Physiotherapy Management of Spasticity in TBI: A Comprehensive Review

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Abstract
Spasticityis an irreversible and debilitating complication associated with traumatic brain injury (TBI), which occurs in 75% of affected patients in their course of recovery. Spasticity is a disorder that is characterized by an increased muscle tone that is dependent on the velocity and exaggerated reflexes, which drastically affect both the functional mobility and activities of daily living and the overall quality of life of TBI survivors. This is a systematic review of the evidence-based physiotherapy applications that are currently used to manage spasticity in the TBI population. The systematic review of current literature indicates that physiotherapy is central to the multidisciplinary approach to post-TBI spasticity using different modalities such as stretching, neurodevelopmental, functional electrical stimulation, constraint induced movement therapy, task specific training, hydrotherapy and robot assisted therapy. The review discusses the development of spasticity after TBI, pathophysiology of the condition, and the instruments used in clinical practice and the effectiveness of various physiotherapeutic interventions. There is evidence that early intervention, personalized treatment plans, as well as combination of various treatment modalities, are the most effective. Nevertheless, there is a great variation in the treatment regimens and outcome measures among the studies and therefore a need to have standardized assessment measures and treatment regimens. The review finds that although physiotherapy is still an essential part of spasticity management, additional high-quality randomized controlled trials are required to set the conclusive treatment guidelines and define long-term functional outcome of spasticity patients in TBI.

Keywords: Traumatic Brain Injury; Spasticity; Physiotherapy; Rehabilitation; Neurorehabilitation

Introduction
Traumatic brain injury is a considerable health challenge in the world, with the number of cases amounting to about 69 million people every year and the condition being a major cause of death and chronic disability, especially in the population of young adults and seniors [1]. The effects of TBI go way beyond the acute injury period as survivors usually develop long-term neurological deficits which have a significant impact on their functional autonomy and quality of life [2]. Spasticity is one of the most common and functional constraints among the host of complications that develop following TBI and appears in 15-75% of patients based on the severity, localisation, and post-traumatic period of the injury [3].

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One of the components of the upper motor neuron syndrome is spasticity as defined by Lance in 1980 and is described as velocity-dependent increase of the tonic stretch reflexes with exaggerated tendon jerks due to hyperexcitability of the stretch reflex [4]. This classical definition has however been extended in the modern literature to include the wide range of motor dysfunction that includes abnormal posturing, co-contraction of agonist and antagonist muscles, and motor loss of selective motor control [5]. Spasticity is a condition that usually begins few weeks to months after the injury and its peak is experienced between three to six months after injury, although delayed onset can be experienced years after the first insult [6].

Pathophysiological processes that lead to post-TBI spasticity are complicated and multifactorial, which includes the interference of descending inhibitory pathways, spinal reflex excitability, mechanical properties of muscle and connective tissue, and maladaptive neuroplasticity [7]. Corticospinal and corticoreticulospinal tract lesions following TBI cause the loss of supraspinal inhibition of spinal reflexes which causes hyperreflexia and elevates muscle tone [8]. Moreover, there are secondaryprocessessuchas neuroinflammation,glutamate excitotoxicity, and abnormal neural circuit reorganization that cause and sustain spasticity [9].

Clinical features of spasticity in TBI victims are diverse and may involve any muscle groups although upper and lower extremities are most likely to be involved [10]. Spasticity can have a variable pattern such as flexor or extensor synergies, local involvement of certain muscle groups, or generalized, involving different body parts [11]. The clinical effect of spasticity is great, and it affects voluntary movement, causing pain and discomfort, reduces the range of movements of the joints, heightens the risk of contractures and pressure ulcers, complicates the process of caregiving, and greatly impairs the quality of life [12].

Spasticity evaluation among TBI patients involves an extensive assessment procedure that involves clinical scales and objective assessment instruments [13]. Despite its subjectivity and low psychometric sensitivity, which have been frequently criticized, the Modified Ashworth Scale is still the most popular clinical instrument used in the practice of physiotherapy [14]. Other assessment instruments comprise the Tardieu Scale that considers velocity-related nature of spasticity, the biomechanical measures based on electromyography and dynamometry and the functional scales that evaluate the consequences of spasticity on the daily living activities [15].

Post-TBI spasticity requires a multidisciplinary approach that includes pharmacological therapy, physical and in extreme cases neurosurgical methods [16]. Physiotherapy is another foundation of spasticity management, which provides non-invasive approaches to address the neurophysiological processes of spasticity management as well as the functional impacts of elevated muscle tone [17]. The practical basis of physiotherapy in the spasticity management is based on the principles of neuroplasticity, motor learning, and mechanical tissue adaptation [18].

Modern physiotherapy practice is using a variety of intervention outcomes in the management of spasticity, both the conventional passive methods of intervention and the new methods using technology [19]. Traditional methods involve manual stretching, positioning, splinting, and neurodevelopmental treatment methods, as the emergent ones are functional electrical stimulation, robotic-assisted therapy, virtual reality training, and hydrotherapy [20]. The choice of relevant interventions must be informed by patient specific aspects,

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spasticity distribution and severity, functional objectives, and resources [21].
Although physiotherapy has proven to be instrumental in the management of post-TBI spasticity, there is a major gap in the evidence base as characterized by the optimal treatment regimes, dose regimes, and the long-term outcomes [22]. The fact that TBI population is heterogeneous, the manifestation of spasticity can vary, and the differences between treatments make it hard to conduct high-quality research and come up with standardized guidelines [23]. This is a full review that tries to synthesize existing evidence on physiotherapy management of spasticity after TBI, critically discusses the effectiveness of different interventions, gaps in existing literature and offer clinical practice and future research suggestions.

Methodology

This comprehensive review was conducted following a systematic approach to identify, evaluate, and synthesize relevant literature on physiotherapy management of spasticity in traumatic brain injury patients. A comprehensive search strategy was implemented across multiple electronic databases including PubMed, MEDLINE, Cochrane Library, CINAHL, PEDro (Physiotherapy Evidence Database), and Google Scholar. The search encompassed publications from January 2000 to September 2024 to capture contemporary evidence while acknowledging seminal works in the field.
The search strategy incorporated a combination of Medical Subject Headings (MeSH) terms and keywords including: "traumatic brain injury," "TBI," "head injury," "spasticity," "muscle hypertonia," "physiotherapy," "physical therapy," "rehabilitation," "therapeutic exercise," "stretching," "functional electrical stimulation," "constraint-induced movement therapy," "robotic therapy," and "hydrotherapy." Boolean operators (AND, OR) were utilized to combine search terms and refine results. Additional articles were identified through manual searching of reference lists of included studies and relevant systematic reviews.
Inclusion criteria were established as priori and comprised: (1) studies involving adult patients aged 18 years or older with TBI and documented spasticity; (2) interventions focused on physiotherapy modalities; (3) studies published in English language; (4) original research articles including randomized controlled trials, cohort studies, case-control studies, and case series; and (5) studies reporting quantifiable outcomes related to spasticity, motor function, or functional independence. Exclusion criteria included: (1) pediatric populations; (2) studies focusing solely on pharmacological or surgical interventions; (3) conference abstracts without full-text availability; (4) duplicate publications; and (5) studies with insufficient methodological detail.
Two independent reviewers screened titles and abstracts for eligibility, with full-text articles retrieved for potentially relevant studies. Any disagreements regarding inclusion were resolved through discussion and consensus. Data extraction was performed systematically using a standardized form capturing study characteristics (author, year, country, study design), participant demographics (sample size, age, time post-injury, injury severity), intervention details (type, duration, frequency, intensity), comparison groups, outcome measures, and key findings including effect sizes where reported.
Methodological quality of included studies was assessed using appropriate critical appraisal tools based on study design. Randomized controlled trials were evaluated using the PEDro scale, which assesses internal validity and statistical reporting [24]. Observational studies were appraised using the Newcastle-Ottawa Scale for cohort and case-control studies [25]. Quality assessment was conducted independently by two reviewers, with discrepancies resolved through consensus.

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Given the anticipated heterogeneity in study designs, populations, interventions, and outcome measures, a narrative synthesis approach was adopted rather than meta-analysis. Evidence was synthesized thematically according to intervention categories including stretching and range of motion exercises, neurodevelopmental techniques, functional electrical stimulation, task-specific training, constraint-induced movement therapy, hydrotherapy, and robotics-assisted therapy. Within each category, evidence regarding efficacy, optimal dosage, and functional outcomes was critically evaluated and summarized.

Discussion

3.1Stretching and Range of Motion Exercises

Stretching exercises represent the most fundamental and widely utilized physiotherapy intervention for spasticity management in TBI patients [26]. Evidence demonstrates that prolonged static stretching, maintained for 20-30 minutes, produces temporary reductions in muscle tone through neurophysiological mechanisms including altered stretch reflex excitability and mechanical changes in muscle-tendon properties [27]. Studies indicate that stretching programs incorporating multiple daily sessions yield superior outcomes compared to single daily stretching, though the effects remain relatively short-lived, typically lasting 30 minutes to several hours post-intervention [28].

Serial casting and splinting provide prolonged stretch to spastic muscles, facilitating sarcomere adaptation and preventing contracture development [29]. Research suggests that serial casting combined with active mobilization produces greater improvements in range of motion and functional outcomes compared to casting alone [30]. However, patient tolerance, skin integrity monitoring, and careful application technique are critical considerations for safe implementation.

3.2.NeurodevelopmentalandTask-Specific Approaches

Neurodevelopmentaltreatment approaches, including Bobath concept and proprioceptive neuromuscular facilitation, emphasize facilitation of normal movement patterns and inhibition of abnormal muscle tone through specific handling techniques and postural adjustments [31]. While these approaches remain popular in clinical practice, high-quality evidence supporting their superiority over task-specific training is limited. Contemporary evidence increasingly favors task-oriented training, which emphasizes repetitive practice of meaningful functional activities within relevant environmental contexts [32].

Task-specific training capitalizes on neuroplasticity principles, promoting motor learning through intensive, repetitive practice of functional movements [33]. Studies demonstrate that high-intensity task-specific training, involving at least 20-40 hours over 8-10 weeks, produces significant improvements in motor function, mobility, and activities of daily living in TBI patients with spasticity [34]. The specificity of training appears crucial, with transfer of improvements primarily occurring for practiced tasks rather than generalizing to unpractised activities.

3.3 Technological Interventions

Functional electrical stimulation (FES) has emerged as a promising adjunct to conventional physiotherapy for spasticity management [35]. FES involves application of electrical currents to stimulate affected muscles, promoting reciprocal inhibition of spastic antagonists and facilitating active movement. Research indicates that FES combined with functional training produces greater reductions in spasticity and improvements in motor control compared to either intervention alone [36].

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Robotic-assisted therapy represents an innovative approach enabling high-intensity, repetitive practice with precise control of movement parameters and real-time feedback [37]. Systematic reviews suggest that robotic therapy produces improvements in motor function comparable to conventional therapy but with greater efficiency in delivering intensive training [38]. However, evidence specific to TBI populations with spasticity remains limited, and cost-effectiveness considerations require further investigation.

Virtual reality-based rehabilitation offers immersive, engaging environments for motor practice with augmented feedback and adaptable difficulty levels [39]. Preliminary evidence suggests that virtual reality training may enhance motor learning and functional outcomes in neurological populations, though specific research in TBI patients with spasticity is scarce [40].

3.4 Hydrotherapy

Aquatic therapy provides unique therapeutic benefits through principles of buoyancy, hydrostatic pressure, and water resistance [41]. The buoyancy of water reduces gravitational effects on spastic muscles, facilitating movement and enabling practice of functional activities that may be difficult on land. Evidence indicates that hydrotherapy programs incorporating strengthening, balance, and functional training produce significant improvements in spasticity, mobility, and quality of life in neurological populations [42]. However, accessibility, infection control considerations, and patient-specific contraindications may limit widespread implementation.

Conclusion

Spasticity after traumatic brain injury can be a complicated clinical problem that needs physiotherapy management that is holistic and unique to each case. Existing data is in the favor of a multimodal strategy that would combine several interventions based on the patient-specific features, the spasticity topography, and functional objectives. Basic management of contracture prevention and tissue extensibility is using stretching exercises, serial casting, and positioning techniques. Task-specific training is one of the cornerstone interventions, and it facilitates neuroplasticity and functional motor recovery by means of intensive and repeated practice of meaningful activities. The use of technological adjuncts such as functional electrical stimulation and robotic-assisted therapy is promising and can improve conventional therapy, allowing the provision of high-intensity training and controlled parameters.

Although progress has been made in the management and knowledge about post-TBI spasticity, the evidence base has major weaknesses. There is a lot of heterogeneity in the literature in terms of the population of patients, intervention plans, outcome variables, and follow-up times, which precludes the possibility of deriving definite treatment guidelines. Small sample sizes, poor methods of quality, and temporality of the follow up nature demonstrates the necessity of large-scale, well-designed randomized controlled clinical trials with longer-term follow-ups to establish long-term, functional outcomes, and cost-effectiveness.

In the future, the study must focus on the creation of standardized testing procedures, determining the best intervention dosage intervals, predictors to the response of treatment, and development of novel interventions such as brain stimulation and use of virtual reality. Moreover, the study of interventions combinations and personalized approaches to medicine considering the unique patient traits and biomarkers can be performed through comparative effectiveness research, which can progress the field of precision rehabilitation.

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To apply in clinical practice, physiotherapists are advised to incorporate evidenced-based, goal-focused practices that focus on the use of early intervention, high-intensity functional training, and incorporation of technological advances when feasible. Continuous evaluation, adjustment of treatment according to patient response, and interdisciplinary cooperation are also needed to achieve the best results. Finally, the TBI-related spasticity is treated through physiotherapy, balancing evidence with clinical experience and patient preferences to provide optimal patient care that will achieve the best functional outcomes and quality of life.

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