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The Effects of Neuromuscular Electric Stimulation on Pain, Function, Muscle Strength and Muscle Architecture in Patients with Rotator Cuff Tendinopathies

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SUMMARY

Background. Knowing the effects of neuromuscular electric stimulation (NMES) and exercise used in shoulder rehabilitation on muscle architecture, pain, muscle strength and quality of life will enable a more accurate and effective treatment plan for patients with rotator cuff tendinopathies (RCT). The aim of this prospective, single-blind, randomized controlled study was to evaluate the effects of NMES combined with conventional therapy in patients with (RCT).

Methods. 41 Patients were randomized into one of the following two intervention groups, five days a week, for six weeks: combination of NMES, thermal agents, manual therapy, and exercise was applied to the CT + NMES group. Combination of conservative therapy (CT), thermal agents, manual therapy, and exercise therapy was applied to the CT group. Before, after the six-week intervention follow-up with results for the following outcome measures: pain, functional capacity, muscle strength, and muscle architecture.

Results. There were significant decreased in VAS ($p < 0.05$), and improvement DASH score ($p < 0.05$), WORC score ($p < 0.05$), external rotation (ER)/internal rotation peak torque 60°/second), and external rotation (ER) peak torque 180°/second ($p < 0.05$) for CT + NMES group in comparison to the CT group. CT + NMES group had exhibited more increases in the muscle thickness and fascicle length values when compared to CT group ($p < 0.05$).

Conclusions. The results of this study support that pre-and post-intervention CT + NMES therapy appears to be an effective treatment in reducing pain, improving functional capacity, muscle strength, and muscle architecture. NMES application can be more useful in the treatment of patients with rotator cuff disease.

KEY WORDS

Rotator cuff tendinopathies; neuromuscular electric stimulation; muscle architecture; muscle strength.

INTRODUCTION

Shoulder pain is very common and one of the most prevalent musculoskeletal disorders in that patients are admitted to hospitals (1). It is the most commonly diagnosed cause of shoulder dysfunction being the causative factor in 74% of cases of shoulder pain About two-thirds of the patients with shoulder pain are diagnosed with rotator cuff disorder. Decreased quality of activities of daily living causes significant joint limitation and injuries (2, 3).

Rotator cuff tendinopathies can possibly be treated successfully with conventional treatments (4). Shoulder rehabilitation should primarily focus on the elimination of pain and restoration of functional movements through the dynamic stability of the rotator cuff and scapular muscles. It is known that conventional treatment is an effective method preferred for rotator cuff problems. The conventional treatment program is aimed to relieve rotator cuff and scapular muscle weakness, stretch the posterior capsule and other soft tissues, and contribute positively to postural abnormalities by correcting pain and dysfunction. Conventional treatment also includes patient education and the use of analgesics, exercise, electrotherapy, functional rehabilitation, and manual therapy (5, 6). Neuromuscular electrical stimulation (NMES) which is a method of physical therapy can be used for functional training or activity to replace the loss of function (7). In shoulder rehabilitation, it has been supported by studies that NMESs are effective in improving pain, function, and activities of daily life (7, 8).

Impairment of shoulder function is also associated with architectural changes of the muscle and tendon unit in rotator cuff tendinopathies. To optimally treat rotator cuff tears, it is necessary to accurately understand the effect of physiotherapy on the muscle architecture and tendon pathology of the rotator cuff (9). However, despite significant improvements that can be gained by noting the changes in architectural parameters resulting from tendon damage, muscle-tendon architecture is often overlooked (10).

The aim of this study was to evaluate the effects of NMES with conventional treatment on pain, functional status, isokinetic shoulder muscle rotator strength, and muscle architectural measurements in patients with rotator cuff tendinopathies.

METHODS

Ethics

Ethical approval was obtained from Ankara Training and Research Hospital with the study number E-19; 28. Date of approval: June 13, 2019.

Study design and selection criteria

This prospective, randomized, single-blind controlled study involved 41 patients with rotator cuff tendinopathies (14 males, 27 females; age ranged, 30–60 years) who were treated at the Physical Medicine and Rehabilitation Department of Ankara Training and Research Hospital A physiotherapist randomly assigned half of the patients to a conventional therapy group (CT) and the other a conventional therapy with electrical stimulation group (CT + NMES) group. The selection was done by drawing lots. These assignments were unknown to both the patients and the physiatrist working with them. This study was approved by the local ethics committee of Ankara Training and Research Hospital and written informed consent was obtained from all of the patients.

The inclusion criteria of the study were: the presence of unilateral shoulder pain a diagnosis of rotator cuff tendinopathies by the physiatrist, and no physiotherapy for the shoulder in the four weeks prior to the study. Patients with rotator cuff tendinopathies and grade 1-2 rupture were included in the study after evaluation by ultrasonography with dynamic tendon method (GE Logiq P5, Wisconsin, USA) using a 12 MHz linear array probe. In addition, potential study subjects needed to have at least two of the following positive signs: Neer, Hawkins tests or the drop arm or pain during the abduction of the shoulder with a painful arch. The consecutively referred patients who met these criteria were informed about the details of the study (10).

Patients were excluded if they had any of the following: a history of acute trauma, surgery or a fracture of the shoulders, a neurological deficit in the upper extremities, an underlying inflammatory rheumatic disease, or signs of cervical pathologies that might be associated with shoulder pain (11).

Evaluation protocol

All the patients were evaluated before and immediately after rehabilitation (at 6th week) by the same physiotherapist using the visual analog scale (VAS), Disabilities of the Arm, Shoulder and Hand Questionnaire (DASH) (12), the Western Ontario Rotator Cuff Index) (WORC) (13) as well as isokinetic measurements of the shoulder external rotation (ER) and internal rotation (IR) muscles.

To perform the isokinetic evaluation, we used a Biodex System 3 Pro™ dynamometer (Biodex Medical Systems, Shirley, NY, USA) to assess the strength of the shoulder ER and IR muscles at constant angular velocities of 60°/second, and 180°/second via a concentric/concentric mode, and these tests were performed by the same physiotherapist.

Before the measurements of each patient began, the dynamometer was calibrated, and it's position was established according to the standard measurement technique in which the device was tilted 50° and oriented 20° and the seat was tilted 85° and oriented 15°. The patients were then seated on a supine position in the isokinetic dynamometer chair at 80° hip flexion and 90° knee flexion with their ankles unrestricted. Their trunks and legs were stabilized by using straps across the chest, waist, and upper thighs. Muscle strength was tested with the shoulder in a modified neutral position (45° abduction and 30° flexion), and the elbow flexed at 90°. The axis of rotation was adjusted with the axis alignment being longitudinal through the head of the shaft of the humerus and the center of the glenohumeral joint in the horizontal plane. The elbow axis was aligned parallel to the entrance axis of the dynamometer, and the neutral hand position was adjusted as indicated by the user's manual. Next, the movement range was set to a painless 90° shoulder rotation around the modified neutral position (45° of IR and 45° of ER). Gravity correction was also used for the testing position. All of these isokinetic protocols were performed exactly according to the manufacturer's recommendations. After explaining the procedure to the patients, they were familiarized with it by performing three submaximal and five maximal repetitions at each speed. The isokinetic evaluation at 60°/second and 180°/second consisted of respectively five and 10 repetitions with maximal effort. In addition, a 30-second rest period was provided between the familiarization trials and 60 second rest period of the main testing. We measured the muscle strength as peak torque (PT) of ER and IR at each speed and used the highest torque value (Newton-meters) recorded during the maximal efforts in the analysis (14).

Muscle architecture measurements were performed using an ultrasound device. Images acquisition was performed by the same trained sonographer with an ultrasonographic system working in B-Mode (GE Logiq P5, Wisconsin, USA) with a 12-MHz linear array probe. Supraspinatus muscle architectural measurements were performed in a sitting position with the arm in adduction and internal rotation, elbow in 90° flexion, and hand in neutral and midline, with the patient exposed to the affected shoulder. Muscle measurements were made before and after treatment. Muscle thickness, fascicle length, and pennation angle, and were measured three times, and the mean value was noted. For fiber length measurement, the linear probe was placed parallel to the plane of the fiber bundles. The probe was positioned along the direction of the fascicles, where the fascicular organization between the superficial and deep aponeurosis on the muscle was better determined. Pennation angle measurements were made by measuring the angle between the fiber bundle and the intramuscular tendon from the point where the fiber bundle attaches to the intramuscular tendon. Muscle thickness was measured from the zone where the muscle was viewed the widest, based on the midpoint of the acromion and placing the probe on the supraspinatus fossa in a transverse position. **Figures 1** and **2** show ultrasonographic measurements of muscle architecture.

Intervention protocols

Patients in CT group received 18 sessions distributed over six weeks (three days per week) of conventional treatment, while the CT + NMES group patients received NMES application with conventional treatment. Conventional treatments and exercise programs were given to both groups (**table I**) (15).

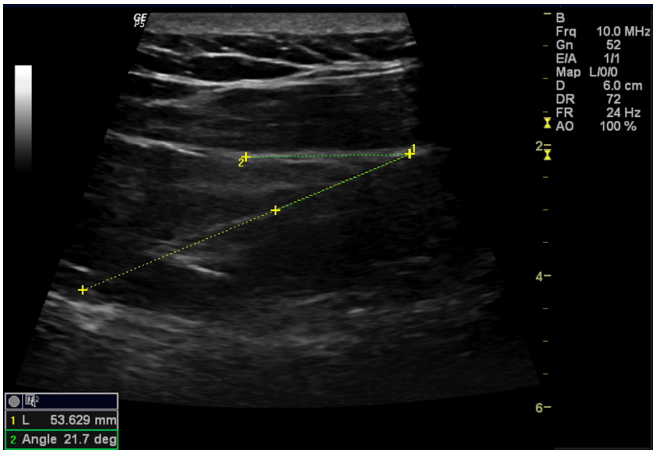

Figure 1. Ultrasonographic imaging of suprapinatus muscle demonstrating the measurement of the pennate angle and fascicle length.

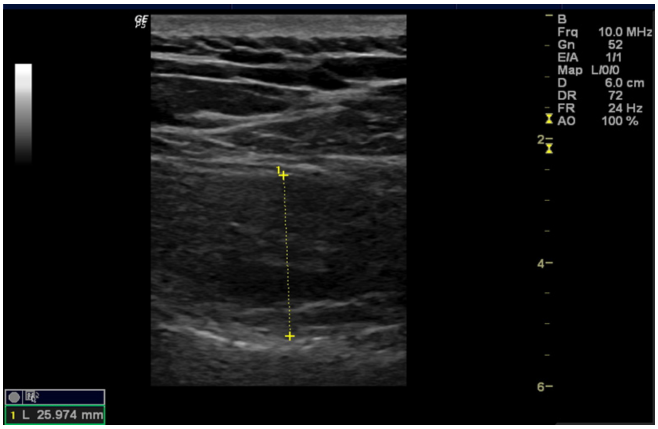

Figure 2. Ultrasonographic imaging of suprapinatus muscle demonstrating the measurement of the muscle thickness.

Electrical stimulation was applied to the CT + ES group in addition to conventional treatment practices. Electrical stimulation, russian current was selected, and a total of 20 minutes were applied, using the "ITO Physiotherapy & Rehabilitation EU-940" model device, at a frequency of 2500 Hz, with a transition time of 400 µs, 10 ms contraction, and 50 ms rest (15). The patients were asked to perform the movement simultaneously with the contraction of the electrical stimulation, to keep the muscle contracted throughout the contraction, and to rest the muscle by ending the movement at the start of the resting period. The intensity of the NMES used in the treatment was the maximum tolerated by each patient. The shoulder was applied in adduction and internal rotation, the elbow was in 90° flexion, and the hand was in the neutral and midline lying position and two self-adhesive electrodes (Valotrude

Table I. Conventional treatment and exercise program in rotator cuff patients.

1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks
Coldpack (10 dk)	Hotpack (20 dk)	Hotpack (20 dk)	Hotpack (20 dk)	Hotpack (20 dk)	Hotpack (20 dk)
Transfers friction massage (10dk)	Stretching exercises	Stretching exercises	Stretching exercises	Stretching exercises	Stretching exercises
Stretching exercises upper trapezius and capsular stretching	Inferior and posterior glide scapula mobilization	Inferior and posterior glide scapula mobilization	Inferior and posterior glide scapula mobilization	Inferior ve posterior glide	Inferior ve posterior glide
Isometric exercises	Isometric + scapular stabilization exercises	Scapular stabilization thera band exercises	Scapular stabilization thera band exercises	Scapular stabilization thera band exercises	Scapular stabilization thera band exercises

self-adhesive electrode; 5 × 5 cm) were used, NMES was applied to supraspinatus muscles for 20minutes/session, once daily, five days a week, for three weeks.

Statistical analysis

Statistical analysis was performed using SPSS Statistics for Windows version 17.0 software program (SPSS Inc., Chicago, IL, USA). For each continuous variable, distribution normality was checked using the Shapiro-Wilk tests. Chi-square tests were used to quantify possible differences in all outcome measures between groups in the study. Results were mentioned as mean value ± standard deviation (SD). P-values less than 0.05 were considered as statistically significant.

RESULTS

A total of 41 patients with rotator cuff pathology were enrolled in this study. The mean age of the CT group and CT + NMES were 52.00 ± 6.69 and 45.20 ± 9.66 years, respectively. There is a statistically significant difference between the groups in terms of mean age (**table II**). In addition, the pre-intervention values of the VAS, DASH, WORC, the isokinetic measurements, and muscle architecture were similar for both groups. There were statistically significant improved functional capacity, pain, muscle strength, and changes in the muscle architecture of the two groups after treatment ($p < 0.05$; **tables III, V**), (pennation angle, except, $p > 0.05$; **table IV**). However, there were statistically significant differences in functional capacity, pain, muscle strength, and changes in the muscle architecture in CT + NMES group compared to the CT group after the treatment (pennation angle, except, ($p < 0.05$; **tables III-V**). According to do effect size it was found that the decrease in pain level in the CT + NMES group, and the increase in WORC scores, muscle thickness, ER/IR 180°/sec were greater.

Table II. Demographic characteristics of the study groups.

Variables		CT	CT + NMES
		N = 21 (%) mean (SD)	N = 20 (%) mean (SD)
Gender	Man	3 (14.3%)	11 (55%)
	Woman	18 (85.7%)	9 (45%)
Age (years)		52.00 ± 6.69	45.20 ± 9.66
BMI (kg/cm²)		29.12 ± 3.24	28.48 ± 4.28

CT: conventional therapy; NMES: neuromuscular electrical stimulation; BMI: Body Weight Index; SD: standard deviation. $^{*}p < 0.05$.

Table III. Clinical measurements before and after treatment.

		Pre-test median (SD)	P^a between groups	Post-test median (SD)	P^b within group	P^c between groups	Effect size
VAS	CT	7.19 ± 2.14	0.433	0.81 ± 1.03	0.805	**0.00**	0.24
	CT + NMES	6.70 ± 1.81		0.90 ± 1.29		**0.00**	**0.86**
DASH	CT	55.07 ± 18.89	0.823	17.48 ± 11.95	0.941	**0.00**	0.07
	CT + NMES	56.46 ± 20.37		17.79 ± 14.17		**0.00**	0.20
WORC score total score	CT	50.62 ± 27.30	0.433	19.71 ± 22.37	0.570	**0.00**	0.52
	CT + NMES	38.18 ± 22.16		16.33 ± 14.33		**0.00**	**1.79**
Physical symptoms	CT	44.87 ± 15.33	0.491	19.38 ± 9.97	0.920	**0.00**	0.21
	CT + NMES	41.45 ± 16.16		19.70 ± 10.28		**0.00**	0.31
Sports and recreation	CT	29.29 ± 11.03	0.555	11.19 ± 6.56	0.265	**0.00**	0.18
	CT + NMES	31.30 ± 10.59		13.90 ± 8.69		**0.00**	0.53
Work	CT	30.24 ± 10.49	0.362	8.14 ± 7.78	0.083	**0.00**	0.18
	CT + NMES	33.05 ± 8.94		12.40 ± 7.53		**0.00**	0.53
Lifestyle	CT	28.67 ± 7.00	0.090	7.57 ± 6.42	0.030	**0.00**	0.62
	CT + NMES	34.35 ± 12.76		13.05 ± 8.99		**0.00**	0.70
Emotions	CT	26.71 ± 7.97	0.694	6.00 ± 5.37	0.038	**0.00**	0.12
	CT + NMES	25.50 ± 11.42		10.00 ± 6.55		**0.00**	0.60

SD: standard deviation; $^*p < 0.05$ between two groups for values (independent sample t-test) and within the group after 6 weeks (dependent sample t-test); P^a: P-values of comparison of baseline values between groups; P^b; P-value of the comparison of the pre-test and 6 weeks later within the group (chi-square test); P^c: P-values of the comparison of change between groups; CT: conventional therapy group; CT + NMES: conventional therapy with neuromuscular electrical stimulation group.

Table IV. Ultrasonographic parameters regarding muscle architecture before and after treatment.

		Pre-test median (SD)	P^a between groups	Post-test median (SD)	P^b within group	P^c between groups	Effect size
Muscle thickness	CT	18.12 ± 2.59	**0.000**	22.33 ± 3.05	**0.000**	**0.000**	**1.41**
	CT + ES	19.81 ± 2.84		24.49 ± 3.19			1.54
Fascicle length	CT	46.26 ± 4.76	0.777	49.41 ± 3.85	0.665	0.000	0.08
	CT + ES	46.73 ± 5.85		50.19 ± 6.97			0.10
Pennation angle	CT	17.58 ± 2.26	0.210	18.28 ± 2.46	0.089	0.199	0.39
	CT + ES	18.56 ± 2.65		19.91 ± 3.45			0.54

SD: standard deviation; $^*p < 0.05$ between two groups for values (independent sample t-test) and within the group after 6 weeks (dependent sample t-test); P^a: P-values of comparison of baseline values between groups; P^b: P-value of the comparison of the pre-test and 6 weeks later within the group (chi-square test); P^c: P-values of the comparison of change between groups; CT: conventional therapy group; CT + NMES: conventional therapy with neuromuscular electrical stimulation group.

Table V. Isokinetic measurements before and after treatment.

		Pre-test median (SD	P^a between groups	Post-test median (SD)	P^b within group	P^c between groups	Effect size
External rotation 60 °/sn	CT	8.25 ± 5.13		16.20 ± 5.58			0.64
	CT + NMES	12.37 ± 7.42	0.045	19.77 ± 9.96	0.162	**0.000**	0.44
Internal rotation 60°/sn	CT	11.12 ± 5.06	0.037	19.98 ± 10.09	0.160	**0.000**	0.47
	CT + NMES	15.37 ± 7.20		24.74 ± 11.17			0.68
External/Internal rotation 60°/sn	CT	1.04 ± 0.77	0.733	0.94 ± 0.44	0.314	0.487	0.10
	CT + NMES	0.97 ± 0.49		0.83 ± 0.24			0.31
External rotation 180 °/sn	CT	11.93 ± 4.01		19.41 ± 6.87			0.57
	CT + NMES	14.73 ± 5.57	0.071	21.59 ± 9.44	0.402	**0.000**	**0.84**
Internal rotation 180°/sn	CT	17.17 ± 6.78		24.00 ± 10.34			0.03
	CT + NMES	16.95 ± 6.85	0.919	27.02 ± 12.10	0.396	**0.003**	2.37
External/Internal rotation 180°/sn	CT	0.74 ± 0.20		0.86 ± 0.27			0.07
	CT + NMES	0.89 ± 0.20	0.021	0.84 ± 0.26	0.836	0.077	**1.75**

SD: standard deviation; $^*p < 0.05$ between two groups for values (independent sample t-test) and within the group after 6 weeks (dependent sample t-test); P^a: P-values of comparison of baseline values between groups; P^b: P-value of the comparison of the pre-test and 6 weeks later within the group (chi-square test); P^c: P-values of the comparison of change between groups; CT: conventional therapy group; CT + NMES: conventional therapy with neuromuscular electrical stimulation group.

DISCUSSION

Many elements, such as poor posture, weakness, and dysfunction of the rotator cuff, degeneration and inflammation of tendons and bursae, capsular tightness, and glenohumeral instability, often cause rotator cuff tendinopathies. For this reason, the main goals in shoulder rehabilitation are: reducing pain, increasing joint mobility, range of motion, and muscle strength, and improving functionality (16, 17). In our study, the physiotherapy interventions led to improvements in the results of the VAS, DASH, WORC, the muscle strength of the shoulder, and muscle architectural measurements in both the CT and CT + NMES groups. Furthermore, the results of our study suggest that conventional management of rotator cuff tendinopathies can reduce the patient's pain, and increase their functionality, and pleasure levels.

NMES is a common physical therapy method used on skeletal muscle to accelerate muscle adaptations, protect damaged muscle, or increase muscle functional capacity (18). Reinold *et al.* reported a benefit of combining isometric training with NMES as shoulder external rotation strength was increased about 22% after shoulder rotator cuff repair (19). Smith *et al.* determined that the application of NMES methods to reduce pain, edema, and muscle spasm, increase range of motion and strength, and reeducation of muscles in conditions such as impingement, rotator cuff tendinopathies shoulder instability, adhesive capsulitis, and scapular pathology showed effective results (20). In our study, thermal agents, exercise, and NMES applications were similar to the literature, reducing pain in both groups and increasing muscle strength and shoulder functionality.

Hara *et al.* demonstrated that as one of these combination techniques, a hybrid training system (HTS) can increase both muscle strength and mass. In addition, it is considered to be a characteristic of HTS that electrically stimulated eccentric muscle contractions result in increased muscle strength and mass in spite of relatively low exercise intensity (21). Furthermore, Imoto *et al.* suggested that NMES combined with rehabilitation for shoulder injuries is effective for improving pain, function, and activities of daily living. NMES could contribute to increasing of the muscle strength changes in muscle fiber composition and muscle thickness structure (22).

It is important to fully understand the changes in the supraspinatus muscle that an important dynamic stabilizer of the glenohumeral joint and most often associated with rotator cuff pathology. Therefore, our study focused on the muscle strength and architectural parameters of this muscle. Melo *et al.* demonstrated that NMES training increased supraspinatus thickness and fascicle length and improved functional status in patients with rotator cuff tendinopathies (23). Hayashi *et al.* found that NMES was significantly increased in the muscle thickness and pennation angle values compared to exercise therapy group in patients with rotator cuff tendinopathies (24).

The results of above studies confirm that NMES application is an effective strategy for improving the muscle atrophy associated with rotator cuff tendinopathies. As far as we know, there is no research that compared neuromuscular electrical stimulation treatment and conservation treatment in the rotator cuff in the literature. We have determined that NMES can be effective in improving pain functional capacity and muscle strength in this study in patients with rotator cuff tendinopathies. Furthermore, we found statistically significant differences in muscle architecture in the NMES application group according to CT the group.

Pennation angles of the supraspinatus were also studied. Kim *et al*. also proposed that the anterior and posterior parts of the muscle have nearly the same fiber lengths, at 6.7 cm and antero-medial part's pennation angles were found as a mean 11.8° and the postero-medial part 12.4° (25). In our study, the pre-treatment values of the supraspinatus muscle in patients with rotator cuff tendinopathies were 17.5° in the CT group and 18.5° in the CT + NMES group; after treatment, it was found to be 18.2° in the CT group and 19.9° in the CT + NMES group. These results are close to the average values in the literature.

The positive impact of NMES application on muscles was shown with ultrasonographic measurement in our study. However, further long-term and larger sample size studies are needed to confirm the effect of NMES application on change of muscle architecture.

Isokinetic assessment of the rotator cuff is a common and reliable component of shoulder muscle examinations. In this study, we evaluated the isokinetic muscle strength based on the concentric/concentric protocol in the seated position with the retracted shoulder in a modified neutral position.

Other results of this study were that VAS, DASH, and WORC scores improved significantly in both groups, but these results were statistically more significant in the CT + NMES group.

To the best of our knowledge, this is the first study to evaluate the effect of conservative therapy, exercise, and NMES on the pain, function, muscle strength, and architectural parameters of patients with rotator cuff tendinopathies. Our findings demonstrate that NMES therapy, when combined with other physiotherapy interventions, provides additional therapeutic benefits in terms of pain, functional status, isokinetic muscle strength, and architectural parameters. Reduction of pain and increased architectural parameters after NMES therapy may provide better functioning of the shoulder in daily living activities and this may have helped to improve muscle strength.

The present study has some limitations. The lack of long-term follow-up, more selective inclusion criteria and small sample size can be considered as the major limitations of this study. The fact that rotator cuff muscles other than the supraspinatus muscle could not be evaluated as a result of keeping the time spent with the patient short because of the COVID-19 pandemic rules.

CONCLUSIONS

According to the results of our study, both treatment methods can be used as an effective treatment choice in patients with rotator cuff tendinopathies. At the same time, they were safe and easy to apply methods. In addition, our findings indicate that NMES application seems to be a more suitable treatment in patients with rotator cuff tendinopathies.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

EME: conceptualization, literature review, writing, data collection, processing. EME, NG, HG: design. NG: audit. EME, HG, CM: resources. EME, CM: analysis, comment. EME, NG, HG, CM: critical review.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

REFERENCES

1. Haahr JP, Ostergaard S, Dalsgaard J, et al. Exercises versus arthroscopic decompression in patients with subacromial impingement: a randomised, controlled study in 90 cases with a one year follow up. Ann Rheum Dis 2005;64(5):760-4.
2. Lewis, J. Rotator cuff related shoulder pain: Assessment, management and uncertainties. Man Ther 2016;23:57-68.
3. Krischak G, Gebhard F, Reichel H, et al. A prospective randomized controlled trial comparing occupational therapy

with home-based exercises in conservative treatment of rotator cuff tears. J Shoulder Elbow Surg 2013;22(9):1173-9.

4. Bennell K, Wee E, Coburn S, et al. Efficacy of standardised manual therapy and home exercise programme for chronic rotator cuff disease: randomised placebo controlled trial. BMJ 2010;340:c2756.
5. Fahy, Galvin, J. Lewis K. Large to massive rotator cuff tendon tears: a protocol for a systematic review investigating the effectiveness of exercise therapy on pain, disability and quality of life. Open Res 2021;4:75.
6. Green, A. Chronic massive rotator cuff tears: evaluation and management. J Am Acad Orthop Surg 2003;11(5):321-31.
7. Pereira S, Mehta S, McIntyre A, et al. Functional electrical stimulation for improving gait in persons with chronic stroke. Top Stroke Rehabil 2012;19(6):491-8.
8. Kim SY, Kang MH, Lee DK, Oh JS. Effects of the Neurac(®) technique in patients with acute-phase subacromial impingement syndrome. J Phys Ther Sci 2015;27(5):1407-9.
9. Ward SR, Hentzen ER, Smallwood LH, et al. Rotator cuff muscle architecture: implications for glenohumeral stability. Clin Orthop Relat Res 2006;448:157-63.
10. Wickiewicz TL, Roy RR, Powell PL, Edgerton VR. Muscle architecture of the human lower limb. Clin Orthop Relat Res 1983;(179):275-83.
11. van Kampen DA, van den Berg T, van der Woude HJ, et al. The diagnostic value of the combination of patient characteristics, history, and clinical shoulder tests for the diagnosis of rotator cuff tear. J Orthop Surg Res 2014 7;9:70.
12. Analan PD, Leblebici B, Adam M. Effects of therapeutic ultrasound and exercise on pain, function, and isokinetic shoulder rotator strength of patients with rotator cuff disease. J Phys Ther Sci 2015;27(10):3113-7.
13. De Smet L. The DASH questionnaire and score in the evaluation of hand and wrist disorders. Acta Orthop Belg 2008;74(5):575-81.
14. Diniz Lopes A, Ciconelli RM, Carrera EF, Griffin S, Faloppa F, Baldy dos Reis F. Comparison of the responsiveness of the Brazilian version of the Western Ontario Rotator Cuff Index (WORC) with DASH, UCLA and SF-36 in patients with rotator cuff disorders. Clin Exp Rheumatol 2009;27(5):758-64.
15. Longo UG, Rizzello G, Petrillo S, Loppini M, Maffulli N, Denaro V. Conservative Rehabilitation Provides Superior Clinical Results Compared to Early Aggressive Rehabilitation for Rotator Cuff Repair: A Retrospective Comparative Study. Medicina (Kaunas) 2019;55(8):402.
16. Arrigo, CA. Peak Torque and Maximum Work Repetition During Isokinetic Testing Of The Shoulder Internal and External Rotators. Isokinetics Ex Sci 1994;4(4):171-5.
17. Nelson, R., Currier, D. Electrophysiological evaluation: An overview. Clinical Electrotherapy. Norwalk, Conn: Appleton & Lange 1991;331-44.
18. McClure PW, Michener LA, Karduna AR. Shoulder function and 3-dimensional scapular kinematics in people with and without shoulder impingement syndrome. Phys Ther 2006;86(8):1075-90.
19. Lin JJ, Hanten WP, Olson SL, Roddey TS, Soto-quijano DA, Lim HK, Sherwood AM. Shoulder dysfunction assessment: self-report and impaired scapular movements. Phys Ther 2006;86(8):1065-74.
20. Pereira S, Mehta S, McIntyre A, *et al*. Functional electrical stimulation for improving gait in persons with chronic stroke. Top Stroke Rehabil 2012;19(6):491–498.
21. Reinold MM, Macrina LC, Wilk KE, Dugas JR, Cain EL, Andrews JR. The effect of neuromuscular electrical stimulation of the infraspinatus on shoulder external rotation force production after rotator cuff repair surgery. Am J Sports Med 2008;36(12):2317-21.
22. Smith N, Hotze R, Tate AR. A Novel Rehabilitation Program Using Neuromuscular Electrical Stimulation (NMES) and Taping for Shoulder Pain in Swimmers: A Protocol and Case Example. Int J Sports Phys Ther 2021;16(2):579-90.
23. Hara K, Matsuse H, Hashida R, et al. The effect of rotator cuff physical exercise combined with electrically stimulated antagonist on shoulder rotator cuff strength. J Orthop Sci 2022;27(1):126-30.
24. Imoto AM, Peccin MS, Teixeira LE, Silva KN, Abrahão M, Trevisani VF. Is neuromuscular electrical stimulation effective for improving pain, function and activities of daily living of knee osteoarthritis patients? A randomized clinical trial. Sao Paulo Med J 2013;131(2):80-7.
25. Melo Mde O, Pompeo KD, Brodt GA, Baroni BM, da Silva Junior DP, Vaz MA. Effects of neuromuscular electrical stimulation and low-level laser therapy on the muscle architecture and functional capacity in elderly patients with knee osteoarthritis: a randomized controlled trial. Clin Rehabil 2015;29(6):570-80.
26. Hayashi I, Enokida M, Nagira K, et al. Change in the pennation angle of the supraspinatus muscle after rotator cuff tear repair. J Shoulder Elbow Surg 2019;28(5):888-92.
27. Kim SY, Sachdeva R, Li Z, Lee D, Rosser BW. Change in the Pathologic Supraspinatus: A Three-Dimensional Model of Fiber Bundle Architecture within Anterior and Posterior Regions. Biomed Res Int 2015;2015:564825.