

# Effects of repetitive peripheral magnetic stimulation on post-stroke upper extremity spasticity using ultrasound elastography: A randomized controlled trial

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## ABSTRACT

**Objectives:** This study aims to investigate the efficacy of repetitive peripheral magnetic stimulation (rPMS) on post-stroke upper extremity spasticity and the fibroelastic properties of spastic muscles using shear-wave elastography (SWE).

**Patients and methods:** Between March 2022 and April 2024, a total of 48 stroke patients with elbow and/or wrist flexor spasticity were enrolled in this double-blind randomized controlled study. Of these, 46 patients completed the study and were randomized into the rPMS group (6 males, 16 females; mean age: 63.27 years; range, 30 to 87 years) and the sham group (14 males, 10 females; mean age: 60.75 years; range, 33 to 86 years). All patients received a conventional rehabilitation program and 10 sessions of rPMS over two weeks. The Modified Ashworth Scale (MAS), Modified Tardieu Scale (MTS, spasticity grade and spasticity angle), SWE, and Fugl-Meyer assessment of the upper extremity (FMA-UE) were used to assess spasticity and motor function prior to treatment, after treatment, and at a four-week follow-up.

**Results:** Between-group analyses showed no significant differences in mean wrist flexor MAS score changes at any time point. The mean elbow flexor MAS scores demonstrated a significantly greater reduction in the rPMS group ( $-0.60 \pm 0.73$ ) compared with the sham group ( $-0.05 \pm 0.46$ ) post-treatment ( $p=0.036$ ). There were no significant between-group differences in wrist flexor spasticity grade changes at any time point ( $p>0.05$ ). The mean wrist flexor spasticity angle demonstrated a significantly greater reduction in the rPMS group ( $-9.05 \pm 11.1$ ) compared to the sham group ( $-0.05 \pm 6.92$ ) at the follow-up ( $p=0.030$ ). For elbow flexors, the changes in mean spasticity grade or angle were similar between the groups at any time point ( $p>0.05$ ). Comparison of the mean shear wave velocity changes in the biceps, brachialis, and pronator muscles revealed no significant differences between groups ( $p>0.05$ ). The increase in FMA-UE scores was significantly greater in the rPMS group than in the sham group both after treatment ( $2.68 \pm 3.32$  vs.  $0.58 \pm 0.92$ ,  $p=0.006$ ) and at follow-up ( $3.45 \pm 5.09$  vs.  $1.04 \pm 2.15$ ,  $p=0.015$ ). No serious side effects were reported.

**Conclusion:** Repetitive peripheral magnetic stimulation is a noninvasive and well-tolerated physical therapy modality. As an adjunct to conventional rehabilitation, it may selectively reduce post-stroke upper extremity spasticity and improve motor function.

**Keywords:** rPMS, shear-wave elastography, spasticity, stroke.

Spasticity is one of the most common problems following stroke and represents a significant barrier to functional recovery during rehabilitation. It can lead to pain, contractures, deformities, and loss of function. The prevalence of post-stroke upper extremity spasticity has been reported to range from 4 to 43%.<sup>[1]</sup> Current treatment strategies include pharmacological, non-pharmacological, and surgical

approaches; however, their variable efficacy and potential adverse effects underscore the need for novel therapeutic interventions.

Repetitive peripheral magnetic stimulation (rPMS) is a painless and noninvasive therapeutic modality with promising potential for reducing spasticity. This technique generates high-intensity electromagnetic fields to induce voltage differences,

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thereby stimulating the peripheral nervous system and muscles.<sup>[2]</sup> When applied to muscles, rPMS directly activates sensorimotor nerve fibers and indirectly stimulates mechanoreceptors, leading to increased somatosensory and proprioceptive afferent input. These signals are transmitted to the primary somatosensory cortex and may modulate corticospinal excitability, enhance inhibitory control of the stretch reflex, and promote cortical reorganization, ultimately contributing to a reduction in spasticity.<sup>[3,4]</sup>

A review of the literature indicates that the effects of rPMS on the neural component of spasticity, reflected by increased muscle tone, have been evaluated; however, no studies have specifically investigated its effects on the biomechanical component, characterized by soft tissue stiffness. Therefore, the present study aimed to examine the effects of rPMS on post-stroke upper extremity spasticity and the fibroelastic properties of spastic muscles.

## PATIENTS AND METHODS

### Study population

This prospective, randomized, sham-controlled, double-blind clinical trial was conducted at the Department of Physical and Rehabilitation Medicine, Ankara University Faculty of Medicine, between April 2022 and March 2024. A total of 184 patients were assessed for eligibility; 136 did not meet the inclusion criteria, and four declined to participate. Consequently, 48 stroke patients with upper extremity spasticity were enrolled and randomized to the rPMS and sham groups. Baseline demographic characteristics of the patients who completed the study (n=46) were as follows: rPMS group (6 males, 16 females; mean age: 63.27 years; range: 30 to 87 years) and sham group (14 males, 10 females; mean age: 60.75 years; range: 33 to 86 years). Inclusion criteria were as follows: age  $\geq$ 18 years; diagnosis of stroke according to the World Health Organization (1989) definition; radiological confirmation of stroke; and spasticity graded 1-3 on the Modified Ashworth Scale (MAS) in the upper extremity arm and forearm flexor muscles. Exclusion criteria included botulinum toxin, phenol, or alcohol injections for spasticity within the last six months; previous antispastic surgery; changes in oral antispastic medications within the last six months; fixed contractures of the elbow or wrist; acute inflammation in the treatment area; bleeding

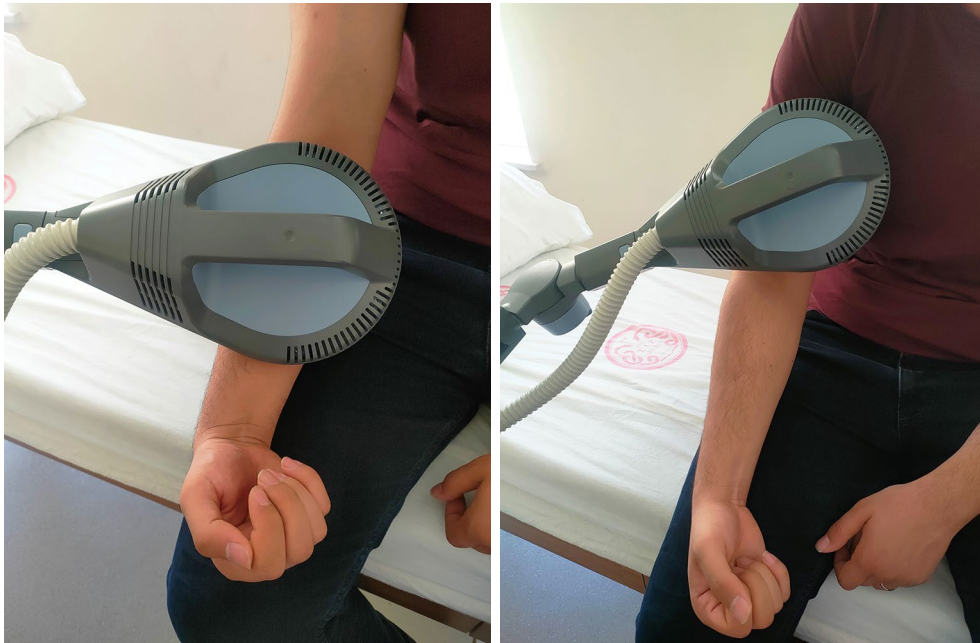
diathesis; implanted devices; vascular conditions such as deep vein thrombosis or arterial disease; and metal implants or unhealed fractures in the treatment region. The study was conducted in accordance with the principles of Good Clinical Practice, and written informed consent was obtained from all participants. Ethical approval was obtained from the Ankara University Faculty of Medicine Clinical Research Ethics Committee (Date: 27.10.2021, Approval No. E-61749811-000-1193990). The trial was registered at ClinicalTrials.gov (Identifier: NCT05141695; November 24, 2021).

### Randomization, concealment, and blinding

Patients were randomized to either the treatment or sham group by researcher HG using Random Allocation Software version 1.0.0 (Developer: Mahmood Saghaei). A block randomization technique with a block size of 2 was used to minimize potential imbalances between the groups. The trial employed a double-blind design in which both the patients and the outcome assessors were blinded to group allocation. Allocation concealment was ensured using sequentially numbered, opaque, sealed envelopes that were opened by researcher ŞK according to a computer-generated randomization sequence.

### rPMS treatment protocol

All patients received a 30-min conventional occupational therapy program five days per week, including range-of-motion exercises, slow passive stretching, strengthening exercises, neurophysiological training, and activities of daily living practice. In addition, patients in the treatment group underwent rPMS therapy for two weeks, consisting of one 9-min session per day, five days per week, for a total of 10 sessions applied to the spastic muscles of the hemiplegic upper extremity, as shown in Figure 1. Patients with both elbow and wrist flexor spasticity received 18 minutes of stimulation daily. In the sham group, the rPMS device was activated; however, the stimulus intensity was set to zero, while the sound recorded during a typical treatment session was played back for nine min. Repetitive peripheral magnetic stimulation was delivered using the preset "Spasticity Reduction Protocol (No. 1013)" on the BTL-6000™ Super Inductive System Elite (BTL Industries Ltd., Hertfordshire, U.K). This protocol comprised six sequences modulating amplitude, frequency (25-150 Hz), and duration, with biphasic sinusoidal pulses of 280 microseconds. Treatment intensity



**Figure 1.** Positioning of the repetitive peripheral magnetic stimulation probe at the wrist and elbow.

was adjusted above the motor threshold to elicit visible muscle contraction.

### Assessment

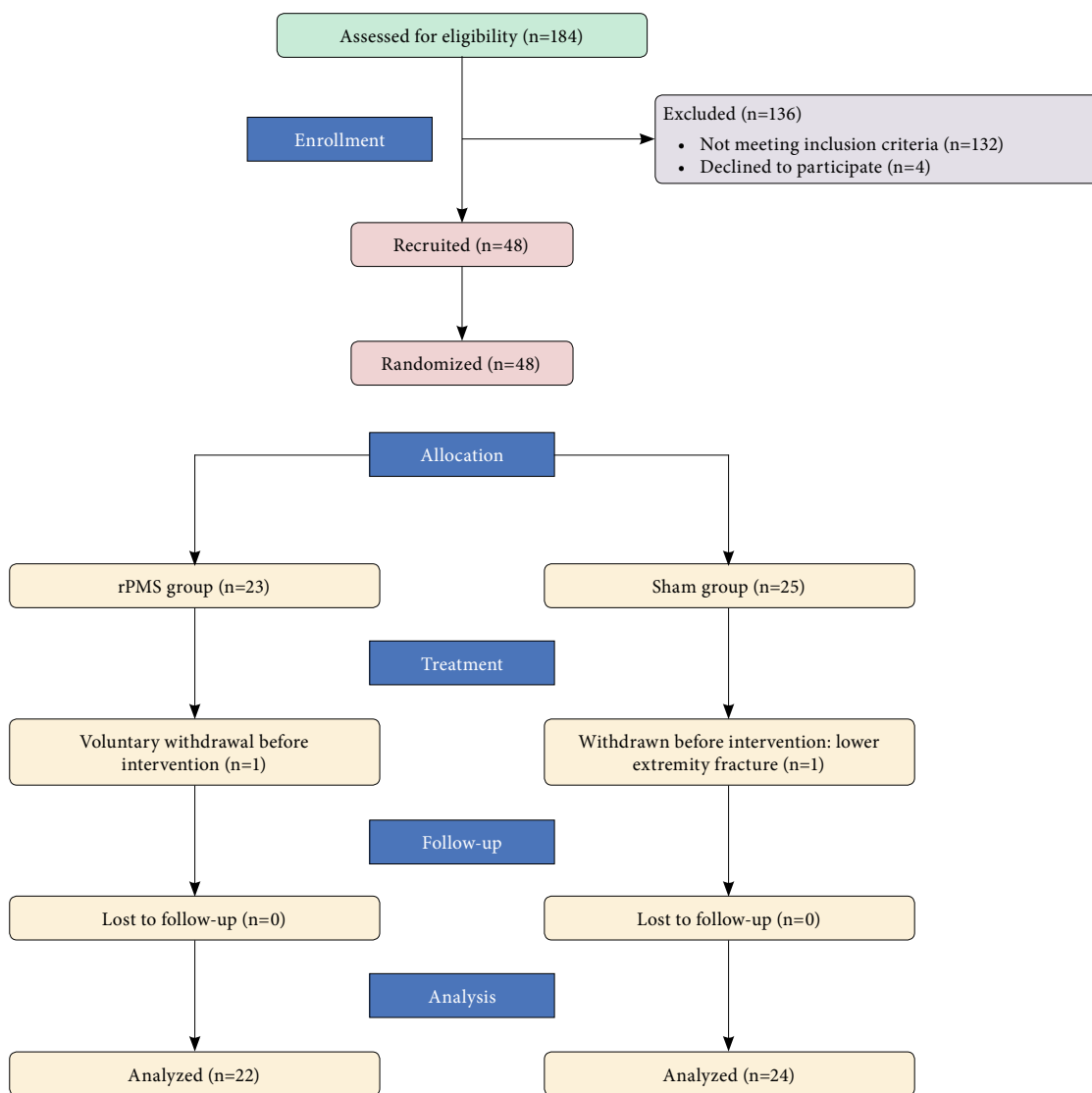
Patients were evaluated at three time points: baseline (pre-treatment), immediately after treatment, and at a four-week follow-up. Assessments included the Fugl-Meyer assessment of the upper extremity (FMA-UE), MAS, the Modified Tardieu Scale (MTS, spasticity grade and spasticity angle), and shear-wave elastography (SWE) for the assessment of tissue stiffness. Greater spasticity is associated with higher MAS and MTS spasticity grades and a lower MTS spasticity angle. All outcome assessments were performed by a blinded assessor (SY), who remained consistent across all evaluation time points. The assessments were conducted on the affected upper extremity.

Shear-wave measurements were performed by a blinded and experienced researcher (AG) using a Siemens Acuson S2000<sup>TM</sup> ultrasound system (Siemens Medical Solutions Inc., CA, USA). The elastic properties of the biceps brachii, brachialis, and pronator teres muscles in the affected upper extremity were evaluated. During assessment, patients were positioned supine on the examination table. After identifying the anatomical locations of the biceps brachii and brachialis muscles, measurements were

obtained for each muscle first with the elbow in full extension and subsequently at 90° of flexion. The pronator teres muscle was then identified, and measurements were performed with the forearm initially in the neutral position and then in pronation. During data acquisition, a layer of acoustic gel was applied between the probe and the skin. The probe was held perpendicular to the skin surface without applying additional pressure, and it was kept stationary throughout measurement while the muscle remained at rest. Elastographic images (color maps) were obtained, and six distinct regions of interest were marked within each muscle for every measurement. The elasticity properties of all examined muscles were automatically calculated by the device and expressed quantitatively in meters per second (m/s), with higher values indicating greater stiffness.

### Sample size

PASS 11 (Version 11.0.4; NCSS, LLC, Kaysville, Utah, USA) was used to calculate the sample size prior to the study. The primary outcome was MAS. The assumed effect size was based on the minimal clinically meaningful difference expected for MAS improvement, as determined by clinical judgment in the absence of prior comparable studies. Power analysis indicated that group sample sizes of 20 and 20 achieve 85% power to detect a difference



**Figure 2.** Flowchart of the patients included in the study.

rPMS: Repetitive peripheral magnetic stimulation.

of  $-0.5$  between the null hypothesis that both group means are  $-0.5$  (rPMS) and the alternative hypothesis that the mean of sham group is  $0.0$  with estimated group standard deviations of  $0.5$  and  $0.5$  and with a significance level (alpha) of  $0.05$  using a two-sided Mann-Whitney U test. Considering an anticipated dropout rate of  $20\%$ , the sample size was increased to 24 participants per group, resulting in a total of 48 patients.

### Statistical analysis

Descriptive statistics included mean, standard deviation, median, minimum, maximum, frequency, and percentage. Categorical variables were compared using the Chi-square, Fisher's exact test, or

Fisher-Freeman-Halton Exact Test; ordinal variables with Mann-Whitney U; and repeated measures with Friedman test. Bonferroni correction was applied for multiple comparisons. A  $p$ -value  $<0.05$  was considered statistically significant. The MAS grades were subjected to a numerical recoding process for the convenience of analysis (MAS 1+ was assigned a value of 2; MAS 2 and 3 were assigned a value of 3). Data were analyzed using IBM SPSS Statistics version 30.0 (IBM Corp., Armonk, NY, USA).

## RESULTS

Due to a miscalculation in one randomization block, the groups were unbalanced, with 23 patients

**TABLE 1**  
Sociodemographic characteristics of patients

	rPMS group (n=22)				Sham group (n=24)				p
	n	%	Mean±SD	Min-Max	n	%	Mean±SD	Min-Max	
Age (year)			63.27±14.76	30-87			60.75±12.55	33-86	0.534
Sex									<b>0.034</b>
Male	66	27.3			14	58.3			
Female	16	72.7			10	41.7			
Time since stroke (mo)			23.49±38.87	0.80-150.80			28.17±31.82	0.73-115.20	0.669
Stroke etiology									1.000
Ischemic	14	63.6			13	54.2			
Hemorrhagic	6	27.3			8	33.3			
Ischemic + hemorrhagic	2	9.1			3	12.5			
Radiological findings									0.171
Focal	17	77.3			14	58.3			
Multifocal	5	22.7			10	41.7			
Affected region									0.230
Cortical	5	22.7			8	33.3			
Subcortical	13	59.1			7	29.2			
Cortical + subcortical	4	18.2			9	37.5			
Hemiplegic side									0.571
Right	11	50.0			10	41.7			
Left	11	50.0			14	58.3			
Dominant hand									1.000
Right	20	90.9			22	91.7			
Left	2	9.1			2	8.3			

rPMS: Repetitive peripheral magnetic stimulation; SD: Standard deviation.

allocated to the rPMS group and 25 to the sham group. One patient in the rPMS group withdrew voluntarily before the intervention, whereas one patient in the sham group was withdrawn before the intervention due to a lower-extremity fracture sustained after major trauma. The number of patients with forearm flexor muscle spasticity was 19 in the rPMS group and 20 in the sham group, while the number of patients with elbow flexor spasticity was 20 and 21, respectively. Analyses were conducted on a total of 46 patients. The flowchart of the study participants is presented in Figure 2.

Baseline sociodemographic and clinical characteristics were comparable between groups with respect to age, stroke duration, stroke type, hemiplegic side, and dominant hand (all  $p>0.05$ ), as shown in Table 1. However, a statistically significant difference was observed in sex distribution, with a higher proportion of women in the rPMS group (72.7%,  $p=0.034$ ). The mean age was 63.3 years in the rPMS group and 60.8 years in the sham group, while the mean stroke duration was 23.5 and 28.2 months, respectively.

In the rPMS group, among patients with wrist flexor spasticity ( $n=19$ ), mean MAS scores showed a significant within-group reduction ( $p=0.001$ ), with a significant decrease immediately post-treatment compared with baseline ( $p=0.029$ ; Bonferroni's correction) and no difference between post-treatment and four-week follow-up, indicating sustained improvement ( $p=0.763$ ), as shown in Table 2. No significant within-group change was observed in the sham group. Between-group comparisons of MAS score changes at baseline, post-treatment, and week 4 were not significant (all  $p>0.05$ ). Similarly, among patients with elbow flexor spasticity ( $n=20$ ), mean MAS scores decreased within the rPMS group ( $p=0.001$ ), with a significant reduction immediately post-treatment compared with baseline ( $p=0.042$ ; Bonferroni's correction) and no change between post-treatment and week 4 ( $p=1.000$ ). No significant within-group change was detected in the sham group ( $p=0.687$ ). Between-group analysis showed a significantly greater post-treatment reduction in the rPMS group ( $p=0.036$ ; Bonferroni's correction), whereas no between-group difference was observed at week 4, as shown in Table 3.

**TABLE 2**  
Intra-group comparison of upper extremity spasticity over time

	rPMS group (n=19)			$p^a$	$p^b$	Sham group (n=20)			$p^a$
	Mean±SD	Median	Min-Max			Mean±SD	Median	Min-Max	
Wrist									
MAS									
T1	2.16±0.89	2.00	1-4		<b>0.029</b>	2.20±1.0	2.00	1-4	
T2	1.53±0.51	2.00	1-3	<b>0.001</b>	0.060	2.05±0.99	2.00	1-4	0.180
T3	1.58±0.60	2.00	1-3		0.763	1.95±0.99	2.00	1-4	
MTSg									
T1	1.95±0.40	2.00	1-3		0.366	1.85±0.48	2.00	1-3	
T2	1.63±0.68	2.00	0-2	<b>0.015</b>	0.258	1.80±0.69	2.00	0-3	0.174
T3	1.53±0.77	2.00	0-2		0.821	1.70±0.65	2.00	0-3	
MTSa									
T1	23.47±11.34	25.00	7-50		0.175	15.10±6.69	18.00	5-25	
T2	16.16±10.57	12.00	0-40	<b>0.007</b>	<b>0.007</b>	15.70±8.45	16.00	0-34	0.476
T3	14.42±10.70	13.00	0-38		0.175	14.95±7.14	16.50	0-28	
SWV prN (m/s)									
T1	2.80±0.43	2.69	1.66-4.20			3.01±0.44	2.99	2.29-3.76	
T2	2.78±0.54	2.81	1.68-4.01	0.449		2.89±0.47	2.93	1.99-3.72	0.834
T3	2.76±0.57	2.86	1.79-3.73			2.92±0.58	2.80	2.14-4.14	
SWV PrP (m/s)									
T1	2.47±0.56	2.53	1.47-3.64			2.47±0.59	2.42	1.45-3.94	
T2	2.41±0.66	2.24	1.22-3.59	0.549		2.48±0.55	2.55	1.53-3.28	0.956
T3	2.43±0.50	2.42	1.58-3.70			2.44±0.45	2.64	1.61-3.22	
Elbow									
MAS									
T1	2.50±0.82	3.00	1-4		<b>0.042</b>	2.29±1.00	2.00	1-4	
T2	1.90±0.71	2.00	1-3	<b>0.001</b>	<b>0.042</b>	2.24±0.99	2.00	1-4	0.687
T3	1.90±0.78	2.00	1-3		1.000	2.19±0.92	2.00	1-4	
MTSg									
T1	1.85±0.36	2.00	1-2		0.366	1.86±0.47	2.00	1-3	
T2	1.60±0.68	2.00	0-2	<b>0.018</b>	0.366	1.90±0.62	2.00	0-3	0.819
T3	1.60±0.68	2.00	0-2		1.000	1.86±0.65	2.00	0-3	
MTSa									
T1	31.40±18.78	33.50	5-60		<b>0.024</b>	28.05 ±16.50	30.00	2-65	
T2	24.10±16.67	23.00	0-55	<b>0.004</b>	<b>0.007</b>	25.81 ±17.96	30.00	0-60	0.316
T3	23.75±16.13	20.00	0-55		0.651	25.43 ±16.80	30.00	0-58	
SWV BcN (m/s)									
T1	3.10±0.68	3.08	1.91-4.07		<b>0.022</b>	2.79 ±0.67	2.72	1.64-4.33	
T2	2.83±0.57	2.72	1.49-4.05	<b>0.042</b>	<b>0.048</b>	2.73±0.77	2.74	1.19-4.28	0.946
T3	2.85±0.62	2.74	1.91-4.09		0.752	2.79±0.67	2.73	1.85-4.52	
SWV BcF (m/s)									
T1	2.51±0.57	2.42	1.50-4.02			2.36±0.61	2.36	1.34-4.00	
T2	2.32±0.65	2.27	1.16-3.94	0.156		2.22±0.55	2.11	1.26-3.70	0.348
T3	2.22±0.37	2.18	1.51-3.07			2.36±0.59	2.27	1.52-3.89	
SWV BrN (m/s)									
T1	2.71±0.57	2.71	1.50-3.67			2.78±0.62	2.89	1.53-3.91	
T2	2.72±0.47	2.65	1.92-3.40	0.705		2.80±0.72	2.66	1.56-4.75	0.662
T3	2.60±0.70	2.32	1.74-4.38			2.84±0.59	2.94	1.98-3.89	
SWV BrF (m/s)									
T1	2.35±0.54	2.49	1.18-3.28			2.48±0.61	2.29	1.43-3.80	
T2	2.35±0.53	2.45	1.35-3.38	0.705		2.14±0.44	2.11	1.17-3.08	0.150
T3	2.34±0.61	2.21	1.53-3.45			2.05±0.40	2.09	1.46-2.84	

rPMS: Repetitive peripheral magnetic stimulation; SD: Standard deviation; MAS: Modified Ashworth Scale; MTSg: Modified Tardieu Scale-spasticity grade; MTSa: Modified Tardieu Scale-spasticity angle; SWV: Shear wave velocity; PrN: Pronator muscle with the forearm in a neutral position; PrP: Pronator muscle with the forearm in a prone position; BcN: Biceps muscle with the forearm in a neutral position; BcF: Biceps muscle with the forearm in a flexed position; BrN: Brachialis muscle with the forearm in a neutral position; BrF: Brachialis muscle with the forearm in a flexed position; T1: Pre-treatment; T2: Post-treatment; T3: Follow-up; pa: Within-group change; pb: Post-hoc comparison of T1-T2, T1-T3 and T2-T3 respectively. Significance values have been adjusted by the Bonferroni correction for multiple tests.



**TABLE 4**  
Within-group comparison of Fugl-Meyer assessment of the upper extremity scores

FM	rPMS group (n=22)			$p^a$	$p^b$	Sham group (n=24)			$p^a$	$p^b$
	Mean±SD	Median	Min-Max			Mean±SD	Median	Min-Max		
T1	26.23±20.70	24.00	4-63		<b>0.001</b>	26.96±21.90	19.50	4-62		0.061
T2	28.91±20.60	26.00	4-63	0.001	<b>0.001</b>	27.54±21.80	19.00	4-62	<b>0.001</b>	<b>0.025</b>
T3	29.68±20.90	26.00	4-64		0.366	28.00±21.70	20.00	4-64		0.718

rPMS: Repetitive peripheral magnetic stimulation; FM: Fugl-Meyer; SD: Standard deviation; T1: Pre-treatment; T2: Post-treatment; T3: Follow-up;  $p^a$ : Within-group change;  $p^b$ : Post-hoc comparison of T1-T2, T1-T3 and T2-T3 respectively. Significance values have been adjusted by the Bonferroni correction for multiple tests.

**TABLE 5**  
Between-group comparison of Fugl-Meyer assessment of the upper extremity change scores

FM	rPMS group (n=22)			Sham group (n=24)			$p$
	Mean±SD	Median	Min-Max	Mean±SD	Median	Min-Max	
T1-T2	2.68±3.32	2.00	0-15	0.58±0.92	0.00	0-3	<b>0.006</b>
T1-T3	3.45±5.09	2.00	0-24	1.04±2.15	0.00	0-10	<b>0.015</b>
T2-T3	0.77±1.99	0.00	0-9	0.45±1.71	0.00	0-8	0.366

rPMS: Repetitive peripheral magnetic stimulation; FM: Fugl-Meyer; SD: Standard deviation; T1: Pre-treatment; T2: Post-treatment; T3: Follow-up; Significant values have been adjusted by the Bonferroni correction for multiple tests.

According to the MTS, a significant within-group reduction in wrist flexor spasticity grade was observed only in the rPMS group ( $p=0.015$ ), although post hoc comparisons were not significant (Table 2). Between-group comparisons of changes observed at baseline, post-treatment, and week 4 were also non-significant ( $p=0.579$ ,  $p=0.882$ , and  $p=1.000$ ; Table 3). Similarly, mean wrist flexor spasticity angle decreased significantly only in the rPMS group ( $p=0.007$ ), with a significant reduction at week 4 compared with baseline ( $p=0.007$ ; Bonferroni's correction). Between-group analysis demonstrated a significantly greater reduction in the rPMS group at week 4 ( $p=0.030$ ; Bonferroni's correction). For elbow flexors, the mean MTS spasticity grade showed a significant within-group reduction only in the rPMS group ( $p=0.018$ ), although post hoc comparisons were not significant. There were no significant between-group differences in changes observed at any time point ( $p=0.153-1.000$ ). The mean MTS spasticity angle decreased significantly only within the rPMS group across time points ( $p=0.004$ ), with significant reductions immediately post-treatment and at week 4 compared with baseline ( $p=0.024$  and  $p=0.007$ ; Bonferroni's correction); however, between-group comparisons were non-significant (all  $p>0.05$ ).

Shear-wave elastography demonstrated a significant within-group reduction in SWV only in the biceps muscle at the elbow neutral position in

the rPMS group ( $p=0.042$ ), with significant decreases both post-treatment and at week 4 relative to baseline ( $p=0.022$  and  $p=0.048$ ; Bonferroni's correction; Table 2). In contrast, the sham group showed no significant within-group reductions in SWV at any assessed muscle or measurement position across the same time points (all  $p>0.05$ ). No significant within-group or between-group differences were observed for the remaining muscles and measurement positions (all  $p>0.05$ ; Tables 2 and 3).

The mean FMA-UE scores increased significantly within both groups ( $p=0.001$  for both), as shown in Table 4. In the rPMS group, mean FMA-UE scores improved significantly post-treatment and at week 4 compared with baseline ( $p=0.001$  and  $p=0.001$ ; Bonferroni's correction), whereas in the sham group, a significant increase was observed only at week 4 ( $p=0.025$ ; Bonferroni's correction). Between-group comparisons demonstrated significantly greater mean FMA-UE score improvements in the rPMS group after treatment and at week 4 ( $p=0.006$  and  $p=0.015$ ; Bonferroni's correction), as shown in Table 5.

## DISCUSSION

In this study, rPMS administered over 10 sessions across two weeks was associated with modest reductions in the wrist and elbow flexor spasticity

in stroke patients. However, rPMS did not result in significant changes in the fibroelastic properties of spastic muscles, and no adverse effects were observed.

Current literature demonstrates substantial heterogeneity in rPMS protocols, including stimulation frequency, intensity, pulse characteristics, session duration, and number of sessions. Previous studies have applied rPMS using frequencies ranging from 5 to 150 Hz, varied pulse durations, and differing stimulation targets, such as flexor versus extensor muscle groups or their antagonists.<sup>[5-8]</sup> These methodological differences underscore the lack of a standardized rPMS protocol and complicate comparisons across studies. Variability also exists regarding the stimulation site. While some investigators have targeted spastic muscles directly, others have applied rPMS to peripheral nerves or the paravertebral region.<sup>[9-12]</sup> As no studies have directly compared these approaches, the optimal stimulation site remains uncertain. Moreover, follow-up durations in most studies are limited, often restricted to immediate or next-day assessments.<sup>[7]</sup> In line with a small number of prior studies, our patients were evaluated at baseline, immediately after treatment, and at 4 weeks.<sup>[5,8,11]</sup>

In the present study, a reduction in MAS score was observed in both elbow and wrist flexor muscles in the rPMS group. These results are consistent with studies in the literature reporting a reduction in spasticity following rPMS treatment.<sup>[5,6]</sup> Chen et al.<sup>[6]</sup> found a decrease in spasticity in both elbow and wrist flexors after a single session of rPMS as reflected by changes in MAS and MTS scores. Krewer et al.<sup>[5]</sup> also reported a reduction in wrist flexor spasticity, assessed using the MTS, after a single session of rPMS in patients following stroke, as well as a decrease in elbow extensor spasticity measured by the MTS after multiple rPMS sessions.

Variations observed across studies, including the results of the present study, may be attributable to differences in the muscle groups targeted by rPMS interventions as well as to heterogeneity in the rPMS protocols employed. Chen et al.<sup>[6]</sup> applied rPMS to six muscle groups in the upper limb, namely the shoulder adductors and extensors, the elbow extensors and flexors, and the wrist extensors and flexors; Krewer et al.<sup>[5]</sup> applied the treatment only to the elbow extensors and flexors, and the wrist extensors and flexors. However, we applied rPMS to the elbow and wrist flexors.

The rPMS protocols differed substantially between studies, particularly with respect to stimulation frequency and dosing strategies. Krewer et al.<sup>[5]</sup> used a standardized high-frequency protocol (25 Hz) with fixed train parameters and a uniform total stimulus dose, whereas Chen et al.<sup>[6]</sup> applied a frequency-adapted approach based on muscle spasticity, combining low- (5 Hz) and high-frequency (20 Hz) stimulation with variable stimulus counts. In our study, six sequences modulating amplitude, frequency (25-150 Hz), and duration, with biphasic sinusoidal pulses of 280 microseconds, were used. Treatment intensity was adjusted above the motor threshold to elicit visible muscle contraction. This methodological heterogeneity may partly account for differences in clinical outcomes across studies.

In the majority of studies investigating the effects of rPMS on spasticity, MAS is the predominant outcome measure, while the MTS is used less frequently. As noted by Patrick and Ada,<sup>[13]</sup> MAS is inadequate for assessing the range of motion limitations attributable to neurological or mechanical factors. Moreover, when MTS is applied, assessment is often limited to a single parameter-either spasticity angle (Y value) or grade.<sup>[5,6]</sup> The present study evaluated both MTS parameters in addition to MAS to investigate the influence of rPMS on neural components.

Shear-wave elastography has gained attention as an objective tool for spasticity assessment, with evidence supporting its correlation with clinical measures.<sup>[14-19]</sup> To our knowledge, this is the first study to investigate the effects of rPMS on upper-extremity spasticity using SWE. In our cohort, significant within-group reductions in biceps SWV were observed in the rPMS group at the neutral elbow position, although no between-group differences were detected. No significant changes were found in the brachialis or pronator muscles. The superficial anatomy of the biceps may partially explain these findings, as deeper muscles pose greater technical challenges for ultrasound assessment. Additionally, factors such as muscle stiffness, age, sex, fibrosis, atrophy, and heterogeneity in stroke and spasticity duration may have influenced SWE results.<sup>[20]</sup> Methodological variability and operator dependence remain important limitations of elastography-based assessments.<sup>[19]</sup>

Functional outcomes were evaluated using all subdomains of the FMA-UE. Unlike previous studies that assessed limited FMA-UE components,<sup>[5]</sup> we

observed improvements in both groups, with greater gains in the rPMS group. This finding aligns with prior evidence suggesting that rPMS may enhance motor recovery after stroke.<sup>[21,22]</sup> Improvements observed in the sham group may reflect spontaneous neurological recovery, particularly in subacute patients.

Several limitations should be acknowledged. The absence of a standardized rPMS protocol limits the interpretation of treatment-specific effects. The 4-week follow-up period precludes conclusions regarding long-term efficacy. Inclusion of both subacute and chronic stroke patients introduced clinical heterogeneity, and the modest sample size prevented subgroup analyses based on stroke duration. Shear-wave elasticity of muscle may exhibit sex-related variability; however, comparisons with age- and sex-matched normative reference values were not performed. Despite these limitations, the study has several key strengths. It was designed as a prospective, double-blind, randomized, placebo-controlled trial, and the sample size was calculated in advance based on power analysis. A comprehensive assessment of spasticity was conducted using both the MAS and MTS, and this study is the first to investigate the effects of rPMS on upper-extremity spasticity through SWE.

In conclusion, rPMS is a non-invasive, well-tolerated intervention that may offer adjunctive benefits when combined with conventional rehabilitation in post-stroke spasticity management. Future studies should incorporate standardized stimulation protocols, longer follow-up periods, and stratified analyses based on spasticity duration.

**Data Sharing Statement:** The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## REFERENCES

1. Doussoulin A, Rivas C, Bacco J, Sepúlveda P, Carvalho G, Gajardo C, et al. Prevalence of spasticity and postural patterns in the upper extremity post stroke. *J Stroke Cerebrovasc Dis* 2020;29:105253. doi: 10.1016/j.jstrokecerebrovasdis.2020.105253.
2. Beaulieu LD, Schneider C. Effects of repetitive peripheral magnetic stimulation on normal or impaired motor control. A review. *Neurophysiol Clin* 2013;43:251-60. doi: 10.1016/j.neucli.2013.05.003.
3. Kamo T, Wada Y, Okamura M, Sakai K, Momosaki R, Taito S. Repetitive peripheral magnetic stimulation for impairment and disability in people after stroke. *Cochrane Database Syst Rev* 2022;9:CD011968. doi: 10.1002/14651858.CD011968.pub4.
4. Pan JX, Diao YX, Peng HY, Wang XZ, Liao LR, Wang MY, et al. 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. *Front Neurol* 2022;13:997913. doi: 10.3389/fneur.2022.997913.
5. Krewer C, Hartl S, Müller F, Koenig E. Effects of repetitive peripheral magnetic stimulation on upper-limb spasticity and impairment in patients with spastic hemiparesis: A randomized, double-blind, sham-controlled study. *Arch Phys Med Rehabil* 2014;95:1039-47. doi: 10.1016/j.apmr.2014.02.003.
6. Chen S, Li Y, Shu X, Wang C, Wang H, Ding L, et al. Electroencephalography mu rhythm changes and decreased spasticity after repetitive peripheral magnetic stimulation in patients following stroke. *Front Neurol* 2020;11:546599. doi: 10.3389/fneur.2020.546599.
7. Werner C, Schrader M, Wernicke S, Bryl B, Hesse S. Repetitive peripheral magnetic stimulation (rpMS) in combination with muscle stretch decreased the wrist and finger flexor muscle spasticity in chronic patients after CNS lesion. *Int J Phys Med Rehabil* 2016;4:352. doi: 10.4172/2329-9096.1000352.
8. Prouza O, Kouloulas E, Zarkovic D. High-intensity electromagnetic stimulation can reduce spasticity in post-stroke patients. *Int J Physiotherapy* 2018;5:87-91. doi: 10.15621/IJPHY/2018/V5I3/173931.
9. Zschorlich VR, Hillebrecht M, Tanjour T, Qi F, Behrendt F, Kirschstein T, et al. Repetitive Peripheral Magnetic Nerve Stimulation (rPMS) as adjuvant therapy reduces skeletal muscle reflex activity. *Front Neurol* 2019;10:930. doi: 10.3389/fneur.2019.00930.
10. Flamand VH, Beaulieu LD, Nadeau L, Schneider C. Peripheral magnetic stimulation to decrease spasticity in cerebral palsy. *Pediatr Neurol* 2012;47:345-8. doi: 10.1016/j.pediatrneurol.2012.07.005.
11. Serag H, Abdelgawad D, Emara T, Moustafa R, El-Nahas N, Haroun M. Effects of para-spinal repetitive magnetic stimulation on multiple sclerosis related spasticity. *Int J Phys Med Rehabil* 2014;2:1000242. doi: 10.4172/2329-9096.1000242.
12. Krause P, Edrich T, Straube A. Lumbar repetitive magnetic stimulation reduces spastic tone increase of the lower limbs. *Spinal Cord* 2004;42:67-72. doi: 10.1038/sj.sc.3101564.

13. Patrick E, Ada L. The Tardieu Scale differentiates contracture from spasticity whereas the Ashworth Scale is confounded by it. *Clin Rehabil* 2006;20:173-82. doi: 10.1191/0269215506cr9220a.
14. Tran A, Gao J. Quantitative ultrasound to assess skeletal muscles in post stroke spasticity. *J Cent Nerv Syst Dis* 2021;13:1179573521996141. doi: 10.1177/1179573521996141.
15. Cao J, Xiao Y, Qiu W, Zhang Y, Dou Z, Ren J, et al. Reliability and diagnostic accuracy of corrected slack angle derived from 2D-SWE in quantitating muscle spasticity of stroke patients. *J Neuroeng Rehabil* 2022;19:15. doi: 10.1186/s12984-022-00995-8.
16. Wu CH, Ho YC, Hsiao MY, Chen WS, Wang TG. Evaluation of post-stroke spastic muscle stiffness using shear wave ultrasound elastography. *Ultrasound Med Biol* 2017;43:1105-11. doi: 10.1016/j.ultrasmedbio.2016.12.008.
17. Eby SF, Zhao H, Song P, Vareberg BJ, Kinnick RR, Greenleaf JF, et al. Quantifying spasticity in individual muscles using shear wave elastography. *Radiol Case Rep* 2017;12:348-52. doi: 10.1016/j.radcr.2017.01.004.
18. Lehoux MC, Sobczak S, Cloutier F, Charest S, Bertrand-Grenier A. Shear wave elastography potential to characterize spastic muscles in stroke survivors: Literature review. *Clin Biomech (Bristol)* 2020;72:84-93. doi: 10.1016/j.clinbiomech.2019.11.025.
19. Lin MT, Yang SM, Wu HW, Chen YH, Wu CH. Utility of ultrasound elastography to evaluate poststroke spasticity and therapeutic efficacy: A narrative review. *J Med Ultrasound* 2023;31:171-7. doi: 10.4103/jmu.jmu\_106\_22.
20. Vola EA, Albano M, Di Luise C, Servodidio V, Sansone M, Russo S, et al. Use of ultrasound shear wave to measure muscle stiffness in children with cerebral palsy. *J Ultrasound* 2018;21:241-7. doi: 10.1007/s40477-018-0313-6.
21. Jiang YF, Zhang D, Zhang J, Hai H, Zhao YY, Ma YW. A randomized controlled trial of repetitive peripheral magnetic stimulation applied in early subacute stroke: Effects on severe upper-limb impairment. *Clin Rehabil* 2022;36:693-702. doi: 10.1177/02692155211072189.
22. Chen ZJ, Li YA, Xia N, Gu MH, Xu J, Huang XL. Effects of repetitive peripheral magnetic stimulation for the upper limb after stroke: Meta-analysis of randomized controlled trials. *Heliyon* 2023;9:e15767. doi: 10.1016/j.heliyon.2023.e15767.