



Effects of radial extracorporeal shock wave therapy on clinical variables and isokinetic performance in patients with knee osteoarthritis: a prospective, randomized, single-blind and controlled trial

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Abstract

Objective This study aims to compare the efficacy of r-ESWT treatment with sham-ESWT on pain, walking speed, physical function, and isokinetic muscle strength in knee osteoarthritis.

Methods The study included 104 patients (mean age 61.0 ± 6.2 years; range 50 to 70 years) who were admitted to our outpatient clinic with newly diagnosed with knee osteoarthritis. Patients were randomly assigned to two groups. Both groups received transcutaneous electrical nerve stimulation for 30 minutes, hot pack for 40 minutes, and home-based exercise program of around the knee strengthening for 30 minutes in a day for three weeks (5 days in a week). Also, one group was treated with r-ESWT, while the other group was treated with sham-ESWT. For r-ESWT, patients received 2000 pulses of shockwave at 2.0 to 3.0 bar weekly for three weeks. All patients were evaluated with visual analog scale (VAS), active knee range of motion (ROM), 20-metre walk test, Western Ontario and McMaster Osteoarthritis Index (WOMAC), Lequesne's disability index, and isokinetic muscle performance before treatment, at the end of treatment, at one month and three months after treatment.

Results When groups were compared, group 1 scores were significantly better than the group 2 in all outcome parameters except WOMAC-stiffness at the end of treatment, at one month and three month follow-up (all $p < 0.05$). The VAS-resting, VAS-movement, knee ROM, 20-m walk test, WOMAC, and Lequesne's disability scores and peak torque values of knee extension improved in both groups with the highest improvement in the r-ESWT group. A comparison of difference of the two group scores showed statistically significant superior improvement in group 1 in all parameters at both one month and three months.

Conclusion Our findings revealed that r-ESWT combined with conventional electrotherapy is an effective treatment for improving pain and physical function in knee osteoarthritis to control symptoms up to three months.

Clinical trials ID NCT04243135

Keywords R-ESWT · Knee osteoarthritis · Pain · Function · WOMAC · Lequesne index

Introduction

Osteoarthritis (OA) is the most common form of degenerative arthritis characterized by degradation and loss of articular cartilage [1]. The main symptoms of OA are pain, stiffness, and physical disability [2, 3]. Optimal management of knee OA

necessitates a combination of non-pharmacological and pharmacological modalities, and surgical treatment is recommended in intractable cases [4]. There are a number of pharmacological and non-pharmacological treatment options for managing knee OA, e.g., modification of daily living activities, weight loss, diet interventions, exercise, manual therapy, physical therapy, electrotherapy (TENS, therapeutic ultrasound, laser), taping, use of assisting devices, bracing, non-steroidal anti-inflammatory drugs acetaminophen, opioids, and injection therapies [5].

Extracorporeal shock wave therapy (ESWT) has been increasingly used to help relieve pain and to remedy musculoskeletal disorders in recent years [6]. ESWT seems to be an effective treatment modality many different musculoskeletal conditions, including rotator cuff tendinopathies, calcifying

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tendinopathy of the shoulder, lateral epicondylitis, greater trochanteric pain syndrome, patellar tendinopathy, Achilles tendinopathy, plantar fasciitis, and bone disorders [7]. ESWT seems to have chondroprotective, antiinflammatory, neovascularization, antiapoptotic, and tissue regeneration effect on tissues which could be relevant in the treatment of OA [8].

Although there are many studies about ESWT on musculoskeletal disorders as well as on chondroprotective effect on

animal have been published, there is very limited evidence in the scientific literature to support the effectiveness of r-ESWT therapy in human knee OA. To the best of our knowledge, only a few studies have assessed the use of ESWT in human knee OA, and these studies have investigated only clinical outcomes, not the muscle performance. Therefore, in this study, we designed a randomized, single-blind, placebo-controlled prospective study to investigate the effect of r-

Fig. 1 Flowchart of the study

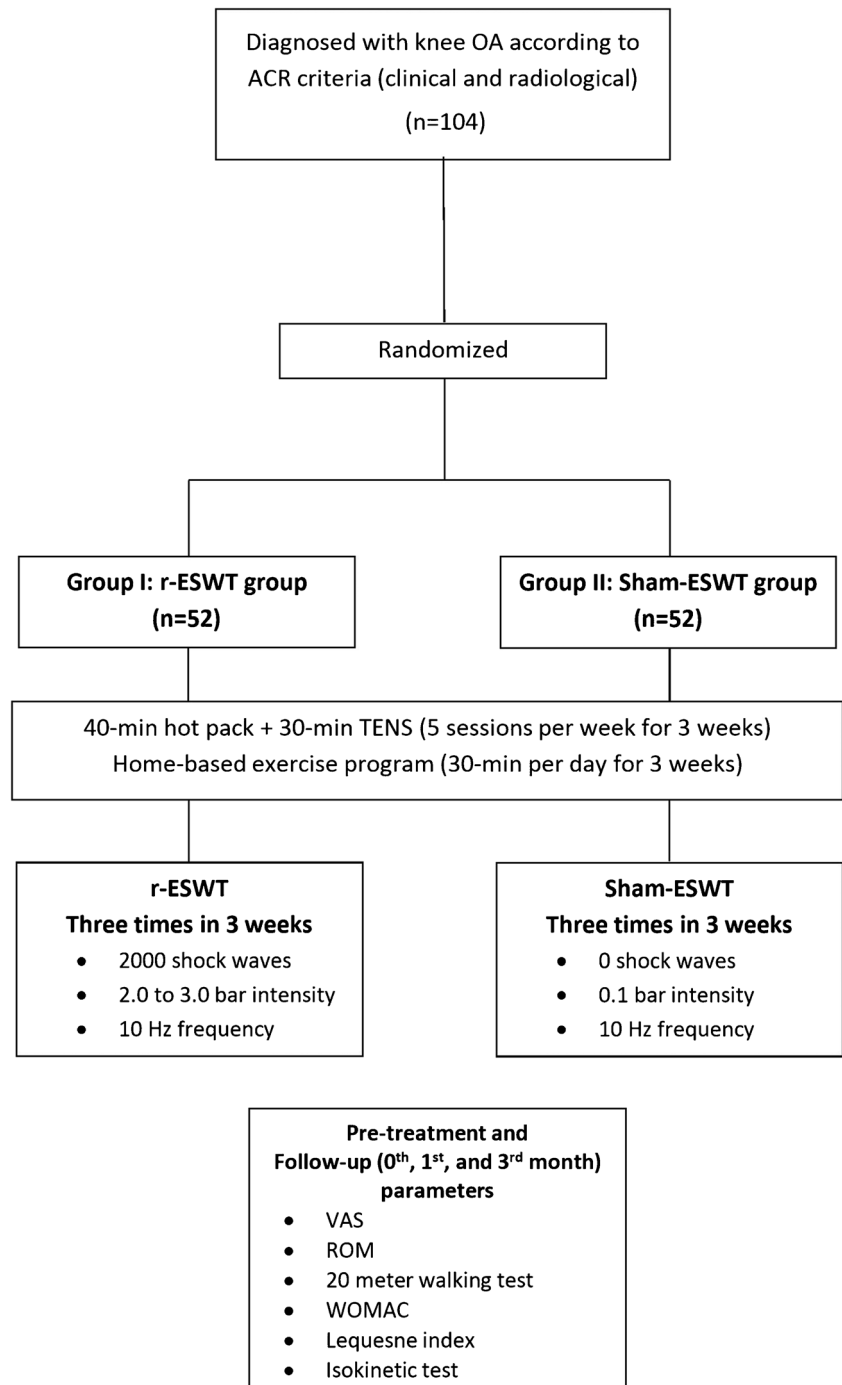


Table 1 Demographic, clinical, radiographic, and isokinetic features of the groups

	ESWT (<i>n</i> = 52) Mean ± SD	Sham-ESWT (<i>n</i> = 52)	<i>P</i> values
Age (years)	60.2 ± 6.3	61.8 ± 6.0	0.183
Gender, <i>n</i> (%)			
Male	10 (19.2%)	9 (17.3%)	0.952
Female	42 (80.8%)	43 (82.7%)	
Weight (kg)	78.0 ± 11.6	81.4 ± 12.9	0.160
Height (cm)	159.7 ± 7.9	162.5 ± 7.6	0.070
Body mass index (kg/m ²)	30.6 ± 4.3	30.8 ± 4.6	0.832
Symptom duration (month)	40.2 ± 21.9	46.8 ± 24.0	0.151
K-L grade, <i>n</i> (%)			
Grade 2	26 (50%)	24 (46.2%)	0.845
Grade 3	26 (50%)	28 (53.8%)	
Baseline evaluations			
VAS at rest	4.5 ± 2.0	4.0 ± 1.0	0.133
VAS during activity	7.4 ± 0.7	7.3 ± 1.0	0.462
Knee ROM	120.2 ± 12.3	120.1 ± 8.0	0.963
20-m walking test	22.7 ± 2.1	23.4 ± 1.8	0.092
WOMAC scores			
Pain	12.0 ± 2.2	12.0 ± 2.5	0.999
Stiffness	2.9 ± 1.5	2.6 ± 0.8	0.277
Physical function	44.4 ± 8.3	44.6 ± 6.8	0.868
Total	59.6 ± 10.5	59.3 ± 8.9	0.857
Lequesne index			
Pain	5.3 ± 1.3	5.6 ± 1.2	0.268
Distance	3.0 ± 0.6	3.2 ± 0.4	0.104
Function	4.0 ± 0.5	4.0 ± 0.7	0.882
Total	12.5 ± 2.0	12.9 ± 1.7	0.197
Isokinetic evaluation, PT (Nm)			
60°/s AV–QPT	34.4 ± 12.8	35.6 ± 11.9	0.614
180°/s AV–QPT	21.5 ± 5.9	20.6 ± 6.0	0.474

VAS, visual analog scale; ROM, range of motion; WOMAC, Western Ontario and McMaster Osteoarthritis Index; QPT, quadriceps peak torque; AV, angular velocity

Italicized *p* values show statistical significance (*p* < 0.05)

ESWT on pain, walking speed, physical function, and isokinetic muscle performance in moderate knee OA and surveyed the outcome of functional activity.

Methods

One hundred four patients (mean age 61.0 ± 6.2 years; range 50 to 70 years) who were admitted to our outpatient clinic between June 2017 and April 2018, and diagnosed with knee OA according to American College of Rheumatology (ACR) diagnostic criteria [9] and with Kellgren–Lawrence (K-L) grade 2 or 3. Patients with secondary OA, severe chronic illness, poor general health status (heart failure, chronic bronchitis, etc.), chronic inflammatory diseases, knee replacement surgery, and prior malignancy were excluded. Patients who

received intra-articular injections (corticosteroid, hyaluronic acid) within the previous six months were also excluded from the study. Flow chart for study is given in Fig. 1.

Patients were randomly allocated to an ESWT (group 1) or sham-ESWT (group 2) by using block randomization. All patients in both groups were applied with a hot pack for 40-minutes, transcutaneous electrical nerve stimulation for 30-min (100 Hz frequency and 60 ms pulse duration), and a home-based exercise program around the knee for 30 minutes per day for three weeks. Three sessions of ESWT were applied to group 1, and sham ESWT was applied to group 2 patients. Also, each patient in group 1 received shockwaves of continuous frequency and intensity (2000 shocks, 10 Hz, 2.0 to 3.0 bar), while the second group of patients received sham-ESWT (0 shocks, 10 Hz, 0.1 bar). In group 1, r-ESWT was undertaken with 2000 pulse each time at a week interval

Table 2 Baseline and after treatment (0, 1, and 3 months) follow-up results of clinical measurements of the groups

	ESWT (<i>n</i> = 52) Mean ± SD	Sham-ESWT (<i>n</i> = 52) Mean ± SD	<i>P</i> values
VAS at rest			
Baseline	4.5 ± 2.0	4.0 ± 1.0	
After treatment			
0th month	1.5 ± 1.2 *	2.0 ± 1.1 *	0.028
1st month	1.2 ± 0.9 *	1.9 ± 1.2 *	0.003
3rd month	1.0 ± 0.8 *	1.9 ± 1.3 *	0.001
VAS during activity			
Baseline	7.4 ± 0.7	7.3 ± 1.0	
After treatment			
0th month	3.6 ± 1.3 *	4.4 ± 1.4 *	0.003
1st month	3.0 ± 1.2 *	4.1 ± 1.4 *	< 0.001
3rd month	2.9 ± 1.4 * ^α	4.4 ± 1.8 *	< 0.001
20 m walking test (sec)			
Baseline	22.7 ± 2.1	23.4 ± 1.8	
After treatment			
0th month	17.3 ± 2.8 *	19.3 ± 2.1 *	< 0.001
1st month	16.7 ± 2.2 *	18.7 ± 2.2 *	< 0.001
3rd month	16.4 ± 2.0 *	19.2 ± 3.2 *	< 0.001
Knee ROM (degree)			
Baseline	120.2 ± 12.3	120.1 ± 8.0	
After treatment			
0th month	127.7 ± 7.9 *	124.2 ± 6.5 *	0.016
1st month	129.6 ± 7.9 *	125.8 ± 6.3 *	0.008
3rd month	131.3 ± 7.0 *	126.0 ± 6.0 *	< 0.001

VAS, visual analog scale; ROM, range of motion

Independent *t* test: ESWT and sham-ESWTItalicized *p* values show statistical significance (*p* < 0.05)

Repeated measures analysis of variance

**p* < 0.001 with baseline^α*p* < 0.001 with after treatment (0th month)

totaling 6000 pulse by using a radial shock wave therapy system (vibrolith ortho tip ESWT (ELMED Turkey)). The other group received sham-ESWT at 0.1 bar in the same area. The patients were placed supine with the affected knee at 90° flexion at each treatment session. The probe was chosen effective treatment depth (5–20-mm focal depth). The shock wave probe was held stationary on tender areas around the knee or at the patellofemoral and tibiofemoral borders of the target knee.

All evaluations were performed at baseline and at the end of treatment, at one month and three months after treatment by the same physiatrist, who was blind to the treatment. Visual analog scale (VAS) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) were used to evaluate pain, joint stiffness, and physical function. The Lequesne's index was used

Table 3 Baseline and after treatment (0, 1, and 3 month) follow-up results of WOMAC scores of the groups

	ESWT (<i>n</i> = 52) Mean ± SD	Sham-ESWT (<i>n</i> = 52) Mean ± SD	<i>P</i> values
WOMAC-pain			
Baseline	12.0 ± 2.2	12.0 ± 2.5	
After treatment			
0th month	5.0 ± 2.6*	6.8 ± 3.0*	0.001
1st month	3.9 ± 2.3*	5.9 ± 2.8*	< 0.001
3rd month	3.5 ± 1.7* ^α	6.5 ± 3.6*	< 0.001
WOMAC-stiffness			
Baseline	2.9 ± 1.5	2.6 ± 0.8	
After treatment			
0th month	1.2 ± 1.1*	1.1 ± 0.9*	0.517
1st month	1.0 ± 1.1*	1.0 ± 0.8*	0.999
3rd month	0.9 ± 1.1*	1.0 ± 1.0*	0.591
WOMAC-function			
Baseline	44.4 ± 8.3	44.6 ± 6.8	
After treatment			
0th month	22.3 ± 9.0*	28.2 ± 9.6*	0.002
1st month	19.9 ± 9.4*	25.7 ± 9.1*	0.002
3rd month	18.3 ± 8.1*	27.8 ± 1.4*	< 0.001
WOMAC-total			
Baseline	59.6 ± 10.5	59.3 ± 8.9	
After treatment			
0th month	28.6 ± 12.0*	36.2 ± 12.8*	0.003
1st month	24.8 ± 12.4*	32.7 ± 12.4*	0.002
3rd month	23.0 ± 10.5 *	35.4 ± 15.7*	0.001

WOMAC, Western Ontario and McMaster Osteoarthritis Index

Independent *t* test: ESWT and Sham-ESWTItalicized *p* values show statistical significance (*p* < 0.05)

Repeated measures analysis of variance;

**p* < 0.001 with baseline^α*p* < 0.001 with after treatment (0th month)

to assess disability. The active knee joint range of motion (goniometric measurement), 20-m walk test, and isokinetic muscle performance were also evaluated for all patients.

The extensor peak torques were performed using the Humac® NORM isokinetic dynamometer (CSMi, Stoughton, MA, USA) at baseline, at the end of treatment, at one month and three months after treatment. The participants were seated on the dynamometric chair and stabilized with waist and chest belts in 90° sitting position for the isokinetic measurement. After performing five submaximal warmup contractions, concentric PT values of the quadriceps at 60° and 180° per second angular velocities were evaluated. The isokinetic test protocol included five repeats at 60° per second, 30 seconds of rest, and 15 repeats at 180° per second.

Table 4 Baseline and after treatment (0, 1, and 3 month) follow-up results of Lequesne's disability scores of the groups

	ESWT (<i>n</i> = 52) Mean ± SD	Sham-ESWT (<i>n</i> = 52) Mean ± SD	<i>P</i> values
Lequesne-pain			
Baseline	5.3 ± 1.3	5.6 ± 1.2	
After treatment			
0th month	2.2 ± 1.2*	3.1 ± 1.6*	0.003
1st month	1.8 ± 1.2*	2.7 ± 1.3*	0.001
3rd month	1.6 ± 1.0*	2.8 ± 1.7*	< 0.001
Lequesne-distance			
Baseline	3.0 ± 0.6	3.2 ± 0.4	
After treatment			
0th month	2.0 ± 0.5*	2.5 ± 0.6*	< 0.001
1st month	2.0 ± 0.5*	2.4 ± 0.6*	0.003
3rd month	1.8 ± 0.6*	2.3 ± 0.8*	0.003
Lequesne-function			
Baseline	4.0 ± 0.5	4.0 ± 0.7	
After treatment			
0th month	2.3 ± 0.8*	2.8 ± 0.8*	0.011
1st month	2.1 ± 0.7*	2.5 ± 0.7*	0.007
3rd month	1.8 ± 0.8* ^α	2.6 ± 0.9*	< 0.001
Lequesne-total			
Baseline	12.5 ± 2.0	12.9 ± 1.7	
After treatment			
0th month	6.6 ± 2.3*	8.4 ± 2.8*	0.001
1st month	6.0 ± 2.3*	7.6 ± 2.5*	0.001
3rd month	5.3 ± 2.1* ^α	7.8 ± 3.2*	< 0.001

Independent *t* test: ESWT and Sham-ESWTItalicized *p* values show statistical significance (*p* < 0.05)

Repeated measures analysis of variance

**p* < 0.001 with baseline^α*p* < 0.001 with after treatment (0th month)

Statistical analysis

Statistical analysis was conducted with the IBM SPSS 22.0 (SPSS Inc., IL, USA) package program. Descriptive statistical results were shown as mean ± standard deviation or median (Q1–Q3) for continuous data, or number (*n*) and percentage (%) for categorical data. Gender of the groups was compared by using the chi-square test. If the data is normally distributed, the independent samples *t* test was used for between group comparisons. The time-varying scores of the groups were assessed with repeated measures analysis of variance (ANOVA) test. The Mann–Whitney *U* tests were used for comparing differences between the groups. *P* values of < 0.05 were considered statistically significant.

A priori required sample size was calculated using the G*Power version 3.1.9.4 software (Heinrich Heine

Table 5 Baseline and after treatment (0, 1, and 3 month) follow-up results of isokinetic parameters of the groups

	ESWT (<i>n</i> = 52) Mean ± SD	Sham-ESWT (<i>n</i> = 52) Mean ± SD	<i>P</i> values
Quadriceps peak torque			
60°/s AV, (Nm)			
Baseline	34.4 ± 12.8	35.6 ± 11.9	
After treatment			
0th month	43.2 ± 12.9 *	37.9 ± 11.7	0.031
1st month	48.1 ± 13.8 *	41.0 ± 12.3	0.007
3rd month	49.8 ± 14.9 *	42.2 ± 12.2 **	0.006
180°/s AV, (Nm)			
Baseline	21.5 ± 5.9	20.6 ± 6.0	
After treatment			
0th month	26.1 ± 8.8 *	21.3 ± 6.2	0.002
1st month	26.8 ± 7.4 *	22.3 ± 5.8	0.001
3rd month	26.0 ± 7.4 *	21.8 ± 6.6	0.003

AV angular velocity

Independent *t* test: ESWT and Sham-ESWTItalicized *p* values show statistical significance (*p* < 0.05)

Repeated measures analysis of variance

p* < 0.001 with baseline*p* < 0.001 with after treatment (0th month)

University, Dusseldorf, Germany) based on the change in the pain score. The sample size was calculated using the combination of power (0.95), α (0.05), and effect size (0.67). As a result, it was found that at least 46 patients (totally 92) in each group should be included in the study in order to reject the hypothesis of indifference.

Results

There were no statistically significant differences in age, weight, height, body mass index, symptom duration, K-L grade, VAS at rest, VAS during activity, knee ROM, 20-metre walk test, WOMAC, Lequesne's disability index, and isokinetic muscle performances between the groups (*p* > 0.05 for all). Demographic, clinical, radiographic, and isokinetic features are shown in Table 1.

Regarding pain VAS at rest, VAS during activity, knee ROM, 20-metre walk test (Table 2), WOMAC (Table 3), Lequesne's disability index (Table 4), and isokinetic test values (Table 5), significant differences were determined between the groups except for WOMAC-stiffness scores at the end of treatment, at one month, and three months after treatment (*p* < 0.05). Also, significant differences were found between baseline values and values at zero, first, and third months after treatment within the groups (all *p* < 0.001). Regarding

Table 6 Comparison of difference between VAS, ROM, 20-m walk test, and isokinetic scores of the groups

$\Delta\%$	BT–AF (0 month) Median [Q1]–[Q3]	BT–AF (1 month)	BT–AF (3 months)
VAS at rest			
r-ESWT	– 66.7 [– 85.7]–[– 50]	– 75 [– 87.5]–[– 60]	– 77.5 [– 100]–[– 63.3]
Sham-ESWT	– 50 [– 66.7]–[– 29.2]	– 50 [– 66.7]–[– 33.3]	– 50 [– 66.7]–[– 29.2]
<i>P</i> values	<i>0.001</i>	<i>< 0.001</i>	<i>< 0.001</i>
VAS during activity			
r-ESWT	– 50 [– 62.5]–[– 50]	– 62.5 [– 62.5]–[– 50]	– 62.5 [– 75]–[– 50]
Sham-ESWT	– 50 [– 62.5]–[31.2]	– 50 [– 62.5]–[37.5]	– 50 [– 62.5]–[– 37.5]
<i>P</i> values	<i>0.006</i>	<i>< 0.001</i>	<i>< 0.001</i>
Range of motion			
r-ESWT	44.4 [41.1]–[45]	45.0 [43.9]–[50]	47.2 [44.4]–[50]
Sham-ESWT	38.9 [33.3]–[43.3]	40.0 [36.7]–[44.4]	40.0 [36.7]–[44.4]
<i>P</i> values	<i>< 0.001</i>	<i>< 0.001</i>	<i>< 0.001</i>
20-m walking test			
r-ESWT	– 34.6 [– 38.5]–[– 26.9]	– 38.5 [– 42.3]–[– 26.9]	– 38.5 [– 42.3]–[– 30.8]
Sham-ESWT	– 23.1 [– 32.7]–[– 19.2]	– 26.9 [– 34.6]–[– 23.1]	– 26.9 [– 34.6]–[– 23.1]
<i>p</i> values	<i>< 0.001</i>	<i>< 0.001</i>	<i>< 0.001</i>
Isokinetic evaluation, PT (Nm)			
60°/s AV–QPT			
r-ESWT	412.5 [325]–[550]	512.5 [362.5]–[600]	525 [387.5]–[600]
Sham-ESWT	337.5 [281.2]–[431.2]	406.2 [325]–[500]	387.5 [318.7]–[518.7]
<i>P</i> values	<i>0.024</i>	<i>0.005</i>	<i>0.006</i>
180°/s AV–QPT			
r-ESWT	166.7 [133.3]–[244.4]	188.9 [155.6]–[238.9]	177.8 [122.2]–[244.4]
Sham-ESWT	122.2 [100]–[166.7]	144.4 [111.1]–[177.8]	122.2 [88.9]–[188.9]
<i>P</i> values	<i>< 0.001</i>	<i>< 0.001</i>	<i>0.001</i>

BT, before treatment; AT, after treatment; VAS, visual analog scale; AV, angular velocity

QPT, quadriceps peak torque

Italicized *p* values show statistical significance ($p < 0.05$)

isokinetic assessments, significant differences were determined in r-ESWT group in the zero, one and three month values, when compared with baseline values (Table 5).

A comparison of the difference between the VAS, ROM, walking speed, isokinetic test, WOMAC, and Lequesne scores of the groups showed significantly superior improvements in r-ESWT group in all parameters at the end of treatment, at one month and three months after treatment ($p < 0.05$) (Tables 6 and 7).

Discussion

Decrease in pain intensity and improvements in physical function are mainly the treatment goals of knee OA. In this study, the effects of r-ESWT treatment in addition to hot pack, transcutaneous electrical nerve stimulation, and exercise on pain, functional capacity, and muscle strength were examined in

patients with moderate knee OA. There was overall improvement in both the r-ESWT and sham-ESWT groups evaluated at zero, one and three months after completion of the treatment, the higher improvement was in the r-ESWT group. These acquisitions lasted at least for three months after r-ESWT treatment.

ESWT has been widely used for various musculoskeletal disorders, including calcifying shoulder tendinitis, lateral epicondylitis, patellar tendinopathy, plantar fasciitis, bone fracture, and avascular necrosis [7]. Recently, there have been many studies investigating the effectiveness of ESWT in degenerative knee diseases. The healing effects of ESWT for knee OA are reported in some rat models. These results reveal that the use of ESWT to the degenerative joint of animals delayed the OA progression, improved motor function, reduced pain, and observed chondroprotective effects on chondrocytes [10, 11]. In recent studies, ESWT has been used for reducing pain and improving knee functions in humans

Table 7 Comparison of difference between WOMAC and Lequesne's disability scores of the groups

$\Delta\%$	BT–AF (0 month) Median [Q1]–[Q3]	BT–AF (1 month)	BT–AF (3 month)
WOMAC scores—knee			
Pain			
r-ESWT	– 73.3 [– 76.7]–[– 60]	– 80 [– 80]–[– 70]	– 80 [– 80]–[– 66.7]
Sham-ESWT	– 56.7 [– 73.3]–[– 36.7]	– 60 [– 73.3]–[– 46.7]	– 66.7 [– 73.39]–[– 43.3]
<i>P</i> values	< 0.001	< 0.001	< 0.001
Stiffness			
r-ESWT	– 66.7 [– 100]–[– 33.3]	– 66.7 [– 100]–[– 66.7]	– 66.7 [– 100]–[– 66.7]
Sham-ESWT	– 66.7 [– 100]–[– 33.3]	– 66.7 [– 100]–[– 66.7]	– 66.7 [– 100]–[– 33.3]
<i>P</i> values	0.681	0.600	0.493
Physical function			
r-ESWT	– 61.4 [– 70.2]–[– 54.4]	– 64.9 [– 75.4]–[– 58.8]	– 65.9 [– 81.6]–[– 57.9]
Sham-ESWT	– 50.9 [– 62.3]–[– 38.6]	– 56.1 [– 63.2]–[– 45.6]	– 56.1 [– 64.0]–[– 39.4]
<i>P</i> values	< 0.001	< 0.001	< 0.001
Total			
r-ESWT	– 64 [– 70]–[– 55.3]	– 69.3 [– 77.3]–[– 60.7]	– 68.7 [– 81.3]–[– 59.3]
Sham-ESWT	– 51.3 [– 62.7]–[– 41.3]	– 58.7 [– 65.3]–[– 49.3]	– 56 [– 67.3]–[– 43.3]
<i>P</i> values	< 0.001	< 0.001	< 0.001
Lequesne index—knee			
Pain			
r-ESWT	– 75 [– 75]–[– 62.5]	– 75 [– 87.5]–[– 75]	– 75 [– 87.5]–[– 75]
Sham-ESWT	– 62.5 [– 75]–[– 50]	– 75 [– 75]–[– 50]	– 75 [– 75]–[– 56.2]
<i>P</i> values	0.006	< 0.001	< 0.001
Distance			
r-ESWT	– 60 [– 60]–[– 60]	– 60 [– 60]–[– 60]	– 60 [– 70]–[– 60]
Sham-ESWT	– 50 [– 60]–[– 40]	– 60 [– 60]–[– 40]	– 60 [– 60]–[– 40]
<i>P</i> values	< 0.001	0.005	0.008
Function			
r-ESWT	– 60 [– 60]–[– 40]	– 60 [– 60]–[– 60]	– 60 [– 80]–[– 60]
Sham-ESWT	– 40 [– 60]–[– 20]	– 60 [– 60]–[– 40]	– 60 [– 60]–[– 30]
<i>P</i> values	0.018	0.004	< 0.001
Total			
r-ESWT	– 66.7 [– 72.2]–[– 55.6]	– 66.7 [– 75]–[– 63.9]	– 66.7 [– 77.8]–[– 61.1]
Sham-ESWT	– 55.6 [– 66.7]–[– 44.4]	– 63.9 [– 66.7]–[– 47.2]	– 63.9 [– 66.7]–[– 50]
<i>P</i> values	0.001	< 0.001	< 0.001

BT, before treatment; AT, after treatment; WOMAC, Western Ontario and McMaster Osteoarthritis Index

Italicize *p* values show statistical significance ($p < 0.05$)

[12, 13]. According to these studies, ESWT can be useful treatment option for knee OA.

In a study by Zhao et al. in 2013, ESWT treatment were found to be more effective than placebo in improving pain and function at three months follow-up after ESWT [14]. Their results showed that up to three months post-intervention ESWT was more effective than placebo in reducing pain on movement. The Lequesne's disability index and the WOMAC score were reduced with ESWT [14]. Cho et al. [15] found that ESWT may reduce pain and improve function in chronic stroke patients with knee OA

and may increase vascular activity at the target site. According to their results, ESWT could be one of the treatment methods appropriate for human knee OA. Lizis et al. [16] compared ESWT with kinesiotherapy for knee OA. They showed that after five weeks post-intervention ESWT was more effective than kinesiotherapy in improving pain on movement at each control period. Lee et al. [17] compared ESWT with intra-articular injections of hyaluronic acid and reported that in both groups, the scores of the VAS, WOMAC, Lequesne's disability index, 40-metre walk test, and stair-climb test were significantly improved

in a time-dependent manner. Accordingly, they suggest that ESWT can be an alternative treatment option to reduce pain and improve physical functions in patients with knee OA. Our results are similar to the results obtained by other authors. In our study, when the patients were evaluated with VAS at rest and during activity, WOMAC, and Lequesne's disability index, statistically significant differences were found between the groups immediately after treatment and at one month and three months. In the comparisons within the groups, there was a statistically significant difference at the end of treatment, at one month and three months after treatment compared with the baseline values. The VAS, WOMAC, and Lequesne scores of both groups were better after treatment. A comparison of the difference between the VAS, WOMAC, and Lequesne scores of the groups showed significantly superior improvements in r-ESWT group. These acquisitions lasted at least three months after three times of r-ESWT. Pain relief effect of ESWT is associated with a decrease in substance P release from the treated area, and loss of unmyelinated nerve fibres at the sites of shock-wave application. Neovascularization and cellular regeneration is also accelerated in the tissue.

Chen et al. compared isokinetic exercise, isokinetic exercise plus ultrasound, and isokinetic exercises plus ESWT in knee OA. They reported a significant improvement with respect to muscle strength and disability in the ESWT plus isokinetic exercise group after treatment and at each follow-up period [18]. Accordingly, they declared that ESWT is better than therapeutic ultrasound in rehabilitation of patients with knee osteoarthritis and popliteal cyamella results in more functional improvements. In our study, isokinetic evaluation was performed for the muscles around the knee, and the before-treatment peak torque values were found to be similar between the groups. In the after-treatment measurements, a statistically significant difference was detected between the groups at each follow-up period. In the comparisons within the groups, the increase in the zero, one and three month peak torque values were detected in r-ESWT group. A comparison of the difference between the peak torque values of the groups showed significantly superior improvements in r-ESWT group at the end of treatment, at one month and three months after treatment. Whether ESWT increases muscle strength is still controversial. When ESWT was applied to pathologic areas around the knee, the muscle strength might have increased as the pain was reduced. Our study showed improvements in pain and physical function after ESWT, which might be related to the more normal gait pattern after treatment, resulting from decreased pain and an increased muscle strength.

Our study had some limitations. The first is that although all the OA patients were given home-based exercise program, they were not questioned as to whether they had performed the exercises regularly. Second, we did not address factors such as number of ESWT sessions, dose, intensity, or frequency that may influence the effect of ESWT on knee OA.

Conclusion

A combination of electrotherapy modalities with r-ESWT may provide more effective improvement in pain and physical functions. Further studies are needed to determine whether ESWT should be recommended at mild (grade I) or severe (grade IV) OA and whether it can be combined with conventional rehabilitation techniques.

Compliance with ethical standards The study protocol was approved by the Medical Ethics Committee at Mustafa Kemal University (Protocol Code: 2017/166). A written informed consent was obtained from all participants.

Conflict of interest The authors declare that they have no conflict of interest.

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