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

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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 goniómetro, función motora con la prueba de Nine Hole Peg Test y Finger Taping Test. A nivel estadístico se aplico el método de banda descriptiva 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 Single Case Study

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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 lead 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 its 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
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).
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 CPMPPlus 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.

DISCUSSION
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 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

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

*Statistical significance difference.

### Table 2. Results

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Baseline</th>
<th>Pre-Treatment</th>
<th>Post-treatment</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spasticity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pROM</td>
<td>103,5°</td>
<td>105,6°</td>
<td>107,4°</td>
<td>104,8°</td>
</tr>
<tr>
<td>cROM</td>
<td>69°</td>
<td>65,4°</td>
<td>87,1°</td>
<td>73,8°</td>
</tr>
<tr>
<td>fROM</td>
<td>34,5°</td>
<td>40,2°</td>
<td>26,6°</td>
<td>31°</td>
</tr>
<tr>
<td>NHPT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affected</td>
<td>2 pegs</td>
<td>1,5 pegs</td>
<td>3,5 pegs</td>
<td>2,5 pegs</td>
</tr>
<tr>
<td>Non-affected</td>
<td>25,38 s</td>
<td>23,65 s</td>
<td>24,58 s</td>
<td>26,19</td>
</tr>
<tr>
<td>FTT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affected</td>
<td>19</td>
<td>20</td>
<td>20</td>
<td>20,5</td>
</tr>
<tr>
<td>Non-affected</td>
<td>44,67</td>
<td>49</td>
<td>44,87</td>
<td>43,6</td>
</tr>
</tbody>
</table>

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.

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