JOURNAL OF MOVE AND THERAPEUTIC SCIENCE

2023; 5(2):m45

Estimulación magnética periférica repetitiva para mejorar la espasticidad y la función de la mano en un paciente con accidente cerebrovascular crónico. Un estudio de un caso

Alfredo Lerín Calvo[1,2]; David Rodríguez Martínez[2]; Enrique Carrasco González[2,3]

1. Departamento de Fisioterapia, Centro Superior de Estudios Universitarios La Salle. Universidad Autónoma de Madrid, Madrid, Aravaca, España.
2. Clínica de rehabilitación Neurológica Neuron Rehab
3. Umiversidad Eurpea Miguel de Cervantes, Valladolid, España

Correspondencia:

Enrique Carrasco González, MSc.
Clínica de rehabilitación Neurológica Neuron Rehab
28003
Teléfono: *(+34) 91 598 8463*
E-mail: enri.96glx@gmail.com

Conflicto de Intereses:

Los autores declaran no tener ningún conflicto de intereses. Este proyecto no ha sido presentado en ningún evento científico

Financiación:

Los autores declaran no haber recibido financiación/compensación para el desarrollo de esta investigación.

DOI: 10.37382/jomts.v5i2.1133

Recepción del Manuscrito:

5-Noviembre-2023

Aceptación del Manuscrito:

21-Diciembre-2023

RESUMEN

Objetivos: El objetivo de este estudio es observar si la estimulación magnética periférica repetitiva puede llegar a mejorar la espasticidad y la función en el miembro superior en pacientes con accidente cerebrovascular crónico.

Métodos: Hombre blanco de 69 años que se le diagnosticó un accidente cerebrovascular isquémico de la arteria cerebral media en julio del 2020. El procedimiento consistió en dos semanas de tratamiento control mediante entrenamiento robótico y orientado a tareas, seguido de cuatro semanas de tratamiento experimental aplicando rPMS, añadiendo el tratamiento control. Finalmente se aplicó el tratamiento control durante 2 semanas más. Se llevaron a cabo evaluaciones de espasticidad utilizando rPMS y un goniometro, función motora con la prueba de Nine Hole Peg Test y Finger Taping Test. A nivel estadístico se aplico el método de banda descriptica de dos desviaciones estándar (DTSD) para ver el efecto del tratamiento aplicado.

Resultados: Se obtuvieron resultados estadísticamente significativos en la espasticidad y la función motora, pero no en la velocidad de los dedos.

Conclusiones: Los resultados mostraron que la aplicación de rPMS, combinada con entrenamiento robótico y orientado a tareas, podría conducir a mejoras en la espasticidad y función motora. Esto refleja nuevos enfoques para el tratamiento de pacientes con ictus en la implicación de la espasticidad y en su función.

Palabras clave: Estimulación Magnética Periférica Repetitiva, Espasticidad, Hiperresistencia, Ictus

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Repetitive Peripheral Magnetic Stimulation to Improve Upper Limb Spasticity and Function in a Chronic Stroke Patient, A Silgle Case Study

Alfredo Lerín Calvo[1,2]; David Rodríguez Martínez[2]; Enrique Carrasco González[2,3]

4. Departamento de Fisioterapia, Centro Superior de Estudios Universitarios La Salle. Universidad Autónoma de Madrid, Madrid, Aravaca, España.
5. Clínica de rehabilitación Neurológica Neuron Rehab
6. Umiversidad Eurpea Miguel de Cervantes, Valladolid, España

Correspondence:

Enrique Carrasco González, MSc.
Clínica de rehabilitación Neurológica Neuron Rehab
28003
Phone: *(+34) 91 598 8463*
E-mail: enri.96glx@gmail.com

Conflict of Interest disclosure:

The authors declare that they have no conflict of interest. This project has not been presented at any scientific event.

Financial disclosure:

The authors declare that they have received no funding/compensation for the development of this research.

DOI: 10.37382/jomts.v5i2.1133

Date of reception:

5-November

Date of acceptance:

21-December-2023

ABSTRACT

Objectives: The objective of this study is to observe whether repetitive peripheral magnetic stimulation can improve spasticity and function in the upper limb in patients with chronic stroke.

Methods: 69-year-old white man who was diagnosed with an ischemic stroke of the middle cerebral artery in July 2020. The procedure consisted in two weeks of control treatment using robotic and task-oriented training, followed by four weeks of experimental treatment applying the rPMS intervention added to the control treatment. Finally control treatment alone was applied for two weeks. Assessments of spasticity using rPMS and a goniometer, motor function with nine hole peg test and speed of finger with Finger Taping Test were carried out. Two standard deviations descriptive band (DTSD) method was carried out to see the effect of treatment applied.

Results: Statistically significant results were obtained in spasticity and motor function, but not on the speed of finger.

Conclusion: The results showed that the application of rPMS, combined with robotic and task-oriented training, could led to improvements in spasticity and motor function. This reflects new approaches for treating chronic stroke patients based on the implication of the spasticity on their function.

Keywords: Repetitive Peripheral Magnetic Stimulation, Spasticity, Hyperresistance, Stroke

INTRODUCTION

Stroke, a leading cause of disability worldwide, has seen a notable increase in incidence among adults aged 20 to 64 years (Katan and Luft, 2018). Upper limb motor deficits are common post-stroke, affecting roughly 50% of patients even four years after the event (Broeks et al., 1999). Spasticity, characterized by increased tonic stretch reflexes and exaggerated tendon jerks, affects approximately 65% of stroke patients, severely limiting mobility and potentially worsening long-term disability (Lance, 1980; Bethoux, 2015; Opheim et al., 2015).

The terminology surrounding spasticity has been debated, leading to suggestions such as renaming it "hyperresistance" to distinguish neural from non-neural resistance, that is essential for understanding conditions like Spastic Dystonia (van den Noort et al., 2017; Puce et al., 2021).

Spasticity scales, like the modified Ashworth Scale, often lack the ability to differentiate between neural and non-neural components (Fleuren et al., 2010), Similarly, the modified Tardieu Scale, which aims to distinguish different types of hyperresistance, has limited reliability for clinical use (Li, Wu and Li, 2014).

This ambiguity in terminology and measurement methods has led to mixed results in scientific articles, complicating the evaluation of spasticity treatments, which frequently involve pharmacological or electrical stimulation-based approaches (Levy et al., 2019; Mahmood et al., 2019; Sun et al., 2019). Consequently, some studies have started exploring a functional perspective on treatment (Pike et al., 2022; Kassam et al., 2023). Repetitive Magnetic Peripheral Stimulation (rPMS) has emerged as a validated method for assessing spasticity, offering a more functional understanding of its impact on upper limb movement in stroke patients (Fernandez-Lobera, Morales and Valls-Solé, 2022). rPMS applies a high-frequency magnetic stimulation over the muscle belly that induces a muscular contraction by stimulation of the terminal branches of motor nerve (Machetanz et al., 1994). This type of stimulation is painless, and his potential for stimulating motor axons over cutaneous and nociceptive fibers has been demonstrated in previous studies (Beaulieu and Schneider, 2015; Beaulieu et al., 2015).

Recent research has highlighted the efficacy of rPMS in reducing spasticity when employing various protocols in stroke patients (Pan et al., 2022). However, it´s unknown how it can affect the function of the patients presenting reflex tonic reactions. Thus, the main purpose of this article is to evaluate the effectiveness of rPMS as a tool for measuring and treating a chronic stroke patient, focusing on a functional evaluation for reducing spasticity and it´s repercussion in the motor function.

METHODS

Participant and History

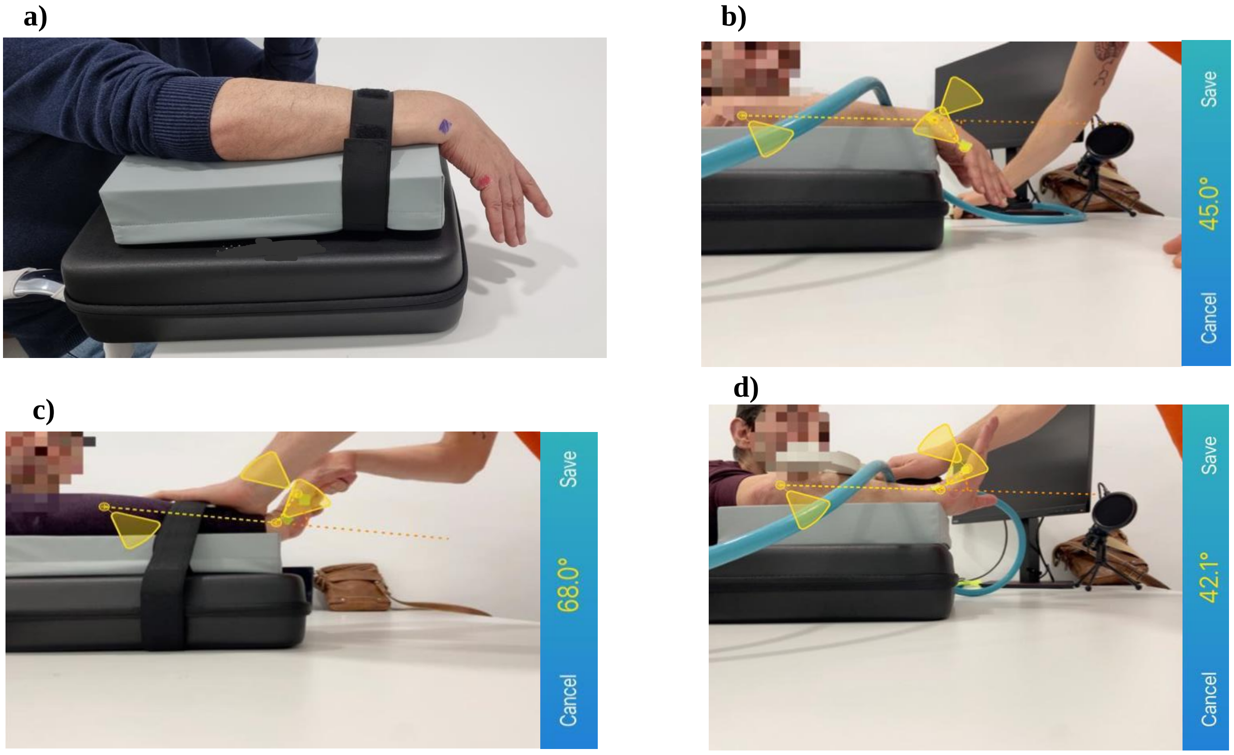
The patient, a 69-year-old man, suffered an ischemic middle cerebral artery stroke in July 2020. This resulted in mild, intelligible dysarthria, moderate right hemiplegia, paresthesia, and significant right finger-nose dysmetria. Over the past year, he received physiotherapy, occupational therapy, and speech therapy to improve his autonomy. Upon evaluation in the clinic, he exhibited fluent speech, but marked right hemiparesis, particularly in distal muscles, limiting his ability to perform tasks requiring a strong grip or pincer motion. He also experienced hypoesthesia and difficulties in daily activities, leading to moderate dependence. His primary goals were to enhance his grasp and object discrimination, allowing him to handle cans, use clothes pegs, open his front door, and recline on his couch using a side button.

Examination Methods

Spasticity: To Assess the spasticity, a protocol employed before in (Fernandez-Lobera, Morales and Valls-Solé, 2022) was used. This protocol included a passive Range of Movement (pROM) evaluation where the therapist manually moved the wrist from a resting position to maximal extension while avoiding reflex reactions. It also involved evaluating the patient's range of movement after rPMS stimulation, termed contraction Range of Movement (cROM). To induce the movement of wrist extension we used a STM9000 Magnetic Stimulator equipped with a figure-eight-coil (SOINDE).

For assessment, the patient's forearm was placed in a pronated position on an adjustable table. Velcro

Figure 1. Preparation and evaluation of spasticity with rPMS. a) Position of the patient for the evaluation. b) Relaxed hand before the stretch. c) pROM of the wrist. d) cROM of the wrist applying the rPMS.



strips secured the forearm in place, allowing the hand to hang freely over the table's edge, establishing a natural wrist angle based on forearm muscle tone. The shoulder was slightly abducted (20º) and the elbow joint maintained at approximately 120º.

We used the Iphone app DrGoniometer (CDM, S.r.L., Cagliari, Italy) to assess the wrist extension angle (Otter et al., 2015; Reid and Egan, 2019). An external evaluator, independent of the study, ensured the iPhone was held perpendicular to the floor and stable on the table. Two markers were affixed to the styloid process of the ulna and the head of the fifth metacarpal. Photos were taken in the initial and final positions to assess both passive Range of Movement (pROM) and contraction Range of Movement (cROM) (Fig. 1). The final Range of Movement (fROM), indicating the impact of spasticity on movement, was determined by subtracting cROM from pROM.

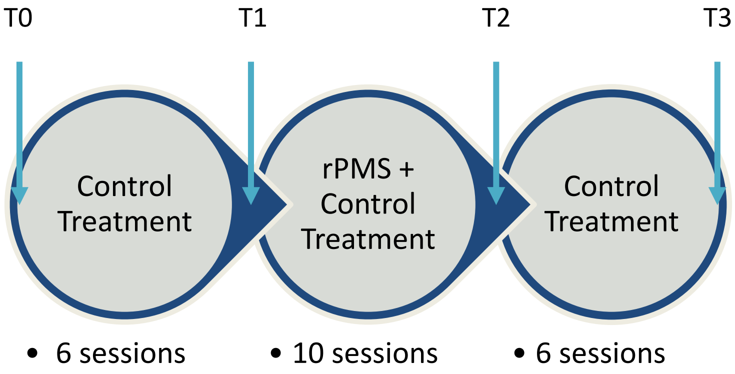
Motor Function: To Assess Motor Function and dexterity of the upper limb, Nine Hole Peg Test (NHPT) was employed. The time required to complete the tasks was measured (Mathiowetz et al., 1985).

Speed of finger tapping: This capacity has been related with functional outcomes like Barthel Index or Frenchay Activities Index in subacute stroke patients, being an indirect measure of biological recovery (De Groot-Driessen, Van De Sande and Van Heugten, 2006). Finger Taping Test (FTT) was measured using an CNS Finger Tapping Test app (Tushar-Kalra, Uttarakhand, India.) (Boukhvalova et al., 2018). The test involved tapping the mobile screen as quickly as possible for 10 seconds, with two attempts for each hand, and the average was used as the final measure. The therapist ensured hand stability to prevent compensatory movements (Arnold et al., 2005).

Intervention

The Treatment procedure is shown in Fig 2. 10 control treatment sessions were carried out for 2 weeks. Afterwards, 10 experimental sessions were conducted for 4 weeks, followed by 6 more control sessions for an additional 2 weeks. This protocol was carried on in order to keep an A1BA2 design, which is recommended for single case studies (Lobo et al., 2017) and applying the number of sessions followed by Krewer’s group (Krewer et al., 2014).

Figure 2. Procedure of treatment and assessments.



Control treatment consisted in Robotic and Task-Oriented Training while the experimental intervention involved the rPMS intervention, applied 10 minutes before the same control treatment.

rPMS intervention

5 Hz low-frequency stimulation with 15 stimulus per train was applied for a total of 750 stimuli over flexors muscles (spastic), and 20Hz High-Frequency stimulation with 30 stimulus per train for a total of 5100 stimuli was used for extensor muscles. The intensity was set at 100% of the muscle contraction threshold, with 1-second rests between trains, following the protocol by (Chen et al., 2020). The average duration of rPMS was 10 minutes.

Robotic and Task-Oriented Training

Control treatment comprised 20 minutes of hand-focused robotic training using the Amadeo robotic system (Tyromotion GmbH Graz, Austria) through the CPMPlus and assisted program, providing 150-200 hand opening and closing movements (Sale, Lombardi and Franceschini, 2012), followed by 15 minutes of adaptive, progressive therapy targeting strength, range of motion, and mobility. Finally, there was 25 minutes of Task-Oriented Training focused on daily living activities aligned with the patient's goals.

Statistical analysis

Two standard deviations descriptive band (DTSD) method was carried out in order to see the effect of treatment applied. DTSD is based on the computation of the standard deviation for the baseline data. Once the standard deviation is computed for the baseline data, bands are drawn on the graph that contain scores within +2 standard deviations from the mean. This procedure has the advantage of being sensitive to changes in variability across the phases of a single-subject design (Nourbakhsh and Ottenbacher, 1994).

RESULTS

All the results obtained after the treatment are reflected on Table 1 and the statistical analysis is reflected in Table 2.

Spasticity

Results in spasticity reflects that there has no significant change in pROM neither after the treatment and after two weeks. However, we could see an increase in cROM post treatment which decreased in the follow-up, still being a significant increase with respect to baseline measure. fROM decreased after the treatment in a statistically significant way, but there were no significant changes after the treatment.

Motor tasks

The patient only showed statistically significant differences when performing NHPT with the affected hand, not with the unaffected hand, and despite of decreasing the number of pegs with the affected hand in the follow-up, results indicate significant changes in this assessment too.

Speed of finger tapping

FTT showed no difference when performed with the affected or unaffected hand.

DISSCUSION

Table 2. Resuts. pROM: Passive Range of Movement; cROM: contraction Range of Movement; fROM: final Range of Movement; NHPT: Nine Hole Peg Test; FTT: Finger Tapping Test.

Assesment	Baseline	Pre-Treatment	Post-treatment	Follow-up
Spasticity				
pROM	103,5º	105,6º	107,4º	104,8º
cROM	69º	65,4º	87,1º	73,8º
fROM	34,5º	40,2º	26,6º	31º
NHPT				
Affected	2 pegs	1,5 pegs	3,5 pegs	2,5 pegs
Non-affected	25,38 s	23,65 s	24,58 s	26,19
FTT				
Affected	19	20	20	20,5
Non-affected	44,67	49	44,87	43,6

Wrist spasticity is a common challenge for stroke survivors, often impairing their ability to perform daily activities (Malhotra et al., 2011; Pundik et al., 2014). Our study reflects an improvement in spasticity after applying an rTMS treatment combined with RAT and TOT that is in accordance with the concept of neural hyperresistance, since the patient has demonstrated changes in cROM and fROM, but not statistically significant changes in pROM.

Table 1. Statistical Analysis. pROM: Passive Range of Movement; cROM: contraction Range of Movement; fROM: final Range of Movement; NHPT: Nine Hole Peg Test; FTT: Finger Tapping Test. *Statistical significance difference.

Assesment	Baseline Mean ± SD	[Upper limit – Lower limit]	Post-treatment	Follow-up
Spasticity				
pROM	104,55 ± 1,48	[107,52 - 101,58]	107,4	104,8
cROM	67,20 ± 2,55	[72,29 – 62,11]	87,1*	73,8*
fROM	37,35 ± 4,03	[45,41 – 29,29]	26,6*	31
NHPT				
Affected	1,75 ± 0,35	[2,46 – 1,04]	3,5*	2,5*
Non-affected	24,52 ± 1,22	[26,96 – 22,07]	24,58	26,19
FTT				
Affected	19,5 ± 0,71	[20,91 – 18,09]	20	20,5
Non-affected	46,84 ± 3,06	[52,96 – 40,71]	44,87	43,6

Other studies have demonstrated an improvement in spasticity measured with Modified Asworth Scale (MAS) or Modified Tardieu Scale (MTS) after applying rPMS (Krewer et al., 2014; Chen et al., 2020), however this is the first study that uses rPMS for measuring changes in spasticity, differentiating the changes observed in cROM, pROM and fROM, which provides a different point of view for treating hyperresistance based on the functional limitation and the characteristics of the patient.

Concerning the neurophysiological effects induced by rPMS, other authors had suggested that rPMS can evoke a sensitivity reduction of the γ-motor regulatory circuit due to the proprioceptive input applied on the muscle layer (Zschorlich et al., 2019). This mechanism differs from treatments like botulinum toxin, which primarily act presynaptically to inhibit acetylcholine release, resulting in decreased neuromuscular junction output (Duchen and Strich, 1968). Based on the results obtained with this work, we could purpose different treatments based on the type of hyperresistance of the patient and its influence on his ADL´s.

Changes in spasticity observed in this work, have therefore led to an improvement in functional capacity assessed with 9HPT but not on the FTT. Thus, improvements obtained in functional capacity would be related to the achievement of the objectives proposed by the patient, not to an increase in the excitability of the corticospinal tract or a recovery of the motor pathways. rPMS would therefore serve as a tool to ensure the patient is able to achieve those actions for which hyperresistance is impeding their accomplishment.

While intensive treatment programmes are commended for stroke recovery at any stage of stroke (Ward, Brander and Kelly, 2019), numerous barriers, including social, economic, and healthcare access issues, limit many patients' ability to benefit from these services (Janssen et al., 2020). Neurological recovery is consequently limited by a ceiling effect due to the dose of therapy they are able to perform, and the inclusion of compensatory strategies for the recovery of functional abilities and independence in daily life becomes more relevant as a therapeutic strategy (Buma, Kwakkel and Ramsey, 2013; Jones, 2017). The use of SMART (Specific, Measurable, Achievable, Relevant, and Timed) objectives, often assessed through the Goal Attainment Scale (GAS), is particularly relevant in this context. This approach allows patients to define their priorities, tailoring their rehabilitation goals based on both the domain of their objectives and the scaled outcome attainment levels (Bovend'Eerdt, Botell and Wade, 2009; Grant and Ponsford, 2014).

This study demonstrates that rPMS can be particularly useful in those cases where, after identifying the influence of spasticity (not muscle shortening/stiffness resulting from prolonged immobilization) on the patient's performance of a function, the increased excitability of the stretch reflex is preventing or delaying the achievement of specific goals that are important for the patient.

Frequently spasticity improves in chronic patients after applying some treatments like botulinum toxin or other pharmacological interventions (Sun et al., 2019), but the assessments used on this trials for measuring spasticity aren´t functional, and other variables like quality of life or motor function don´t improve, and recent evidence suggests that the use of such treatments should be reduced (Lindsay et al., 2016; Multani et al., 2019). rPMS could be a useful tool for the assessment and treatment of spasticity based on functional deficits because it could result in a more accurate approach to post-stroke upper limb rehabilitation processes focusing on the neural component of the hyperresistance and its influence in function.

Finally, despite the significant changes observed in different variables, after the last assessment carried out as a follow-up, (2 weeks after applying the treatment), a trend towards a decrease in the cROM was observed and an increase in the fROM. When an infiltration with botulinum toxin is applied, it is known that there are certain variables that can modify the time of onset and duration of the effect, but it is estimated that it takes between 2 and 5 days for the effect to appear, and that it lasts approximately 2-3 months, with the maximum peak occurring at 5-6 weeks. (Ledda et al., 2022). However, we do not know the duration of the effect of rPMS on spasticity, nor the time required for the reversibility of the changes achieved, so further research is needed to understand these questions so that the dose of rPMS application can be adjusted in future studies.

Furthermore, it is necessary to know whether the dose of rPMS application can modify the effects obtained, and if so, to obtain the necessary evidence to establish individualized treatment approaches based on the specific requirements of the patients.

The limitations of this study design lacks external validity, highlighting the need for placebo-controlled research to assess the true impact of the technique on functionality, despite observing significant changes using a validated statistical method for single-case designs (Nourbakhsh and Ottenbacher, 1994).

The patient's specific characteristics hindered a direct comparison with the original NHPT procedure, which measures the time to place all pegs. the Minimum Detectable Change (MDC) of this test is established based on this measurement, with cut-off values of 6.8 seconds for the unaffected limb and 32.8 seconds for the affected limb (Chen et al., 2009). This makes it challenging to directly correlate our findings with existing literature. Hence, the significance obtained from our analysis holds significant weight in assessing whether the changes stem from the experimental treatment.

CONCLUSION

In conclusion, this single case study evaluated the effectiveness of repetitive Peripheral Magnetic Stimulation (rPMS) in reducing upper limb spasticity and improving function in a chronic stroke patient. The results showed that the application of rPMS, combined with robotic and task-oriented training, led to improvements in spasticity and motor function.

This study provides valuable insights into the application of rPMS for measuring and addressing upper limb spasticity in stroke patients. By differentiating the changes observed in cROM, pROM, and fROM, the study offers a functional perspective on treating hyperresistance based on the individual's limitations and characteristics. Furthermore, the combination of rPMS with robotic and task-oriented training appears to be a promising approach for improving motor function in chronic stroke patients.

However, further research with larger sample sizes and controlled designs is necessary to validate these results and establish the optimal parameters for rPMS intervention.

FRASES DESTACADAS

- En el tratamiento, se deben icluir estrategias compensatorias para la recuperación de capacidades funcionales y la independicia en la vida diaria.
- La disminución de la espasticidad puede mejorar la capacidad functional del paciente.
- Se podria llegar a porponer diferentes tratamietnos en función del tipo de hiperresistencia del paciente y su implicación en las Actividades de la Vida Diaria

HIGHLIGHTS

- The treatment should include compensatory strategies for the recovery of the functional abilities and independence on daily life becomes more relevant as a therapeutic strategy
- Decreasing spasticity can improve the patient´s functional capacity
- We could purpose different treatments based on the type of the hiperresistance of the patient and influence on his ADL´s.

REFERENCIAS

Arnold, G. et al. (2005) 'Sensitivity and Specifity of Finger Tapping Test Scores for the Detection of Suspect Effort', The Clinical Neuropsychologist, 19(1), pp. 105–120. Available at: https://doi.org/10.1080/13854040490888567.

Beaulieu, L.-D. et al. (2015) 'Noninvasive neurostimulation in chronic stroke: a double-blind randomized sham-controlled testing of clinical and corticomotor effects', Topics in Stroke Rehabilitation, 22(1), pp. 8–17. Available at: https://doi.org/10.1179/1074935714Z.0000000032.

Beaulieu, L.-D. and Schneider, C. (2015) 'Repetitive peripheral magnetic stimulation to reduce pain or improve sensorimotor impairments: A literature review on parameters of application and afferents recruitment', Neurophysiologie Clinique/Clinical Neurophysiology, 45(3), pp. 223–237. Available at: https://doi.org/10.1016/j.neucli.2015.08.002.

Bethoux, F. (2015) ‘Spasticity Management After Stroke’, Physical Medicine and Rehabilitation Clinics of North America, 26(4), pp. 625–639. Available at: https://doi.org/10.1016/j.pmr.2015.07.003.

Boukhvalova, A.K. et al. (2018) ‘Identifying and Quantifying Neurological Disability via Smartphone’, Frontiers in Neurology, 9. Available at: https://doi.org/10.3389/fneur.2018.00740.

Bovend’Eerdt, T.J.H., Botell, R.E. and Wade, D.T. (2009) ‘Writing SMART rehabilitation goals and achieving goal attainment scaling: a practical guide’, Clinical rehabilitation, 23(4), pp. 352–361. Available at: https://doi.org/10.1177/0269215508101741.

Broeks, J.G. et al. (1999) ‘The long-term outcome of arm function after stroke: results of a follow-up study’, Disability and rehabilitation, 21(8), pp. 357–364. Available at: https://doi.org/10.1080/096382899297459.

Buma, F., Kwakkel, G. and Ramsey, N. (2013) ‘Understanding upper limb recovery after stroke’, Restorative neurology and neuroscience, 31(6), pp. 707–722. Available at: https://doi.org/10.3233/RNN-130332.

Chen, H.M. et al. (2009) ‘Test-Retest Reproducibility and Smallest Real Difference of 5 Hand Function Tests in Patients With Stroke’, http://dx.doi.org/10.1177/1545968308331146, 23(5), pp. 435–440. Available at: https://doi.org/10.1177/1545968308331146.

Chen, S. et al. (2020) ‘Electroencephalography Mu Rhythm Changes and Decreased Spasticity After Repetitive Peripheral Magnetic Stimulation in Patients Following Stroke’, Frontiers in neurology, 11. Available at: https://doi.org/10.3389/FNEUR.2020.546599.

Duchen, L.W. and Strich, S.J. (1968) ‘The effects of botulinum toxin on the pattern of innervation of skeletal muscle in the mouse’, Quarterly Journal of Experimental Physiology and Cognate Medical Sciences, 53(1), pp. 84–89. Available at: https://doi.org/10.1113/expphysiol.1968.sp001948.

Fernandez-Lobera, M., Morales, M. and Valls-Solé, J. (2022) ‘Repetitive peripheral magnetic stimulation for the assessment of wrist spasticity: reliability, validation and correlation with clinical measures’, Disability and Rehabilitation, 44(18), pp. 5257–5267. Available at: https://doi.org/10.1080/09638288.2021.1925979.

Fleuren, J.F.M. et al. (2010) ‘Stop using the Ashworth Scale for the assessment of spasticity’, Journal of neurology, neurosurgery, and psychiatry, 81(1), pp. 46–52. Available at: https://doi.org/10.1136/JNNP.2009.177071.

Grant, M. and Ponsford, J. (2014) ‘Goal attainment scaling in brain injury rehabilitation: strengths, limitations and recommendations for future applications’, Neuropsychological rehabilitation, 24(5), pp. 661–677. Available at: https://doi.org/10.1080/09602011.2014.901228.

De Groot-Driessen, D., Van De Sande, P. and Van Heugten, C. (2006) ‘Speed of finger tapping as a predictor of functional outcome after unilateral stroke’, Archives of physical medicine and rehabilitation, 87(1), pp. 40–44. Available at: https://doi.org/10.1016/J.APMR.2005.09.022.

Janssen, J. et al. (2020) ‘Factors Influencing the Delivery of Intensive Rehabilitation in Stroke: Patient Perceptions Versus Rehabilitation Therapist Perceptions’, Physical Therapy, 100(2), p. 307. Available at: https://doi.org/10.1093/PTJ/PZZ159.

Jones, T.A. (2017) ‘Motor compensation and its effects on neural reorganization after stroke’, Nature reviews. Neuroscience, 18(5), pp. 267–280. Available at: https://doi.org/10.1038/NRN.2017.26.

Kassam, F. et al. (2023) ‘Canadian Physicians’ Use of Intramuscular Botulinum Toxin Injections for Shoulder Spasticity: A National Cross-Sectional Survey’, Toxins, 15(1), p. 58. Available at: https://doi.org/10.3390/toxins15010058.

Katan, M. and Luft, A. (2018) ‘Global Burden of Stroke’, Seminars in neurology, 38(2), pp. 208–211. Available at: https://doi.org/10.1055/S-0038-1649503.

Krewer, C. et al. (2014) ‘Effects of Repetitive Peripheral Magnetic Stimulation on Upper-Limb Spasticity and Impairment in Patients With Spastic Hemiparesis: A Randomized, Double-Blind, Sham-Controlled Study’, Archives of Physical Medicine and Rehabilitation, 95(6), pp. 1039–1047. Available at: https://doi.org/10.1016/j.apmr.2014.02.003.

Lance, J. (1980) Spasticity: Disordered Motor Control. Chicago: Year Book Medical Publishers.

Ledda, C. et al. (2022) ‘Time to onset and duration of botulinum toxin efficacy in movement disorders’, Journal of Neurology, 269(7), pp. 3706–3712. Available at: https://doi.org/10.1007/s00415-022-10995-2.

Levy, J. et al. (2019) ‘Does botulinum toxin treatment improve upper limb active function?’, Annals of Physical and Rehabilitation Medicine, 62(4), pp. 234–240. Available at: https://doi.org/10.1016/j.rehab.2018.05.1320.

Li, F., Wu, Y. and Li, X. (2014) ‘Test-retest reliability and inter-rater reliability of the Modified Tardieu Scale and the Modified Ashworth Scale in hemiplegic patients with stroke’, European journal of physical and rehabilitation medicine, 50(1), pp. 9–15. Available at: https://pubmed.ncbi.nlm.nih.gov/24309501/ (Accessed: 30 December 2022).

Lindsay, C. et al. (2016) ‘Pharmacological interventions other than botulinum toxin for spasticity after stroke’, Cochrane Database of Systematic Reviews, 2016(10). Available at: https://doi.org/10.1002/14651858.CD010362.pub2.

Machetanz, J. et al. (1994) ‘Magnetically induced muscle contraction is caused by motor nerve stimulation and not by direct muscle activation’, Muscle & Nerve, 17(10), pp. 1170–1175. Available at: https://doi.org/10.1002/mus.880171007.

Mahmood, A. et al. (2019) ‘Effect of Transcutaneous Electrical Nerve Stimulation on Spasticity in Adults With Stroke: A Systematic Review and Meta-analysis’, Archives of Physical Medicine and Rehabilitation, 100(4), pp. 751–768. Available at: https://doi.org/10.1016/j.apmr.2018.10.016.

Malhotra, S. et al. (2011) 'Spasticity and contractures at the wrist after stroke: time course of development and their association with functional recovery of the upper limb', Clinical rehabilitation, 25(2), pp. 184–191. Available at: https://doi.org/10.1177/0269215510381620.

Mathiowetz, V. et al. (1985) 'Adult Norms for the Nine Hole Peg Test of Finger Dexterity', The Occupational Therapy Journal of Research, 5(1), pp. 24–38. Available at: https://doi.org/10.1177/153944928500500102.

Multani, I. et al. (2019) 'Botulinum Toxin in the Management of Children with Cerebral Palsy', Pediatric Drugs, 21(4), pp. 261–281. Available at: https://doi.org/10.1007/s40272-019-00344-8.

van den Noort, J.C. et al. (2017) 'European consensus on the concepts and measurement of the pathophysiological neuromuscular responses to passive muscle stretch', European Journal of Neurology, 24(7), pp. 981-e38. Available at: https://doi.org/10.1111/ene.13322.

Nourbakhsh, M.R. and Ottenbacher, K.J. (1994) 'The statistical analysis of single-subject data: a comparative examination', Physical therapy, 74(8), pp. 768–776. Available at: https://doi.org/10.1093/PTJ/74.8.768.

Opheim, A. et al. (2015) 'Early prediction of long-term upper limb spasticity after stroke', Neurology, 85(10), pp. 873–880. Available at: https://doi.org/10.1212/WNL.0000000000001908.

Otter, S.J. et al. (2015) 'The reliability of a smartphone goniometer application compared with a traditional goniometer for measuring first metatarsophalangeal joint dorsiflexion', Journal of Foot and Ankle Research, 8(1), p. 30. Available at: https://doi.org/10.1186/s13047-015-0088-3.

Pan, J.-X. et al. (2022) 'Effects of repetitive peripheral magnetic stimulation on spasticity evaluated with modified Ashworth scale/Ashworth scale in patients with spastic paralysis: A systematic review and meta-analysis', Frontiers in Neurology, 13. Available at: https://doi.org/10.3389/fneur.2022.997913.

Pike, S. et al. (2022) 'Chronic stroke survivors with upper limb spasticity: linking experience to the ICF', Disability and Rehabilitation, 44(15), pp. 3925–3937. Available at: https://doi.org/10.1080/09638288.2021.1894490.

Prigatano, G.P. and Wong, J.L. (1997) 'Speed of finger tapping and goal attainment after unilateral cerebral vascular accident', Archives of physical medicine and rehabilitation, 78(8), pp. 847–852. Available at: https://doi.org/10.1016/S0003-9993(97)90198-2.

Puce, L. et al. (2021) 'Spasticity, spastic dystonia, and static stretch reflex in hypertonic muscles of patients with multiple sclerosis', Clinical Neurophysiology Practice, 6, pp. 194–202. Available at: https://doi.org/10.1016/j.cnp.2021.05.002.

Pundik, S. et al. (2014) 'Functional Brain Correlates of Upper Limb Spasticity and Its Mitigation following Rehabilitation in Chronic Stroke Survivors', Stroke research and treatment, 2014. Available at: https://doi.org/10.1155/2014/306325.

Reid, S. and Egan, B. (2019) 'The validity and reliability of DrGoniometer, a smartphone application, for measuring forearm supination', Journal of Hand Therapy, 32(1), pp. 110–117. Available at: https://doi.org/10.1016/j.jht.2018.03.003.

Sale, P., Lombardi, V. and Franceschini, M. (2012) 'Hand Robotics Rehabilitation: Feasibility and Preliminary Results of a Robotic Treatment in Patients with Hemiparesis', Stroke Research and Treatment, 2012, pp. 1–5. Available at: https://doi.org/10.1155/2012/820931.

Sun, L.-C. et al. (2019) 'Efficacy and Safety of Botulinum Toxin Type A for Limb Spasticity after Stroke: A Meta-Analysis of Randomized Controlled Trials', BioMed Research International, 2019, pp. 1–17. Available at: https://doi.org/10.1155/2019/8329306.

Ward, N.S., Brander, F. and Kelly, K. (2019) 'Intensive upper limb neurorehabilitation in chronic stroke: outcomes from the Queen Square programme', Journal of neurology, neurosurgery, and psychiatry, 90(5), pp. 498–506. Available at: https://doi.org/10.1136/JNNP-2018-319954.

Zschorlich, V.R. et al. (2019) 'Repetitive Peripheral Magnetic Nerve Stimulation (rPMS) as Adjuvant Therapy Reduces Skeletal Muscle Reflex Activity', Frontiers in Neurology, 10(AUG), p. 930. Available at: https://doi.org/10.3389/FNEUR.2019.00930.