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Efficacy of radial extracorporeal shockwave therapy in rehabilitation following arthroscopic rotator cuff repair

A STROBE compliant study

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Abstract

Rotator cuff tear is a common cause of shoulder pain and disability. Arthroscopic rotator cuff repair (ARCR) is performed to treat a torn tendon. Postoperative joint immobilization is essential, but it is a problem that needs to be addressed in the rehabilitation process. This study aimed to evaluate the effects of radial extracorporeal shock wave therapy (rESWT) in patients who underwent ARCR and required active movement after the immobilization period. This study was an open-label, prospective, single-arm trial of 30 inpatients aged >18 years who underwent ARCR. A total of 6 rESWT sessions, along with the conventional rehabilitation program for ARCR patients, were provided at the hospital's sports rehabilitation center for 2 weeks. The application sites of rESWT are periscapular muscles (supraspinatus, infraspinatus, teres minor, and rhomboid). Evaluations were conducted 3 time points—baseline, immediately after the first session of rESWT, and after 2 weeks of intervention. The outcome measures were the numeric pain rating scale for pain, and shoulder flexion, scaption flexion, abduction, horizontal adduction, external rotation, and internal rotation for shoulder range of motion. For shoulder function, disabilities of the arm, shoulder and hand, shoulder pain and disability index, and simple shoulder test were used, and muscle strength was expressed by grip strength. supraspinatus and infraspinatus evaluated thickness, tone, and stiffness. The muscle strength (95% CI, –3.554 to –0.073) and supraspinatus tone ($P = .017$) showed significant changes immediately after the first session of rESWT. Further, there was significant improvement in ROM ($P < .01$); shoulder function ($P < .01$); and muscle strength (95% CI, –3.561 to –0.625), supraspinatus stiffness (95% CI, –67.455 to –26.345), and infraspinatus stiffness ($P = .045$) after 2 weeks of intervention. However, muscle thickness and tone were significantly improved only in supraspinatus ($P = .044$, $P = .040$). Rehabilitation with radial extracorporeal shock wave therapy additionally applied to the periscapular muscles in patients who started active movement in rehabilitation after arthroscopic rotator cuff repair is effective for shoulder function and muscle properties (muscle strength, thickness, tone, and stiffness). However, a randomized controlled trial is needed to further assess the effects of radial extracorporeal shock wave therapy alone.

Abbreviations: ARCR = arthroscopic rotator cuff repair, CPM = continuous passive motion, DASH = disabilities of the arm, shoulder, and hand, ICC = intraclass correlation coefficient, MCID = minimal clinically important difference, NPRS = numeric pain rating scale, RCT = randomized controlled trial, rESWT = radial extracorporeal shock wave therapy, ROM = range of motion, SPADI = shoulder pain and disability index, SST = simple shoulder test, TENS = transcutaneous electrical nerve stimulation.

Keywords: arthroscopic surgery, extracorporeal shock wave therapy, physical therapy, postoperative care, rotator cuff injuries

1. Introduction

Rotator cuff tear is a common cause of shoulder pain and disability.[1] It can be treated using surgical arthroscopic rotator cuff repair (ARCR).[2] Immobilization of the shoulder joint is essential for the stable recovery of the tendon during the acute phase after ARCR.[3] However, joint immobilization should reduce capsules and ligaments and induce adhesion of

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate: This study was approved by the Institutional Review Board (IRB) of Sahmyook University. Informed consent was obtained from all individual participants included in the study. All procedures performed in studies involving human participants were by the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Competing interests: The authors declare that they have no competing interests.

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connective tissues around the joint. Thus, these factors should be considered during postoperative rehabilitation.[4,5]

The concept of rehabilitation following ARCR is the healing of the repaired tendon, and physical therapy is so important in postoperative management.[6] Among them, radial extracorporeal shock wave therapy (rESWT) can contribute to the healing of tissues by pain control caused by hyperstimulation analgesia[7] and increasing new blood vessels at the myotendinous junction.[8,9] A previous study reported significant improvements in pain and function after rESWT for tendinopathy of the biceps brachii long head.[10] However, only muscle regeneration was improved after surgery in a surgical rate model,[11] and no studies have evaluated the effects of rESWT on the recovery of tendons after ARCR.

The purpose of this study was to investigate the additional effects of rESWT in conventional physical therapy rehabilitation for ARCR patients after 6 weeks of the joint immobilization phase, based on the evidence that rESWT promotes pain control and recovery. We hypothesize that the immediate changes in muscle properties (muscle strength, thickness, tone, and stiffness) after 1 application of rESWT will be maintained even after 2 weeks, as well as positive benefits in pain and shoulder function.

2. Methods

2.1. Study design

This was an open-label, prospective, single-arm intervention study structured according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement Cohort's guidelines. This study was conducted at the Sports Rehabilitation Center of The Better Hospital from May 10, 2021, to July 8, 2021. A pretest-posttest design was used for evaluation at baseline and 2 weeks after the intervention. Additionally, to assess immediate changes, a mid-test was performed after a single session of rESWT to conduct a total of 3 evaluations—at baseline, immediately after the first session of intervention, and after 2 weeks of intervention.

2.2. Participants

Participants were recruited by posting an announcement on the bullet board at the information desk of the Sports Rehabilitation Center of The Better Hospital. Patients who were hospitalized for rehabilitation after ARCR from May 10, 2021, were recruited. The evaluation of eligibility criteria was performed by a physical therapist (H.-J.K.) referring to the medical certificate and surgical record received from the orthopedic surgeon. Potential participants were screened and enrolled according to the inclusion and exclusion criteria. The inclusion criteria were adults aged >18 years who wished to participate in the study and underwent ARCR 6 weeks prior. The exclusion criteria were the elderly aged >65 years who underwent graft augmentation for a large tear, had a previous history of surgeries at the surgical site, and had shoulder osteoarthritis.[12,13]

2.3. Interventions

After ARCR, the participants underwent rESWT and Better Hospital's programmed physical therapy rehabilitation (physical agents and ROM exercises). The intervention, which was conducted by a total of 4 physical therapists, 1 rESWT, 2 physical agents, and 1 ROM exercise, was provided without any changes for 2 weeks.

2.3.1. Radial extracorporeal shock wave therapy. rESWT was provided using Masterpuls® MP200 (Storz Medical AG, Tägerwilen, Switzerland). The participants were asked to sit with the exposed scapula. After applying gel to the trigger points (supraspinatus, infraspinatus, teres minor, rhomboid), according to the 90° rule, a 15-mm applicator was applied in transverse and diagonal directions at the myotendinous junction and spread around the muscle belly using a smoothing technique (Fig. 1).[14] A total of 2000 pulses of 11 Hz frequency were applied at 2.0 bars of air pressure in each session.[15,16]

2.3.2. Physical therapy rehabilitation program.

2.3.2.1. Physical agents. Physical agents used for postoperative rehabilitation were included in superficial heat therapy, microwave therapy, and transcutaneous electrical nerve stimulation (TENS).

To relax the tissues by increasing the pain threshold of the peripheral nerves in the irradiated area,[17] superficial heat therapy was applied using infrared radiation (IR) by IR-2014 (AJINMEDICAL, Jeonju, Republic of Korea). In a sitting position, the participants were asked to expose their shoulder joint that underwent ARCR and irradiated with IR for 15 minutes at a distance of 50 cm. The intensity was controlled using a dial, and irradiation was provided at moderate heat intensity.

Microwave therapy was provided using Biowave HM-801 (Hanil-TM, Seoul, Republic of Korea) to increase the temperature and blood circulation of deep tissues.[18] After IR, the participants were asked to expose their shoulder joints in a sitting position. The participants were irradiated for 5 minutes at a distance of 20 cm. The intensity of the treatment was 2450 MHz and 100 W.

TENS was provided using BM-420 (Hanil-TM, Seoul, Republic of Korea). Automatic modulation of intense TENS of 100 to 300 Hz was provided to block the transmission of nociceptive information from peripheral nerves by stimulating Aδ fibers.[19] After MWT, TENS was applied with a maximum

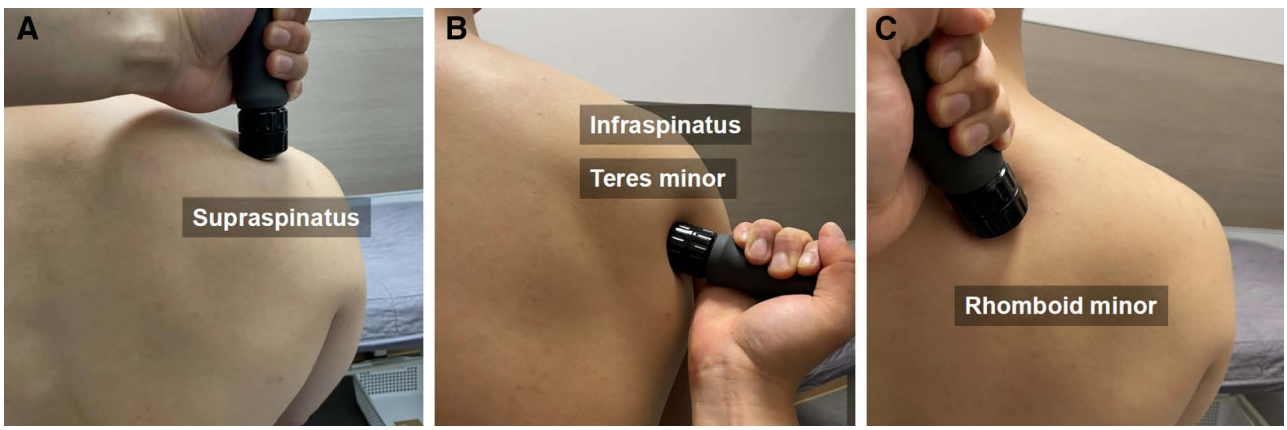

Figure 1. Radial extracorporeal shock wave therapy application site.

output current of <33 mA, and the suction electrode was set to <100 mm Hg for 15 minutes.

2.3.2.2. Range of motion exercise. Continuous passive motion (CPM) was performed using ARTUS-703S (Eugene Medicare, Seoul, Republic of Korea). CPM is a passive ROM exercise that is the most frequently used treatment after shoulder joint surgery. It helps maintain the motility of patients without any support.[20] The instrument was set to a scaption of 180° flexion to 20° of extension. The speed was set to the maximum at level 5, and CPM was provided for 20 minutes.

After CPM, the participants autonomously performed active ROM (AROM) exercises depending on their conditions under the supervision of a physical therapist in charge of therapeutic exercises for 1 hour and 30 minutes. For those who could not conduct AROM due to pain or did not have full mobility, a T-bar (BALANCEBODY, Suncheon, Republic of Korea) was used to conduct active-assisted ROM exercise.

2.3.3. Analgesic intake. In addition to the rESWT and physical therapy rehabilitation program, inpatients received analgesics twice a day (8 AM and 6 PM) to relieve postoperative pain. In addition, 1 tablet of afloqualone for muscle relaxation; 1 tablet of aceclofenac, a nonsteroidal antiinflammatory drug; and 1 tablet of omeprazole for the treatment of gastric and duodenal ulcers or erosions, were prescribed.

2.4. Outcome measures

All evaluations of patients with ARCR, excluding self-reported questionnaires, were conducted by a single therapist at baseline, immediately after the first session of intervention (immediate change), and after 2 weeks of intervention (postintervention change). For immediate changes, muscle strength, tone, and stiffness were assessed.

2.4.1. Primary outcome measures.

2.4.1.1. Pain. The numeric pain rating scale (NPRS), which was rated from 0 points (no pain) to 10 points (the most severe pain), was used to evaluate pain.[21] The pain was divided into usual and worst pain for assessment. The NPRS showed a high test-retest reliability (intraclass correlation coefficient [ICC] = 0.74),[22] and the minimal clinically important difference (MCID) was 1.1 to 2.2 points.[21,23]

2.4.2. Secondary outcome measures.

2.4.2.1. Range of motion. The ROM of the shoulder was assessed using a universal goniometer, according to international guidelines.[24] High intraobserver reliability was observed (ICC = 0.91–0.99).[25] Shoulder flexion, abduction, horizontal adduction, external rotation, internal rotation, and scaption flexion were assessed from the active movements of the participants.[26] In particular, horizontal adduction can help to evaluate the unique contracture of the posterior capsule after ARCR.[27]

2.4.2.2. Shoulder function. Shoulder function was evaluated using the disabilities of the arm, shoulder, and hand (DASH); shoulder pain and disability index (SPADI); and a simple shoulder test (SST).

The DASH is a widely used tool for assessing shoulder disability.[28] It is a self-reported questionnaire consisting of 30 items that are evaluated on a 5-point scale. The minimally detectable change of DASH was 10.5,[29–31] and the MCID ranged between 8.1 and 13 points in previous studies.[31,32]

The SPADI measures the level of perceived disability by the participants and consists of 13 items and 2 subdomains. A total of 5 and 8 items measured pain and disability, respectively, and the total score of the tool was 100 points. A higher score indicated greater disability.[33,34] The test-retest reliability of SPADI (ICC) was 0.89,[35] and the MCID ranged between 14.1 and 20.6 points in a previous study.[32]

The SST is a questionnaire developed by Washington University Hospital in the United States to assess the shoulder. The questionnaire consists of 12 items related to daily life that are evaluated using "yes" or "no." A higher score indicates greater functional loss of the shoulder. The intra- and interobserver reliabilities (r) of SST were 0.97 and 0.85, respectively,[36] and the MCID was 2 points.[37]

2.4.2.3. Muscle strength. The muscle strength of the rotator cuff was highly correlated with grip strength, evaluated using a dynamometer (R = 0.91).[38] Grip strength was measured using a dynamometer (TKK-5401, Japan). TKK is the most ideal dynamometer with a low error value compared with other models.[39] The participants were asked to hold the dynamometer and lower their arms naturally. The arm was placed away from the body to prevent the dynamometer from being in contact with the body, and the participants were asked to apply their maximum force as directed by the therapist. Measurements were performed twice, and the mean values were recorded.[40]

2.4.2.4. Muscle thickness. Muscle thickness was measured using an ultrasound imaging unit (Bodymetrix Pro System, Intelametrix, Livermore). The probe was placed vertically without any force to measure muscle thickness after applying a water-soluble transmission gel to the region of evaluation. Subsequently, 2.5 MHz of ultrasound was focused as a strong peak at the boundaries between tissues, and the tissue thickness was measured by converting the distance between the focused points into mm.[41] The previously reported test-retest reliability (ICC) was 0.99.[41] In our study, the muscle belly of the supraspinatus and infraspinatus were measured, and the distance from the tip of the deep adipose tissue to the muscle tissue was measured (mm) (Fig. 2).[42]

2.4.2.5. Muscle tone and stiffness. The muscle tone of the supraspinatus and infraspinatus was measured using Myoton PRO (Myoton AS, Tallinn, Estonia). Myoton PRO can assess muscle properties in a simple and noninvasive manner, and the intrarater reliability was 0.94 to 0.99 in a previous study.[43] The measurement items were muscle tone (Hz) and stiffness (N/m). Muscle tone is a parameter indicating muscle tension, such as muscle activity, on electromyography.[44] Muscle stiffness is defined as the tissue's resistance to external forces.[45] The participants were asked to maintain a prone position in the treatment room at 24 °C.[46] Myoton PRO probe was placed perpendicular to the muscle belly of the supraspinatus and infraspinatus. Measurements were repeated 3 times (5 impulses with low force) at intervals of 15 seconds, and the average value of the repeated measurements was recorded.[47]

2.5. Ethics and dissemination

This study was approved by the Institutional Review Board of Sahmyook University (2-1040781-A-N-012021035HR, 04/22/2021) before enrollment of the first participant on May 10, 2021. This study was registered as a clinical trial on Clinicaltrials.gov (NCT04848103, 04/13/2021). Participants who were selected using the inclusion and exclusion criteria have explained the purpose and method of the study to confirm their participation, in agreement with the ethical standards of the Declaration of Helsinki. Written consent was obtained from participants who wished to participate in the study, and a 1-page document describing the study was provided. The participants were told that the pain may worsen as the intervention was applied to the shoulder and that they may withdraw from the study at any time point.

2.6. Sample size

The sample size was calculated by assessing changes in the SST score of the group that received extracorporeal shock wave

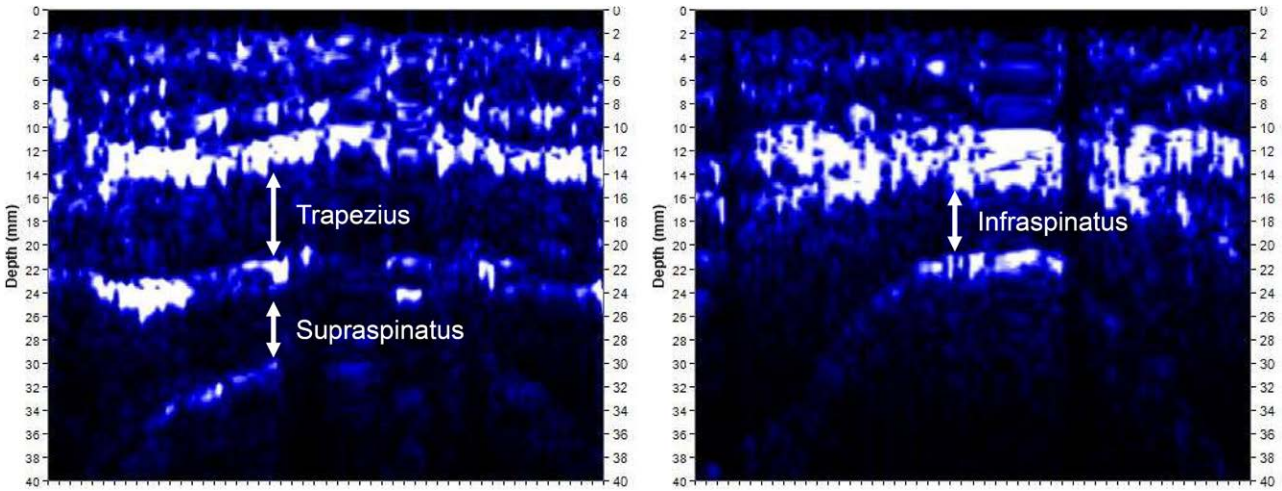

Figure 2. Measurement of muscle thickness using Bodymetrix.

therapy in a study by Kolk et al.[48] G*power 3.1 (Franz Faul, Universitat Kiel, Germany) was used for calculation. A total of 24 participants were required assuming an effect size f(v) of 0.27, power of 0.80, single group, and 3 measurements. Considering a dropout rate of 20%, a total of 30 participants were recruited.

2.7. Statistical analysis

All statistical analyses were conducted using IBM SPSS software, version 25. Descriptive statistics were used to analyze the statistical and clinical characteristics of the enrolled participants. Continuous variables are presented as mean and standard deviation, while categorical variables are presented as numbers and percentages. Immediate and postintervention changes were analyzed to assess the endpoints of the variables. First, the Kolmogorov–Smirnov test was conducted to assess the normal distribution of data. A paired *t*-test was conducted for normally distributed variables, and the Wilcoxon signed-rank test was conducted for variables that were not normally distributed. The effect size of each variable was calculated as Cohen's d and classified according to Cohen's definition (small = 0.20, medium = 0.50, large = 0.80).[49] Statistical significance (α) was set at $P < .05$.

3. Results

Figure 3 shows the flow diagram of this study based on the STROBE guidelines. A total of 42 potential participants were screened for eligibility, and 12 participants were excluded (does

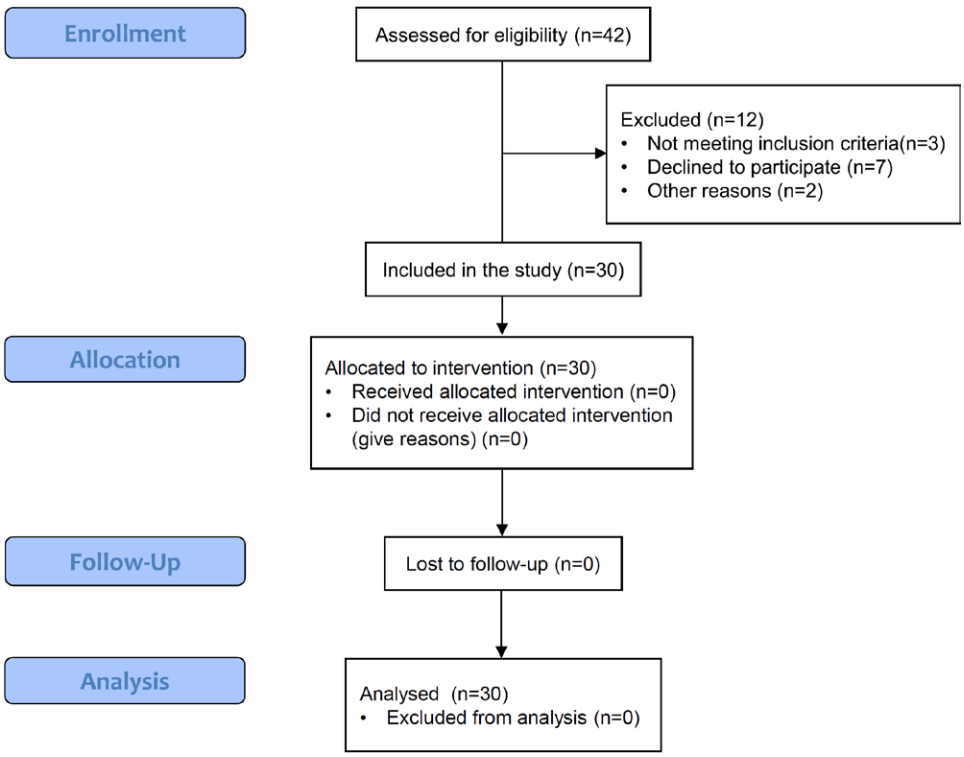

Figure 3. Flow diagram of participant recruitment, allocation, and analysis.

not meet the inclusion criteria, refused to participate in the study, refused ESWT). All the 30 enrolled participants received the intervention for 2 weeks and were included in the final analysis. Treatment compliance of all participants was not unusual because only ESWT was added to the existing rehabilitation protocol. In addition, adverse effects due to ESWT did not occur.

3.1. General characteristics of participants

Table 1 shows the general characteristics of the enrolled participants. Most of the participants were in the mid-age group (age = 49.47 ± 5.22) and had the right side affected (73%). The pressure of intensity of rESWT at a default of 11 Hz was 1.59 ± 0.69.

ARCR was performed for tendon repair of the supraspinatus and/or subscapularis, and capsular release, biceps tenodesis, and subacromial decompression were additionally performed depending on the individual participants.

3.2. Primary outcomes

3.2.1. Pain. The NPRS measured at baseline and postintervention is shown in Table 3. Both usual pain and worst pain did not significantly decrease postintervention from baseline ($P > .05$).

3.3. Secondary outcomes

3.3.1. Range of motion. ROM measured at baseline and postintervention are shown in Table 3. All shoulder flexion (95% CI, –49.462 to –24.604), flexion in scaption (95% CI, –53.622 to –30.645), abduction (95% CI, –44.367, –16.967), horizontal adduction (95% CI, –25.652, –5.014), external rotation (95% CI, –12.897, –4.770), and internal rotation (95% CI, –11.230, –3.103) significantly improved postintervention from baseline. In particular, shoulder flexion and scaption flexion showed greater effect sizes (d = 1.26, d = 1.51).

3.3.2. Shoulder function. Shoulder function was assessed at baseline and postintervention using a self-reported questionnaire (Table 3). The DASH ($P < .01$), SPADI (95% CI, 11.828–24.121), and SST ($P < .01$) were significantly improved postintervention from baseline.

3.3.3. Muscle strength. Grip strength was measured at baseline, immediate change, and postintervention change, and there was a significant, small effective improvement immediately after the first session of intervention (95% CI, –3.554 to –0.073; d = 0.30) and a significant small effect postintervention (95% CI, –3.561 to –0.625; d = 0.36) (Tables 2 and 3).

3.3.4. Muscle thickness. Muscle thickness was assessed at baseline and postintervention (Table 3). Muscle thickness was significantly changed only in the supraspinatus, with a small effect size ($P = .044$, d = 0.38).

Table 1

General characteristics of participants.

Patients (n = 30)	
Age (SD)	49.47 (5.22)
Male (%)/female (%)	16 (53)/14 (47)
Affected side (left/right)	8/22
Weight, kg (SD)	66.73 (10.96)
Height, cm (SD)	166.57 (9.09)
BMI, kg/m^2 (SD)	23.94 (2.51)
bar (SD)	1.59 (0.69)

Bar = intensity of pressure, BMI = body mass index, SD = standard deviation.

Table 2

Immediate effects after radial extracorporeal shock wave therapy.

	Paired *t*-test			Wilcoxon signed-rank test			
	Baselines	Immediate change		Baselines	Immediate change		
Outcome measures	Mean (SD)	Mean (SD)	MD (95% CI)	Median (IQR)	Median (IQR)	*Z*	*Effect size**
Muscle strength							
Grip strength	28.10 (5.05)	29.91 (6.82)	–1.81 (–3.554, –0.073)†				0.30
Muscle tone							
Supraspinatus				20.90 (2.40)	20.80 (5.10)	–2.382†	0.26
Infraspinatus				20.00 (3.93)	19.45 (5.28)	–0.113	0.05
Muscle stiffness							
Supraspinatus	399.07 (51.12)	422.30 (45.85)	–23.23 (–48.744, 2.277)				0.48
Infraspinatus				388.00 (140.75)	390.00 (72.00)	–0.587	0.02

CI = confidence interval, IQR = interquartile range, MD = mean difference, SD = standard deviation.
*Cohen's d.
†$P < .05$.

Table 3

Changes after 2 weeks of interventions.

Outcome measures	Paired *t*-test			Wilcoxon signed-rank test			
	Baselines Mean (SD)	postintervention Mean (SD)	MD (95% CI)	Baselines Median (IQR)	Postintervention Median (IQR)	*Z*	Effect size*
Pain							
Usual pain				5.00 (2.00)	4.00 (2.00)	–0.766	0.09
Worst pain				5.00 (2.50)	5.00 (2.00)	–0.595	0.14
Range of motion							
Flexion (0–180°)	132.30 (36.06)	169.33 (20.75)	37.03 (–49.462, –24.604)†				1.26
Flexion in scaption (0–180°)	124.37 (33.58)	166.50 (20.68)	42.13 (–53.622, –30.645)†				1.51
Abduction (0–180°)	117.33 (39.58)	148.00 (37.64)	30.67 (–44.367, –16.967)†				0.79
Horizontal Adduction (0–130°)	98.33 (27.74)	113.67 (16.71)	15.34 (–25.652, –5.014)†				0.67
External rotation (0–90°)	65.00 (16.71)	73.83 (13.75)	8.83 (–12.897, –4.770)†				0.58
Internal rotation (0–70°)	35.50 (13.79)	42.67 (15.24)	7.17 (–11.230, –3.103)				0.49
Shoulder function							
DASH				75.42 (29.38)	60.00 (23.75)	–3.121†	0.72
SPADI-pain	62.93	47.00	–15.93 (9.656, 22.211)†				0.85
SPADI-disability	58.50	39.25	–19.25 (11.940, 26.560)†				0.99
SPADI-total	60.21	42.23	–17.98 (11.828, 24.121)†				0.98
SST				9.00 (1.50)	7.00 (4.00)	–2.815†	0.67
Muscle strength							
Grip strength	28.10 (5.05)	30.19 (6.60)	2.09 (–3.561, –0.625)†				0.36
Muscle thickness							
Supraspinatus				7.00 (3.18)	8.00 (2.63)	–2.010†	0.38
Infraspinatus				7.70 (3.38)	7.00 (2.73)	–0.447	0.04
Muscle tone							
Supraspinatus				20.90 (2.40)	21.10 (1.43)	–2.054†	0.25
Infraspinatus				20.00 (3.93)	20.40 (3.73)	–0.889	0.21
Muscle stiffness							
Supraspinatus	399.07	445.97	46.90 (–67.455, –26.345)†				1.08
Infraspinatus				388.00 (140.75)	390.00 (83.00)	–2.008†	0.45

CI = confidence interval, DASH = disabilities of the arm, shoulder and hand, IQR = infraspinatus, MD = mean difference, SD = standard deviation, SPADI = shoulder pain and disability index, SST = simple shoulder test.

*Cohen's d.

†$P < .05$.

3.3.5. Muscle tone. Muscle tone was assessed at baseline, immediately after the first session of intervention, and postintervention (Tables 2 and 3). Significant immediate changes in muscle tone were observed only in the supraspinatus ($P = .017$). Significant postintervention changes were also observed only in the supraspinatus ($P = .040$). For both immediate and postintervention changes in the muscle tone of the supraspinatus, a small effect size was observed (d = 0.26, d = 0.25).

3.3.6. Muscle stiffness. Muscle stiffness was assessed at baseline, immediately after the first session of intervention, and postintervention (Tables 2 and 3). There was no significant immediate change in muscle stiffness ($P > .05$). However, there were significant postintervention changes in both the supraspinatus (95% CI, –67.455 to –26.345) and infraspinatus ($P = .045$). Large effect size was observed for the supraspinatus, which showed significant changes in muscle thickness and tone (d = 1.08).

4. Discussion

This study is a prospective single-arm trial to investigate the effect of additional application of rESWT on pain, shoulder function, and muscle properties in postoperative rehabilitation following ARCR. Pain control was important in postoperative rehabilitation, but there was no significant improvement and significant improvement was seen in all other variables.

In the results of this study, there was no significant improvement in both usual pain and worst pain through NPRS ($P = .444$, $P = .552$). This finding was consistent with a previous study comparing the ARCR (n = 59) and control (n = 61) groups, in which pain decreased 3 months after surgery but the NPRS scores increased at 6, 12, and 24 months.[50] This suggests that pain control after ARCR is unstable for up to 24 months. The absence of a significant decrease in pain may be related to the minor side effects of pain from rESWT[51] and a relatively short period of 2 weeks to induce definite changes in pain.

ROM and shoulder function (DASH, SPADI, SST) were significantly improved in the postintervention evaluation ($P < .05$). This is consistent with the findings of a study by Gumina et al,[22] in which the small lesion group showed increased ROM from 45 days (T1) to 70 days (T2). The similarity of the ROM increase in the active motion phase after the end of the immobilization phase confirmed that the intervention methods applied in this study were appropriate.

Shoulder function evaluation showed significant improvements in the MCID scores of the DASH and SPADI, except for SST. In the result analysis through the change of the average value of the DASH that showed a medium effect size (d = 0.72), when the MCID was set to 8.1 to 13 points, there was a significant improvement in the MCID, with a difference of 10.28 points. Although there was a medium effect due to the SST (d = 0.67), when the MCID was set to 2 points, there was no significant result, with a difference of 1.37 points. Parametric tests were conducted to assess the subdomains of the SPADI (pain, disability, and total) and showed a large effect size (d = 0.85, d = 0.99, d = 0.98). In addition, when the MCID was set to 14.1 to 20.6 points, there was a significant improvement in all subdomains. It is thought that the SST showed a more meaningful decrease in our study than the SST at 6 months in a previous study[52] comparing early motion and immobilization after ARCR. Compared with studies that provided rehabilitation after conventional ARCR,[26,50] ROM, function, and pain of the shoulder were further improved in our study.

Our study was a single-arm study, and all effects cannot be attributed to rESWT alone. Thus, immediate changes were assessed after the first rESWT session to evaluate its effects. Grip strength (95% CI, –3.554 to –0.073) and supraspinatus muscle tone significantly improved ($P < .05$). This finding was consistent with significant postintervention changes in the grip strength (95% CI, –3.561 to –0.625) and muscle tone of the supraspinatus ($P < .05$). Therefore, these findings suggest that rESWT alone changes grip strength and muscle tone. Additionally, the significant improvement in the muscle thickness of the supraspinatus may be highly correlated with the increase in muscle tone in immediate and postintervention changes. Based on our findings and those of previous studies, muscle tone and muscle activity may be related to one another.[44] Previous studies also showed that muscle activity is correlated with muscle thickness through ultrasound imaging,[53–56] further supporting the notion that activated muscles after rESWT have an increased muscle tone, which may contribute to the increased muscle thickness. Moreover, this finding is supported by the results of a previous study, in which grip strength was highly correlated with rotator cuff strength.[38]

Although muscle stiffness did not show significant immediate changes ($P > .05$), it showed significant postintervention changes in the supraspinatus (95% CI, –67.455 to –26.345) and infraspinatus ($P = .045$). In a study by Marusiak et al[57] using Myoton, increased muscle stiffness in patients with Parkinson disease compared to that in healthy participants did not necessarily indicate positive changes. However, based on a previous study that reported a positive correlation between muscle stiffness and contractile force and muscle activity[58] and our findings showing that muscle stiffness increased through changes in grip strength and muscle tone and thickness, increased muscle stiffness may indicate positive outcomes.

rESWT after ARCR can improve muscle properties of the rotator cuff, such as muscle tone and stiffness, and affect muscle thickness and strength. Thus, rESWT may be used to improve ROM and shoulder function after ARCR in clinical settings.

This study is meaningful as, to the best of our knowledge, it is the first study to quantitatively and qualitatively assess the effects of rESWT in the rehabilitation of patients after ARCR. In addition, although it was a single-arm study, the effects of rESWT alone could be assessed immediately after the first session of rESWT and after 2 weeks of intervention. However, several limitations must be considered when interpreting these findings. First, it is pointed out that the only drawback of rESWT is that it may increase treatment-related pain,[51] and side effects reported in other studies include redness and superficial hematomata on the skin.[59] Second, the participants were only hospitalized for 2 weeks to undergo rehabilitation at Better Hospital, which limited the long-term assessment of the effects. Additionally, as hospitalized patients were enrolled as the participants of this study, there were difficulties in establishing and providing effective treatment to the control group that did not undergo rESWT. Moreover, there may have been biasing by a single therapist who provided rESWT, and the effects of rESWT may differ according to the skill level of the therapist.

Therefore, to further assess the feasibility of rESWT for postoperative rehabilitation of surgeries including ARCR, an RCT is necessary with a sufficient experimental period and comparable control group. Furthermore, large sample size is required for the generalization of the findings, and a multicenter study may be necessary to reduce bias by therapists who provide the intervention.

5. Conclusions

In this study, immediate changes in the muscle tone of the supraspinatus were observed after a single session of radial extracorporeal shock wave therapy in the immobilization phase after arthroscopic rotator cuff repair. In addition, after 2 weeks of intervention, there were significant changes in the range of motion; grip strength; muscle thickness, tone, and stiffness of the supraspinatus. These findings may be the therapeutic outcomes of the physical therapy rehabilitation program combined with additional radial extracorporeal shock wave therapy. In the future, a randomized controlled trial with a control group is necessary to assess the independent effects of radial extracorporeal shock wave therapy.

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