].

The comprehensive results indicate that compared to rehabilitation training alone or conventional therapy, hyperbaric oxygen combined with rehabilitation demonstrates multidimensional, synergistic rehabilitation advantages. Regarding core functional outcomes, this combined approach significantly promotes the recovery of neurological deficits and improves limb motor function. Simultaneously, it effectively alleviates depression and anxiety commonly experienced after stroke, with positive mutual reinforcement observed between emotional improvement and physical functional recovery. At the mechanistic level, the benefits of combined therapy are supported by improvements in multiple physiological indicators: it optimizes blood rheology, elevates levels of brain-derived neurotrophic factor (BDNF) with key neuroprotective and reparative roles, and effectively mitigates oxidative stress damage. Collectively, these effects create a more favorable microenvironment for neuronal survival and functional remodeling. In summary, hyperbaric oxygen combined with rehabilitation therapy represents a comprehensive rehabilitation strategy that holistically improves neurological function, limb motor abilities, and emotional status in stroke patients, demonstrating clear clinical efficacy and application value. Current evidence supports its widespread adoption in clinical rehabilitation during the stroke recovery phase. Future research should focus on conducting multicenter, large-scale randomized controlled trials to explore optimal hyperbaric oxygen therapy parameters and treatment cycles, as well as delve into the molecular mechanisms and neural circuitry involved in combined therapy. Table 5 shows the efficacy of hyperbaric oxygen therapy combined with comprehensive rehabilitation training for stroke patients.

Table 5. Effect of HBOT Combined with comprehensive rehabilitation on stroke

Author	Sample	Treatment	Outcome Measures	Conclusion
Chen et al.	90	Experimental: Conventional rehabilitation + HBOT; Control: Conventional rehabilitation	Neurological deficit score, Limb function score ,QOL	More significant improvement in experimental group
Guan et al.	73	Research: Rehabilitation training + HBOT; Control: Rehabilitation training	Hemorheology indicators, Lovett muscle strength grading ,NIHSS, BI, mRS ,PHQ-9, GAD-7	More significant improvement in research group
Tursungul Abdurahman et al.	116	Observation: Conventional treatment + Rehabilitation training + HBOT; Control: Conventional treatment + Rehabilitation training	Serum BDNF levels, Hip and knee joint muscle strength (FHF, FHE, FKF, FKE)	More significant improvement in observation group
Li et al.	93	Observation: Conventional treatment + Rehabilitation training + HBOT; Control: Conventional treatment + Rehabilitation training	Lovett muscle strength grading ,NIHSS, FMA ,Oxidative stress indicators (ROS, CAT, SOD)	More significant improvement in observation group

mRs:Modified Rankin Scale,PHQ-9:Patient Health Questionnaire-9,GAD-7:Generalized Anxiety Disorder-7, FHF: Flexion of the Hip,FHE: Extension of the Hip,FKF:Flexion of the Knee,FKE:Extension of the Knee, ROS:Reactive Oxygen Species,CAT:Catalase,SOD:Superoxide Dismutase

3.6 HBOT Combined with Smart Rehabilitation

In recent years, with the rapid advancement of artificial intelligence technology, its application in the field of rehabilitation medicine has deepened continuously, giving rise to intelligent rehabilitation devices and technologies. These novel intelligent rehabilitation methods, such as virtual reality systems and upper limb rehabilitation robots, have been progressively applied in the clinical rehabilitation practice of stroke patients. Among these, the combined application of hyperbaric oxygen therapy and intelligent rehabilitation technology offers new insights and effective pathways for comprehensive rehabilitation of neurological functions following stroke.

3.6.1 HBOT Combined with Virtual Reality Technology

Virtual reality (VR) technology is a comprehensive tool that creates a three-dimensional virtual environment through computer simulation and uses sensory devices to immerse users in interactive

experiences. In the field of rehabilitation medicine, VR technology provides an innovative intervention by creating safe, controllable, repeatable, and motivating training scenarios for patients. Research by Shen Linfang and colleagues demonstrated that hyperbaric oxygen combined with virtual reality technology has significant therapeutic effects on stroke patients with depression and upper limb hemiplegia^[28]. The study included 80 patients, and the results showed that the combined treatment group experienced significant improvements in depression symptoms, upper limb motor function, and daily living abilities compared to the control group^[28]. This improvement may be due to the fact that virtual reality technology, through immersive and gamified training methods, significantly enhanced the patients' motivation and enjoyment in participating in the training. While improving motor function, virtual reality technology also effectively alleviates depressive symptoms.

3.6.2 HBOT Combined with Upper Limb Rehabilitation Robot

Rehabilitation robots provide high-intensity, repetitive, and task-oriented training, making them especially suitable for early-stage patients with impaired motor control. Li Jia and colleagues applied hyperbaric oxygen therapy combined with upper limb rehabilitation robots, and the results showed that the combined treatment group demonstrated significant therapeutic effects in the Brunnstrom stages, Fugl-Meyer upper limb scores, and modified Barthel index compared to the control group^[29]. This study indicates that the combination of hyperbaric oxygen and robotic training more effectively promotes the transition of upper limb movement patterns from synergistic to isolated movements, significantly improving the patients' functional abilities in daily activities.

Both studies indicate that the combined treatment group showed significant improvements in daily living activities and motor function. This reflects an important trend in stroke rehabilitation, moving towards more intelligent and technologically integrated approaches, with broad clinical potential for widespread application. Future research can further explore the effects of combining different intelligent rehabilitation technologies, providing a more comprehensive and in-depth theoretical foundation for the field of stroke rehabilitation, while also offering more effective treatment options for clinical practice. Table 6 shows the therapeutic effects of HBOT combined with smart rehabilitation devices on stroke patients

Table 6. Effect of HBOT Combined with Smart Rehabilitation on stroke

Author	Sample	Treatment	Outcome Measures	Conclusion
Sheng et al.	80	Control: Conventional rehabilitation; Observation: Conventional rehabilitation + HBOT + VR	HAMD, Fugl-Meyer, MBI	More significant improvement in observation group
Li et al.	72	Control: Conventional rehabilitation training; Observation: Conventional rehabilitation training + HBOT + Upper limb rehabilitation robot training	Brunnstrom, Fugl-Meyer Assessment for upper limb, MBI	More significant improvement in observation group

4. Conclusions

HBOT is a safe and effective treatment for stroke, and when combined with various rehabilitation methods, it demonstrates more significant effects in stroke recovery. This study is the first to systematically summarize the research on combined HBOT treatment, and the results indicate that combined therapy has significant advantages in improving neurological function, motor function, cognitive abilities, and daily living activities in stroke patients.

This study primarily focuses on randomized controlled trials, and combined treatments across multiple domains have shown positive clinical outcomes. However, most studies still have some limitations, including small sample sizes and a lack of long-term follow-up data. Furthermore, the parameters of HBOT vary across studies, and there has been no standardized parameter setting in treatment protocols. Therefore, future research should focus on determining the optimal timing, frequency, and parameters for HBOT in stroke patients, and exploring the most effective treatment combinations to further enhance rehabilitation outcomes.

With the continuous advancement of technology, stroke rehabilitation should integrate cutting-edge technologies. Smart devices can monitor patients' rehabilitation progress in real-time, optimize the treatment process through data feedback and artificial intelligence, and promote neural plasticity, thereby improving treatment outcomes. In the future, as smart rehabilitation technologies continue to innovate and improve, conducting more related clinical trials will become a key direction. As smart rehabilitation

devices gradually become more widespread, some of these devices have started to be included in insurance coverage, which will help popularize more treatment options and benefit a larger number of patients. With technological advancements and policy support, smart rehabilitation is gradually becoming a research focus in stroke treatment, providing patients with more efficient and personalized rehabilitation solutions.

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