

ASSESSMENT OF SPASTICITY AND ITS CLINICAL ASPECTS IN THE NEW TECHNOLOGY ERA

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Abstract. The present paper aims to present a complex approach to what is currently the assessment of spasticity based on new technologies. In the current context, spasticity requires a more precise quantification and therapeutic management, in which the technology represented by biosensors, robotics, information provided by medical imaging and biomechanics, but also artificial intelligence, allow understanding the pathophysiology of post-stroke sequelae. In this study, we aimed to review these aspects, by consulting the specialized literature, focused on identifying the neuronal or non-neuronal factors that are involved in central motor neuron lesions. The article aimed to identify how spasticity and its complications are defined and perceived by the clinician or therapist in practice and the clinical needs for a comprehensive and dynamic assessment and available technology with dual role in research and clinical practice. The results of the article demonstrated the need for research in this field and the benefits they bring for the management of spasticity.

Keywords: stroke, spasticity, risk factors, assessment, wearable sensors, role of technology

Introduction

Spasticity is a complex motor disorder of neurological origin (He et al., 2023, Aloraini et al., 2015), a disabling feature of chronic neurological conditions, whose onset is poorly understood.

Spasticity has a substantial impact on people's quality of life (Amin et al. 2024). It is a peripheral symptom of central lesions occurring in nerve structures (brain, spinal cord or upper motor neurons-UMN).

Considered a troublesome complication (Biering-Sørensen et al., 2006), this complex phenomenon has been defined in multiple ways and has different meanings for patients and therapists (Marsden, 2016). It leads to long-term disability.

The most widely cited definition emphasising the UMN component (Trompetto et al. 2014, Marsden, 2016) is that published by Lance (1980). This definition emphasises that spasticity is '*a motor disorder characterised by a speed-dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon reflexes, resulting from hyperexcitability of the stretch reflex as a component of central motor neuron syndrome*'.

In 2005, the EU-SPASM Consortium suggested that the definition should first and foremost reflect the reality of clinical practice more clearly. The group proposed the following definition: '*a disorder of sensory and motor control resulting from a central motor neuron lesion that manifests*

as intermittent or continuous muscle activation' (Pandyan et al., 2005).

In common conditions such as stroke, cerebral palsy, and multiple sclerosis, muscle spasticity can occur in a variety of anatomical locations and motor forms manifested in the periphery. From a clinical point of view, although rarer in medical practice, traumatic injuries of the spine and spinal cord, or brain trauma, amyotrophic lateral sclerosis, hereditary spastic paraplegia, and some infections such as meningitis or encephalitis can lead to the development of peripheral spasticity.

The prevalence and severity of spasticity in these subjects is poorly defined in studies. Martin et al. (2014) and Kuo & Hu (2018) have proposed estimates of the prevalence of spasticity in the most common condition. In clinical rehabilitation practice, more important than these estimates seems to be the estimated risk of developing this movement disorder for each individual, based on diagnosis and individual risk factors, all of which can help in long-term prediction of needs and a subject-centred approach.

Materials and Methods

The material collected for this analysis came from the following databases: PubMed. Keywords for identifying recent articles included for the searches performed keywords such as: 1: "spasticity after stroke", 2: "stroke risk factors", 3: "technology spasticity assessment", 4: "technology spasticity rehabilitation".

Mainly articles reporting recent results, published in English, which were available abstract and

extenso. The article aimed to identify 1) how spasticity and its complications are defined and perceived by the clinician or therapist in practice and 2) the clinical needs for a comprehensive and dynamic assessment and available technology with dual role in research and clinical practice.

Risk of occurrence and associated risk factors

Most stroke patients, especially the elderly, with ischemic lesions or mild functional impairment do not develop spasticity, meaning that not all upper motor nerve lesions cause muscle hypertonia.

In contrast, estimates of the incidence of spasticity in the context of intracranial haemorrhage range from 30 to 80% (Kuo & Hu 2018) or 39.5% after the first stroke with paresis (Zeng et al., 2021). Katoozian et al. (2018) report a 2.5-fold increased risk of occurrence in the first 3 months in subjects with intracerebral haemorrhage, severe paresis or impaired functional abilities.

The study by Liao et al. (2023) highlighted the correlation between basal ganglia haemorrhage (which has a frequency of 24.02%) and moderate to severe spasticity, with the risk being even higher in cases of brain stem haemorrhage (frequency of 36.84%).

At the same time, by analysing the degree of spasticity associated with intracranial haemorrhage, studies have identified a correlation between spasticity and the location of the lesion, age, NIHSS scores (stroke severity quantification scores) and harmful habits such as alcohol consumption or smoking. (Liao et al. 2023)

Urban et al. (2010) identified a 42.6% risk in patients with post-stroke central paresis as an initial sign. These authors say that paresis and hemihypoesthesia present at the onset of the incident are predictive factors that can predict the onset of spasticity. Loss of deep tendon reflexes accompanied by post-injury upper motor neuron hypotonia is considered a negative sign, indicating progression to spasticity (Trompetto, 2014).

Young people with haemorrhagic stroke and moderate/severe functional impairment should be closely monitored as a crucial part of spasticity management in order to develop appropriate recovery and rehabilitation strategies. (Cheng et al., 2023)

Degrees of spasticity

Spasticity can range from mild muscle stiffness to severe, painful and uncontrollable muscle spasms. (Ghai et al., 2013) Described as stiffness (Rivelis et al., 2023), complications of spasticity can be observed initially in muscle tone and muscle contractions and then, in the long term, can lead to more profound secondary changes in the joints and bones, with structural deformities and

impaired quality of life due to changes in the way movements are performed. Ghai et al. (2013) also draw attention to the low self-esteem that may be present in these subjects who are no longer able to care for themselves, with personal hygiene becoming poor due to muscle dysfunction. For this reason, psychological factors can influence the evolution of subjects with spasticity.

In children with cerebral palsy, muscle spasticity has neural and non-neural components, can interfere with the acquisition of skills and functions, and can serve to facilitate them. In these subjects, therapeutic reduction must be analysed in terms of functional impact and multiple factors associated with motor age, especially since after the age of 3, the passive properties of muscles change (Willerslev-Olsen et al. 2013).

In contrast, post-stroke spasticity is caused by a reduction in the spatial threshold of the tonic reflex, so the active ROM angle at which it begins to manifest will be influenced by descending and segmental signals under the control of motor neurons.

Spasticity and muscle rigidity after stroke, according to Mullick et al. (2013), arise due to changes in descending facilitatory control in combination with dynamic and/or presynaptic control deficits of the fibres that conduct motor neuron inputs.

It occurs as a result of limitations in the adjustment range of the threshold at which the tonic reflex manifests, i.e. the joint angle at which the stretch reflex begins to act due to descending and segmental influences on the motor neurons.

The results of studies suggest that spasticity and rigidity appear as deficits in descending facilitatory control, combined with deficits in dynamic and/or presynaptic fusimotor control of inputs to the motor neurons.

Characteristic symptoms after the onset of spasticity

After lesions of the descending motor pathways, spasticity is accompanied by paresis occurring in the upper motor neuron syndrome.

It should be noted that muscle symptoms evolve, are dynamic, and their maximum extent is clinically visible days or months (Ghai et al., 2013) after the initial lesion.

There are conditions in which the lesions are non-progressive (cerebral palsy) or progressive (multiple sclerosis) or have the potential to become progressive (a new stroke).

Initially, *in the acute phase* of brain damage, muscle tone is flaccid, deep tendon reflexes decrease, then hyporeflexivity is replaced by

painful stiffness due to muscle shortening, contractures and spasms.

With few exceptions, spasticity is found mainly in the flexor muscles of the upper limb (Urban et al. 2010) and extensor muscles of the lower limb, with higher values occurring when the muscle is elongated (Trompetto, 2014).

Spasticity depends on the speed of muscle contraction and the range of motion that changes the length of the fibres, and a characteristic clinical sign is the 'clasp knife phenomenon'.

The muscles around a joint are involved in the process of co-contraction, in which they participate as agonists and antagonists.

In healthy individuals, the voluntary activation of some muscles inhibits those in the other group and vice versa to achieve voluntary and functional movement. However, in UMN, mutual inhibition in voluntary movements is lost and abnormal muscle hyperactivity occurs, limiting functionality by restricting strength and movement.

Spastic hypertonia has two components: stretch reflex-mediated hypertonia, which is spasticity, and hypertonia that alters soft tissues (non-reflex or intrinsic hypertonia) (Trompetto, 2014).

Quantification of spasticity

Spasticity, seen as a peripheral symptom of central nervous system damage, must be diagnosed and quantified in order to apply appropriate and individualised treatment management.

Management should follow two axes: 1) assessment of the central cause and 2) assessing the peripheral effects (which may occur after different periods of time) to establish general therapeutic goals such as improving function, reducing the risk of peripheral musculoskeletal complications, alleviating pain and supporting the maintenance of hygiene, dressing and transfers (Ghai et al., 2013).

It should be emphasised that these central causes and peripheral effects are dynamic. Even if the central lesion becomes stable, peripheral changes may evolve even long after the initial incident.

To assess and determine its severity, scales based on the clinician's knowledge and simple to apply, biomechanical measurements of joint changes or some neurophysiological methods are used (Biering-Sørensen et al., 2006; He et al., 2023). However, Biering-Sørensen et al. (2006) considered that these are not easy and reliable methods for daily clinical assessment.

Neurophysiological studies use the Hoffman reflex and the F wave, which quantify the excitability of the reflex arc and the alpha motor neuron. These can provide information about the

mechanisms underlying the onset of spasticity but are not based on standardised protocols, and alternative or improved objective solutions are needed. (He et al., 2023)

Yu et al. (2020) consider that the tonic stretch reflex threshold is difficult to implement, requiring multiple slow passive stretches to be assessed. They propose that spasticity be assessed based on signals obtained from a surface electromyogram (sEMG) that quantifies movements or responses to electrical stimuli together with an adaptive neuro-fuzzy inference system (ANFIS), which Yu et al. (2020) have named the sEMG-ANFIS method.

Although it has been a widely researched topic, the assessment of spasticity still requires attention to identify the optimal assessment method and not to quantify the value of resistance to passive movement (Aloraini et al., 2015).

Clinically, there is a difference in the degree of spasticity manifestation in active and passive movements. According to He et al. (2023), assessments should be a combination of the two to understand the changes holistically and to have improved assessments.

The need for a comprehensive and dynamic assessment

Effective treatment requires an understanding of the pathophysiology, natural progression and impact on patient performance. The therapist's analysis should focus on epidemiology, the presumed mechanisms of spasticity, clinical manifestations and post-treatment evidence and outcomes (Kuo et al., 2018). the effects of spasticity and muscle contracture during dynamic tasks such as walking (van der Krogt et al., 2016). The International Society for Neuromodulation (INS) recommends that when faced with a subject with spasticity, the therapist should examine multiple aspects: the nature of spasticity, establishing how it developed in relation to the etiological lesion, its changes over time and under therapy, throughout the day (depending on emotional state) and during sleep, the association of other symptoms such as pain, as well as changes in pressure or touch. The degree of spasticity fluctuates under extrinsic or intrinsic influences, differing from individual to individual, which is why new assessment methods need to be developed and applied.

Quantification is very important for early intervention and comprehensive treatment in order to optimise recovery outcomes.

From a clinical point of view, it is crucial to be able to differentiate and weigh spasticity between

nervous resistance and the muscle changes it causes (Willerslev-Olsen et al., 2013).

After assessment, recovery strategies can be tailored to the predominance of the components involved in the symptoms accompanying spasticity: a predominantly neurogenic component may benefit from therapies to reduce the spinal stretch reflex, while stretching and physical exercise are more appropriate and effective for those with a non-neurogenic component. (Lindberg et al., 2011)

The ideal assessment method should be sensitive to many aspects (depending on age, activity, emotional state, for example), easy to apply (both for the therapist in terms of learning the technique, assessment time, availability and handling of the devices used, and for the subject being assessed) demonstrating reliability and increased reproducibility, the cost-effectiveness factor should not be neglected. Many clinical methods are based on the clinician's knowledge, which leads to low reliability.

Given the importance of spasticity assessment and its relevance to motor impairment and rehabilitation techniques, together with the stated limitations of existing clinical scales, many attempts have been made to provide clinically effective and reliable solutions. Low-cost, dynamic monitoring can be achieved through remote assessments. Clinicians and therapists face many challenges in managing spasticity, but state-of-the-art technological opportunities and solutions can meet these needs.

Complementing traditional clinical scales, technical devices are playing an increasingly significant role in the objective assessment of spasticity.

Technical devices for assessing spasticity have evolved and play a dual role in research and clinical practice, both in assessment and therapy. Some of these devices make it possible to assess the mechanical or electrical properties of muscles and joints during both passive and active movements, which an assessment scale cannot provide.

♦ **Devices such as isokinetic dynamometers** can assess speed-dependent resistance by controlling the speed of joint movement and quantifying the resistance force exerted by the muscles.

Robotic devices (e.g. Amadeo, which assesses hand spasticity) have been developed for use as active therapy. The device performs controlled movements of the limbs and measures the resistance, stiffness or biomechanical parameters of the muscle-joint complex.

♦ A major advantage for both the subject and the therapist can also be **wearable sensors**, which provide quantitative data on movement and muscle resistance and can quantify joint angles, movement speed and acceleration during passive or active exercises or in the subject's daily activities.

The novelty is that these sensors are integrated into orthoses that subjects can wear throughout the day, during functional activities, in different emotional situations. These devices have the advantage of recording and analysing large amounts of values and data, remotely transmitting the stroke subject's situation to the therapist and, above all, providing dynamic feedback on the subject's progress.

There are new emerging technologies such as devices that combine various sensors (inertial measurement units or EMG) integrated into wearable devices to ensure continuous monitoring.

Various systems and devices are being developed and proposed in research institutions and on the market that should respond to the individual factors of the subject, therapeutic objectives and individual rehabilitation needs, offering comfort at affordable prices.

Research such as that by Amin et al. (2024) highlights reliable devices with features such as remote monitoring, clinical data collection, low energy consumption, and use of the cloud for longitudinal monitoring of spasticity and to reduce costs. Dynamic splints have been developed to quantify muscle spasms in the flexors of the hand (Yang et al., 2021). The team of De Santis et al. (2024) developed a portable system based on inertial measurement units that can assess spasticity during the pendulum test for subjects with spinal cord injuries with spasticity in the lower limbs (knee extensors). It is possible that many of the devices developed for a specific type of pathology will be applied to stroke subjects in the near future.

The use of these devices, especially dynamic and combined ones, may represent a new step in the deeper understanding of spasticity and its effects. Although some of these are still in the experimental stage, these devices also require implementation according to standardised guidelines and protocols for use in order to achieve reliable results.

Many results have been reported on the effects of exercise programmes using these new devices, such as dynamic orthoses, muscle stimulation devices or virtual reality. Improvements in upper limb motor function in stroke patients using new

devices have been observed in the form of greater range of motion and improved dexterity, albeit not significantly, but orthoses produce the best results for subjects with spastic stroke. (Song et al., 2024) Following the finding that training incorporating wearable devices can provide augmented feedback that can also be a valuable complement to traditional clinical assessments used for stroke subjects, which can improve therapy outcomes (Johansson & Öhberg, 2025).

In rehabilitation that also incorporates devices with internal sensors, clinicians can enjoy new facilities by being able to accurately and validly monitor and individualise the intervention according to the subject's needs. (Lanotte et al., 2024)

The advantage of portable virtual immersive technology used in therapy is that it provides high-quality feedback that can increase synaptic efficacy, optimising the flow of information between the cerebral cortex and subcortical structures with the aim of restoring normal sensory feedback, resulting in better coordination and functionality of the limbs of stroke subjects (Song et al., 2024).

Weizman et al. (2022) analysed studies that used wearable inertial sensors that can estimate translational and rotational body movements, exaggerated by speed in the case of modified stretch reflexes in spasticity. The researchers emphasised that the usefulness and interest in these devices will bring benefits in contrast to clinical assessments that do not use instruments (Weizman et al., 2022).

Further research is needed to investigate and optimise the effectiveness and, in particular, the accuracy of methods for assessing spasticity and all the changes it causes (He et al., 2023).

Multiple studies provide valuable results on assessment and recovery interventions in stroke subjects, The results will lead to standardisation of technology integration in the treatment of post-stroke dysfunction, thus providing clinicians with effective strategies for improving spastic limb function (Zeng et al., 2021), for quality values and for eliminating errors (Silva et al., 2024).

Thanks to the characteristics of these portable devices, the treatment and management of spasticity will enter a new phase/era. The new devices have advantages such as:

- they are lightweight and portable, making outpatient therapy accessible and easy to apply in multiple environments, in everyday life and activities

- they have multiple control options for settings that tailor therapy to the subject's needs, combining assessment with therapy.

These features will bring new insights and data that will lead to more therapeutic benefits for people with spasticity.

Conclusion

We know that different tests, scales and devices assess different aspects of spasticity.

Reliable monitoring (for both the therapist and the subject with spasticity), at low cost, reproducible, dynamic and, above all, over long periods of time, can be achieved through remote assessments using technologies and devices that can manage spasticity but must overcome many challenges. However, the opportunities and solutions offered by state-of-the-art technology, based on electrophysiological and biomechanical techniques, can meet these requirements.

With the emergence and development of new devices that attempt to solve the problems faced by therapists and subjects with spasticity, new monitoring functions will help document many characteristics of spasticity. However, standardised guidelines for their use will be necessary for their widespread implementation in clinical practice or extensive research.

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