

CASE REPORT

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Anatomical and metabolic brain imaging correlation of neurological improvements following hyperbaric oxygen therapy—post-stroke recovery: a case report

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Abstract

Background Stroke remains a leading cause of long-term disability, with limited recovery potential during the chronic phase. Hyperbaric oxygen therapy has shown promise in promoting neuroplasticity and functional recovery through mechanisms such as the hyperoxic-hypoxic paradox.

Case presentation We report the case of a 45-year-old Arabic male who experienced a left-sided hemorrhagic stroke and presented with persistent neurological deficits 15 months post-event. He exhibited right hemiparesis, impaired gait requiring a wheelchair, and cognitive dysfunction. The patient underwent 83 sessions of hyperbaric oxygen therapy over 16 weeks (2.0 ATA, 90 minutes with air breaks). Pre- and postintervention assessments included neurological and cognitive evaluations alongside advanced imaging: diffusion tensor imaging and Single photon emission computed tomography. Clinically, the patient showed marked improvements in muscle strength, spasticity, balance, and walking—progressing from wheelchair dependence to ambulation with a quadruped cane. Cognitive testing demonstrated improved attention, verbal memory, and processing speed. Imaging findings supported these changes: diffusion tensor imaging showed increased fractional anisotropy in major white matter tracts, and single photon emission computed tomography demonstrated significant perfusion increases in the right motor cortex (+ 15.83%) and right frontal lobe (+ 15.92%).

Conclusion This case highlights hyperbaric oxygen therapy's potential to facilitate recovery in chronic post-stroke stages by enhancing neuroplasticity and neurovascular function in nonnecrotic brain regions. Advanced imaging techniques, such as diffusion tensor imaging and single photon emission computed tomography, provide valuable insights into treatment efficacy and may support personalized therapeutic protocols in the future.

Keywords Hyperbaric oxygen therapy, HBOT, DTI, SPECT, Post stroke rehabilitation

Introduction

In recent years, growing evidence has highlighted the neuroplasticity effects of dedicated hyperbaric oxygen therapy (HBOT) protocols [1]. These effects have been demonstrated in patients with stroke and traumatic brain injuries, even during the delayed chronic stage, months to years after the acute insult [1–13]. The repeated, intermittent increases in oxygen concentration during HBOT activate many of the mediators and cellular mechanisms

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typically induced by hypoxia, but without the associated risks, a phenomenon known as the hyperoxic-hypoxic paradox (HHP) [4, 5].

Among its effects, intermittent hyperoxic exposure during HBOT has been shown to influence hypoxia-inducible factor 1 (HIF-1) levels, enhance matrix metalloproteinase (MMP) activity, stimulate vascular endothelial growth factor (VEGF), and promote stem cell proliferation, angiogenesis, and improved blood flow in ischemic brain regions [5, 6]. These mechanisms collectively target areas of metabolic dysfunction—nonnecrotic but impaired brain regions—contributing to functional recovery [7].

The use of advanced neuroimaging techniques, such as magnetic resonance imaging (MRI) with diffusion tensor imaging (DTI) and single photon emission computed tomography (SPECT), has the potential to identify these regions prior to treatment. This approach may enable clinicians to set realistic expectations and tailor treatments on the basis of individual metabolic and structural brain profiles [8].

This case report describes a stroke patient with persistent right-sided hemiparesis, along with substantial challenges in mobility, balance, and cognition, who initiated HBOT 15 months after the acute event. The outcome of the HBOT treatment included significant clinical improvements correlating with changes in MRI-DTI and brain SPECT imaging. The physiological basis of these outcomes and the combined use of structural and metabolic/perfusion brain imaging are further discussed.

Case presentation

A 45-year-old arabic male with a medical history of hypertension had hemorrhagic stroke 15 months prior to his referral for HBOT. The clinical presentation of the stroke included weakness on the right side and slurred speech. The initial CT scan showed a large left intracerebral haemorrhage with ventricular collapse and surrounding edema. Follow up imaging showed a midline shift with incipient entrapment. An external ventricular drain was inserted and was removed after 3 weeks. Since the stroke, the patient had significant challenges in mobility, balance, and cognition. After the incident the patient did physiotherapy and occupational therapy after which he showed some motor improvement.

Following the acute event, the patient underwent physiotherapy and occupational therapy, which resulted in partial motor improvement. Nevertheless, he continued to experience significant impairments in mobility, balance, and cognition.

Throughout the post-stroke rehabilitation period, and prior to referral to our clinic, the patient received

ongoing physiotherapy. In parallel, sertraline was prescribed to manage anxiety and depressive symptoms. To address spasticity in the left knee extensors, botulinum toxin was administered to the semitendinosus and semimembranosus muscles. Despite these interventions, the patient developed progressive contractures in the bilateral knee flexors and pronator muscles, along with shortening of the right pectoral muscle. Myofasciotomies were subsequently performed on the affected muscle groups.

The patient continued with intensive physiotherapy and occupational therapy aimed at improving muscle strength, coordination, balance, and overall functional mobility. He demonstrated gradual progress in both strength and ambulation. Additionally, targeted physical exercises were introduced to further support motor recovery. Concurrently, intensive speech therapy was provided to address dysarthria and aphasia, with a focus on articulation, clarity, and communication.

After 15 months of the primary incident; a thorough pre-HBOT evaluation encompassed included detailed physical assessment. Computerized neurocognitive evaluation (NeuroTrax™) and advanced brain imaging, including MRI-DTI, and a SPECT scan.

Baseline physical examination: The patient used the wheelchair for indoor and outdoor ambulation. He could ambulate for few minutes with a quadruped cane with close supervision if asked to. The patient presented with reduced muscle strength on the right side as follows: Shoulder Flexors 3+/5, Elbow Flexors 3/5, hip flexors 3+/5, knee extensors 3/5, ankle dorsiflexors 3/5. The patient couldn't perform right and left tandem and semi tandem. FICSIT score was 1. COSMOS Treadmill Data pre-treatment assessment, it was observed that he was bearing most of his body weight on the left side (72%), with only 28% on the right side.

The pretreatment neuropsychological testing revealed that the global cognition measured a little below the average range, with some variability among the measured cognitive domains. MoCa showed a score of 23/30 and NeuroTrax showed a below average score in sustained attention, immediate and delayed verbal memory, immediate and delayed nonverbal memory, and information processing speed.

Baseline MRI findings: There was evidence of an old haemorrhage overlying the left thalamus with ex vacuo dilatation of the left lateral ventricle, consistent with compensatory changes (Fig. 1). Signal alteration in the right occipital/cuneus area, indicative of an old ischemic event. Presence of old microbleeds in the left pons and a prior lacunar infarct in the left occipital region. Small vessel disease (Fazekas grade 1) noted in bilateral frontal and parietal regions.



Fig. 1 Brain MRI exhibited old haemorrhagic stroke in the left thalamus (yellow arrow) with ex vacuo dilatation of third and left lateral ventricle

Brain SPECT Findings: Mildly reduced tracer uptake in the left cerebral hemisphere, correlating with observed motor and cognitive deficits.

Intervention: The patient underwent 83 HBOT sessions, performed daily, 5 days per week. Each session included 90 minutes of 100% oxygen at two atmospheres (2ATA), with 5-minutes air breaks every 20 minutes.

Post-HBOT Evaluation: Following the HBOT protocol, the initial assessments were repeated and compared with the baseline tests with the following findings:

Clinical outcomes
Neurological improvements

- **Speech:** Notable improvements in fluency and expression as he would search for words and could not complete a sentence before treatment. Post treatment he can say full sentences fluently with a rich vocabulary.
- **Physical evaluation:**
 - **Strength:** Significant improvement in strength in the right upper and lower limbs (Table 1)
 - **Tone:** Reduced spasticity in the right upper limb. Post HBOT; the patient can tie his shoelaces

Table 1 Comparison between the muscle strength of different muscle groups in the right upper and lower limbs in pre and post HBOT

Muscle group tested	Pre-treatment	Post-treatment
Shoulder flexors	3 + /5	4/5
Elbow flexors	3/5	4 + /5
Hip flexors (knee flexed)	3 + /5	4/5
Knee extensors	3/5	4/5
Ankle dorsiflexors	3/5	4/5

independently, he can use his right hand for grooming tasks, such as combing hair.

- **Gait and Posture:** Marked improvements in walking ability, with better posture and reduced assistance needed for ambulation. He now uses a quad-ruped cane for walking without human assistance instead of the wheelchair. The post treatment Gait assessment on Cosmos treadmill showed a significant improvement in his stance, showing a more symmetrical weight distribution. He is now bearing 49% of his weight on the left side and 51% on the right (Tables 2 and 3).
- **Sensation:** Enhanced sensation of light touch and deep sensation (proprioception) in the right lower extremity. The patient demonstrated awareness of joint position during weight-bearing.

Cognitive improvements

- **Focused and Sustained Attention:** Significant improvement in the patient's ability to maintain attention during tasks (Neurotrax showed 8.6% improvement in attention)
- **Immediate Verbal Memory:** Enhanced ability to recall verbal information shortly after presentation, reflecting improvements in memory encoding and retrieval. (Neurotrax showed 31.2% improvement in verbal memory).
- **Information Processing Speed:** Notable increase in the speed of processing and responding to information, contributing to overall cognitive efficiency (Neurotrax showed 10.7% improvement in information processing speed).

Brain imaging

MRI: No significant changes in structural imaging (haemorrhage, ischemic areas, or small vessel disease).

In Table 4; the significant changes in DTI-Fractional Anisotropy (FA) which is a measure used to evaluate white matter integrity, directionality and order. A Parcellation of white matter fiber tracts.

While in Table 5; the significant changes in DTI-Mean Diffusivity (MD) is a measure used to evaluate white matter fiber density. A lower value of MD indicates higher density.

SPECT scan: As compared with the baseline; increased perfusion was demonstrated in the motor cortex, temporal and frontal regions (+15.92%), reflecting improved neural activity. Enhanced perfusion was also observed in sensory regions, aligning with the recovery of sensation and improved cognitive function (Fig. 2, Table 6).

Long term follow up

The patient completed the treatment course over a 3-month period. Since then, the clinical team has conducted regular monthly follow-ups to monitor his post-treatment condition. Notably, the patient has consistently reported sustained physical and cognitive improvements, with no subjective evidence of regression following the conclusion of therapy.

Strengths and limitations

This case report demonstrates significant strengths, including a detailed correlation between advanced imaging findings (MRI DTI, SPECT) and clinical improvements, quantitative metrics for objectivity, and rare insights into the therapeutic potential of HBOT, supported by longitudinal data spanning 82 sessions. It highlights specific neurological improvements and

Table 2 Comparison between the muscle power in pre and post HBOT

Power	Pre-treatment	Post-treatment
Sit to stand (repetitions in 30 seconds)	4	5
Right-hand strength (handheld dynamometer) (Kgf)	11	25
Left-hand strength (handheld dynamometer) (Kgf)	28	35
Right-leg strength (leg dynamometer) (Kgf)	12	18.5
Left-leg strength (leg dynamometer) (Kgf)	13.95	23.5

Table 3 Comparison between balance in pre and post HBOT

Balance	Pre-treatment	Post-treatment
Romberg (eyes open) time (in seconds) modified position	10	30
Semi-tandem right (eyes open) (in seconds) with cane	Unable to do	30
Semi-tandem left (eyes open) (in seconds) with cane	Unable to do	30
Tandem right (eyes open) (in seconds) with cane	Unable to do	30
One-leg stand right (in seconds) with cane	Unable to do	10
One-leg stand left (in seconds) with cane	Unable to do	30
FICSIT score (normal 28/28)	1	13

Table 4 DTI FA Pre- and Post-HBOT Comparison

Anatomical structure	Functional domain	Baseline	After intervention	Change in % (%)
Left Cingulum (Hippocampus)	Learning, memory, behavior, sensation, and perception	0.23	0.31	33.07
Left Inferior cerebellar peduncle	Proprioceptive sensory input with motor vestibular functions	0.38	0.48	25.65
Right Medial lemniscus	Sensory pathway of fine touch	0.39	0.46	17.85
Right Cingulum (hippocampus)	Learning, memory, behavior, sensation, and perception	0.44	0.51	14.05
Left Medial lemniscus	Sensory pathway of fine touch	0.41	0.47	12.43
Right Inferior cerebellar peduncle	Proprioceptive sensory input with motor vestibular functions	0.41	0.46	10.96
Right corticospinal tract	Motor pathway controlling the left side of the body	0.36	0.39	8.88
Right posterior thalamic radiation	Sensory and motor pathways (mainly visual)	0.35	0.38	8.33

Table 5 DTI MD Pre- and Post-HBOT Comparison

Anatomical structure	Functional domain	Baseline	After intervention	Change in % (%)
Right medial lemniscus	Sensory pathway of fine touch	1.15	0.80	30.69
Left medial lemniscus	Sensory pathway of fine touch	1.11	0.79	29.03
Right cingulum (hippocampus)	Learning, memory, behavior, sensation, and perception	1.16	0.88	24.59
Right Inferior cerebellar peduncle	Proprioceptive sensory input with motor vestibular functions	1.00	0.86	14.09
Right sagittal striatum	Visual memory and face recognition	1.30	1.18	8.88
Right external capsule	Regulating responses from cortex, learning and behavior	1.12	1.03	8.70
Posterior limb of right internal capsule	Sensory pathway	1.01	0.93	8.53
Left cingulum (hippocampus)	Learning, memory, behavior, sensation, and perception	0.74	0.68	8.29

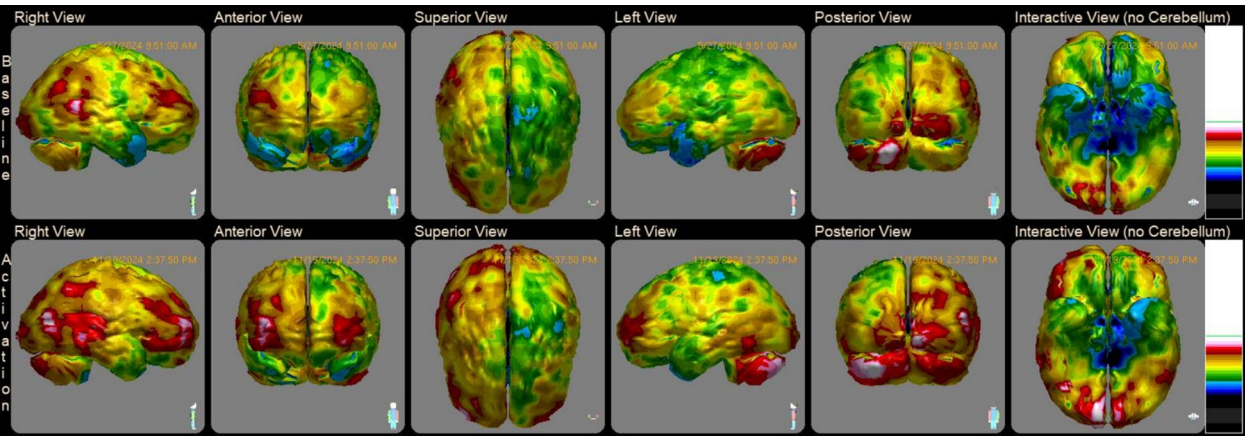


Fig. 2 Single photon emission computed tomography scan showed marked improvements in the post-treatment single photon emission computed tomography (second row) perfusion as compared with the baseline (first row)

Table 6 SPECT; the brain regions pre- and post-HBOT perfusion comparison

Anatomical structure	Functional domain	Baseline	After intervention	Change in % (%)
Brodmann area 38 left	Emotion memory, memory processing and language function	0.59	0.75	26.86
Brodmann area 11 right	Emotional regulation, reward and motivation, decision making and social behaviors	0.72	0.86	19.59
Brodmann area 37 left	Visual memory, language processing, objective recognition and auditory processing and speech	0.75	0.89	19.42
Brodmann area 25 left	Emotion regulation, mood, motivation, decision making, memory, and behavioral control	0.64	0.76	18.98
Brodmann area 31 right	Emotional regulation, memory, attention, awareness, cognitive flexibility, and social cognition	0.78	0.91	15.92
Brodmann area 25 right	Emotional regulation, mood, affective control, decision making, cognitive/behavioral flexibility, and mental health	0.74	0.86	15.83
Brodmann area 32 right	Emotional regulation, cognitive control, attention, pain processing, and social behavior	0.76	0.88	15.8
Brodmann area 47 left	Language processing, cognitive flexibility, decision making, reward processing, inhibition, behavioral control, and social cognition	0.74	0.85	15.13

targeted brain recovery in Brodmann areas, offering valuable implications for similar conditions. However, its single-case design, absence of a control group,

and limited focus on the HBOT protocol reduce generalizability. Subjectivity in clinical observations, potential confounding factors, and limited long-term

follow-up further constrain the findings, emphasizing the need for broader studies to validate these outcomes.

Discussion and conclusions

In recent years, growing evidence from both clinical and preclinical studies has demonstrated the therapeutic potential of dedicated hyperbaric oxygen therapy (HBOT) protocols for post-stroke patients, including those in the chronic phase. Multiple studies [1–13] have shown that HBOT can promote neuroplasticity and functional recovery in metabolically impaired but structurally preserved brain regions, sometimes referred to as “nonnecrotic dysfunctional tissue,” even years after the initial insult.

These regions can be identified by combining anatomical imaging (for example, MRI) with functional modalities such as single-photon emission computed tomography (SPECT). A mismatch between SPECT perfusion deficits and intact MRI anatomy indicates viable brain tissue that may respond to HBOT. In our case, such a mismatch was clearly evident, providing the rationale for initiating treatment 15 months post-stroke.

Compared with other published HBOT studies in post-stroke patients, this case is notable for combining objective neuroimaging changes (DTI and SPECT) with significant functional improvements in a patient recovering from a hemorrhagic stroke. Although the HBOT literature predominantly focuses on ischemic stroke, recent data, including studies recent data, such as [2, 8], highlight promising outcomes in hemorrhagic stroke cases as well. This case contributes to that growing subset by demonstrating recovery aligned with specific changes in DTI and SPECT.

Diffusion Tensor Imaging (DTI): DTI provides information about the integrity of white matter tracts, which are vital for understanding neuroplasticity and recovery following neurological injuries [1]. In this case, notable improvements were observed in key white matter regions, including the corticospinal tract and medial lemniscus, as indicated by increases in fractional anisotropy (FA) post-HBOT. These changes suggest enhanced axonal integrity and re-establishment of neural connections [6, 7]. Previous studies have demonstrated that FA is a reliable marker of white matter integrity, correlating higher values with better functional outcomes in stroke rehabilitation [1, 8]. The observed increases in FA align with the patient’s motor function recovery, including improved strength, gait, and sensory processing. Furthermore, reductions in mean diffusivity (MD) in regions such as the cingulum and inferior cerebellar peduncle reflect decreased water diffusion, signifying recovery of axonal structure and function [1]. These findings underscore DTI’s potential as a noninvasive tool to monitor

post-stroke neuroplasticity and the effects of interventions such as HBOT.

Single Photon Emission Computed Tomography (SPECT): SPECT imaging, utilizing ECD as the tracer, plays a critical role in evaluating cerebral perfusion and metabolic activity in stroke recovery. In this case, SPECT revealed increased perfusion in the motor cortex, frontal lobe, and sensory areas following HBOT. These changes correlate with the patient’s substantial motor and cognitive improvements. Increased perfusion in the motor cortex likely facilitated the recovery of motor strength and posture, while enhanced perfusion in the frontal cortex and temporal regions aligned with improved language fluency, attention, and memory. These findings are consistent with existing literature that links increased brain activity to functional recovery after HBOT [6].

Clinical implications and practical takeaways for physicians

Clinical implications

Although conventional MRI showed no structural changes post-HBOT, as expected in the chronic stage, the combination of functional and microstructural improvements seen on SPECT and DTI underscore the value of advanced imaging to monitor treatment response and guide personalized rehabilitation strategies. This case reinforces the hypothesis that HBOT can facilitate recovery by targeting metabolic and microstructural dysfunctions in nonnecrotic regions.

With accumulating evidence, the use of advanced neuroimaging techniques may help refine patient selection criteria and optimize individualized treatment protocols, ultimately enhancing outcomes for a broader range of post-stroke patients.

Practical takeaways for physicians

This case highlights the emerging role of HBOT as an adjunctive therapy for patients with chronic neurological deficits, especially when recovery has plateaued following standard rehabilitation. While HBOT is widely established in the treatment of chronic damaged tissue owing to radiation injury, and nonhealing ischemic wounds, its application in neurorehabilitation is increasingly supported by clinical data.

Key Clinical Takeaways:

1. Patient Selection is Crucial:

HBOT should be considered in patients with persistent neurological impairments (for example, post-stroke, TBI, hypoxic injury) who have reached a plateau with conventional therapies but demonstrate brain regions with preserved structural integrity

and ongoing metabolic dysfunction on imaging (for example, brain SPECT).

2. Imaging-Guided Decision-Making:

Functional and microstructural imaging, such as SPECT and DTI, can identify candidates likely to benefit from HBOT. In this case, perfusion deficits in Brodmann areas corresponded with clinical improvements, suggesting imaging can also serve as a monitoring tool.

3. Track Objective Improvements:

Use of validated assessments (for example, NeuroTrax™, dynamometry, gait analysis) allows clinicians to quantify cognitive, motor, and sensory improvements pre- and post-HBOT, reinforcing the objective nature of observed benefits.

4. HBOT protocol duration:

To induce meaningful neuroplasticity and angiogenesis, protocols should include a minimum of 40 sessions, with up to 80 daily sessions recommended for more severe cases [14–16].

5. Multidisciplinary Approach is Essential:

HBOT should be integrated into a broader neurorehabilitation program that includes physical, speech, and cognitive therapy, as well as nutritional and psychological support.

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Author contributions

SK, MG, ZW, UQ, RZ, and SE analyzed and interpreted the patient data regarding the MRI, DTI, and SPECT. All authors read and approved the final manuscript.

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Data availability

All data generated or analyzed during this study are included in this published article.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Written informed consent was obtained from the patient for publication of this case report and any accompanying images. A copy of the written consent is available for review by the Editor-in-Chief of this journal.

Competing interests

SK, MG, ZW, UQ, and RZ work for The Brain and Performance Centre. Authors affiliations are listed above and none of the authors have any conflicts of interests to declare.

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