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Clinical utility of extracorporeal shock wave therapy in restoring hand function of patients with nerve injury and hypertrophic scars due to burns: a prospective, randomized, double-blinded study

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Background: Joint contractures and nerve injuries are common after hand burns. Extracorporeal shock wave therapy (ESWT) is effective not only for the regeneration of various tissues, including scar tissues, but also for reducing pain and pruritus in patients with burns. Researchers have attempted to explore the effects of ESWT on hand dysfunction caused by nerve injury following burns.

Materials and methods: The authors evaluated the effects of ESWT (compared to sham stimulation) on hands with nerve injury and hypertrophic scars and, thereby, on hand function. The current study was a double-blind randomized controlled trial involving 120 patients. The ESWT parameters were as follows: energy flux density, 0.05–0.30 mJ/mm^2; frequency, 4 Hz; 1000–3000 impulses per treatment; and 12 treatments, one/week for 12 weeks. Outcome measures were as follows: 10-point visual analog scale for pain, Jebsen-Taylor hand function test, grip strength, Purdue Pegboard test, ultrasound measurement of scar thickness, and skin characteristics before and immediately after 12 weeks of treatment.

Results: No significant intergroup difference was noted after the initial evaluation ($P > 0.05$). More significant improvements were found in the ESWT group than in the sham group in terms of the VAS score ($P = 0.004$), extension ROMs of hand joints ($P = 0.02$), the JTT scores (writing, small, and light) ($P < 0.001$, $P < 0.001$, and $P = 0.002$), and skin characteristics (melanin, skin distensibility, and biologic skin elasticity) ($P = 0.004$, $P < 0.001$, and $P < 0.001$). Other measured outcomes did not differ between the two groups after the treatment.

Conclusion: The authors identified the clinically beneficial effects of ESWT in promoting hand function, improving scarring, and alleviating scarring-related pain, thereby highlighting its advantages in improving hand function that has been impaired due to nerve injury and hypertrophic scars after burns.

Keywords: burn, extracorporeal shock wave therapy, hand function, hypertrophic scar, nerve injury

Introduction

Burns that occur in the hand cause early joint range-of-motion (ROM) limitations and hand muscle weakness that significantly affect quality of life. Hand burns, though restricted to a small total body surface area (TBSA), can have significant functional consequences[1]. Therefore, if partial or full-thickness burns occur in the hand, they are defined as major burns that require intensive rehabilitation[2]. Localized neuropathies occur in 15–37% of cases after hand burns[3]. Nerve injuries are accompanied by regeneration and peripheral nerve healing over time[4]. Hand rehabilitation should begin as soon as possible after injury, and continuous rehabilitation is required depending on the wound healing process and the time of nerve injury recovery[5]. Hand rehabilitation programs are conducted to address the acute stage, and physical and occupational therapies are conducted for purposes such as restoration of joint ROM, improvement of hand function, and suppression of pain and hypertrophic scarring. The care plans for hand dysfunctions are continuously modified through the phases of rehabilitation. Various modalities are used to treat hand dysfunction after

HIGHLIGHTS

- Effects of ESWT on hands with nerve injury and hypertrophic scars were studied.
- It was a double-blind randomized controlled trial on an ESWT group and a sham group.
- The ESWT group had significant improvements in ROM, VAS, and JTT scores than sham.
- ESWT can improve hand function after nerve injury and scars after STSG.

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burns. However, each burn center has a different hand rehabilita tion protocol, and the need for new treatment modalities is ever-increasing.

Restrictions on regeneration after nerve injury can delay nerve reinnervation, resulting in limited muscle function. Therefore, if a functional decline occurs due to nerve injury, treatment for nerve regeneration should be initiated from the beginning[6]. Extracorporeal shock wave therapy (ESWT) generates a mechanical stimulus that induces two physical effects (mechanotransduction and cavitation). ESWT has been proven to have a regenerative effect on various tissues, such as ligaments, tendons, bones, and scars[7–10], and is widely applied to patients with burns[11–14]. Recent studies have attempted to apply ESWT to nerve damage[15–17]. Mechanotransduction has been confirmed to have peripheral nerve regeneration effects by influencing the sur rounding microenvironment, which can affect Schwann cell dif ferentiation, myelin gene regulation, and axon regeneration[16].

However, the effect of ESWT on hand dysfunction due to nerve injury or hypertrophic scarring after burns has not been investigated yet. The current study aimed to determine the effect of ESWT on hand function and its mechanism of action in patients with hypertrophic scarring and nerve injury after burns.

Material and methods

This was a double-blind, randomized controlled trial. The patients began recruiting from the Department of Rehabilitation Medicine in April 2019, and the study ended in April 2024. Our study was approved by the Ethics Committee and was registered in Clinical Trials. Written informed consent was obtained from all patients. This study has been reported in line with Consolidated Standards of Reporting Trials (CONSORT) Guidelines.

Each of the 60 patients enrolled in the study was the first-time patient admitted to this burn center, had no experience with ESWT, was $\geq$18 years old, more than 50% of the hand is burned, burns occurred on the right hand, which is the dominant hand, had a deep partial-thickness (second-degree) or a full-thickness (third-degree) burn, which had been treated with a split-thickness skin graft (STSG) after the thermal injury, nerve injury to the hand was confirmed by electromyography, and all patients were in the re-epithelialization phase (Fig. 1). The exclusion criteria were as follows: other causes of musculoskeletal diseases (rheumatoid arthritis, degenerative joint diseases, etc.) that may affect hand dysfunctions, malignant tumors, pregnancy, or unstable scars (acute infection or coagulopathy) that may cause damage to the scar area during hand treatment.

The first 120 patients with burn, who met our inclusion/exclusion criteria, were randomly allocated, using a computer program, to either the ESWT group ($n=60$) or the sham group ($n=60$). During the 12 weeks of treatment, eight patients in the ESWT group and nine patients in the sham group dropped out because their hand function improved and the patient refused treatment or did not periodically visit and perform ESWT after discharge. Ultimately, 52 patients in the ESWT group and 51 in the sham group were included (Fig. 2).

Intervention

Patients underwent one ESWT or sham treatment session per week for 12 weeks. ESWT was conducted using the Duolith SD-1 device (StorzMedical), with focused shock wave (Fig. 3). ESWT was performed around the most hypertrophic scars for treatment, at an intensity of 100 impulses/cm^2, an energy flux density (EFD) of 0.05–0.30 mJ/mm^2, and frequency of 4 Hz. Regarding the volume of treatment, 1000–3000 impulses were administered per session for 12 sessions held at 1-week intervals. The sham group received treatment using an adapter that transmits ESWT sound and vibration but does not emit energy, making the sham group feel like they were receiving ESWT[13,14].

Patients in both groups received burn rehabilitation for improving hand functions, including positioning, use of orthotics, scar lubrication for the scars, and occupational therapy. In both groups, occupational therapy involved task-specific training on a table for 30 min a day, 5 days a week (from Monday to Friday) to improve the ROMs of hand joints and muscle strength.

Outcome measures

To evaluate the effects of ESWT, pain severity, hand function, joint ROM, scar thickness, and skin characteristics were assessed before and immediately after 12 weeks of treatment.

A 10-point visual analog scale (VAS) was used to measure the scar pain severity, with ratings ranging from 0 (no pain) to 10 (unbearable pain). Patients were assessed using the total active motion (TAM) scoring system of the American Society for Surgery of the Hand, and the total scores of flexion and extension are the sum of the metacarpo-phalangeal joints, proximal interphalangeal joints, and distal interphalangeal joints of the five fingers of the hand[18,19]. The Jebsen-Taylor hand function test (JTT) was used to measure the performance speed of standardized seven tasks, each scored on a 0–15-point scale (with higher scores indicating better hand function)[20]. Grip and pinch strengths were quantified using a hand-held dynam

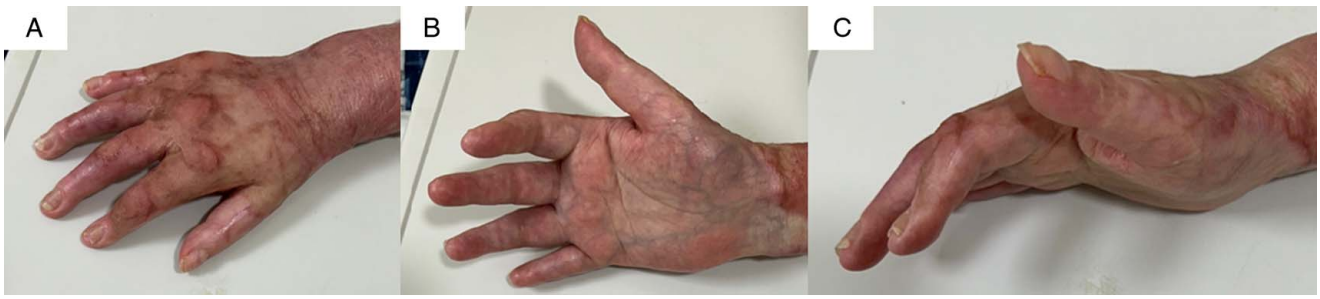

Figure 1. Hand with burn injuries that met the inclusion criteria of this study: (A) Dorsal side, (B) Palmar side, (C) Lateral side.

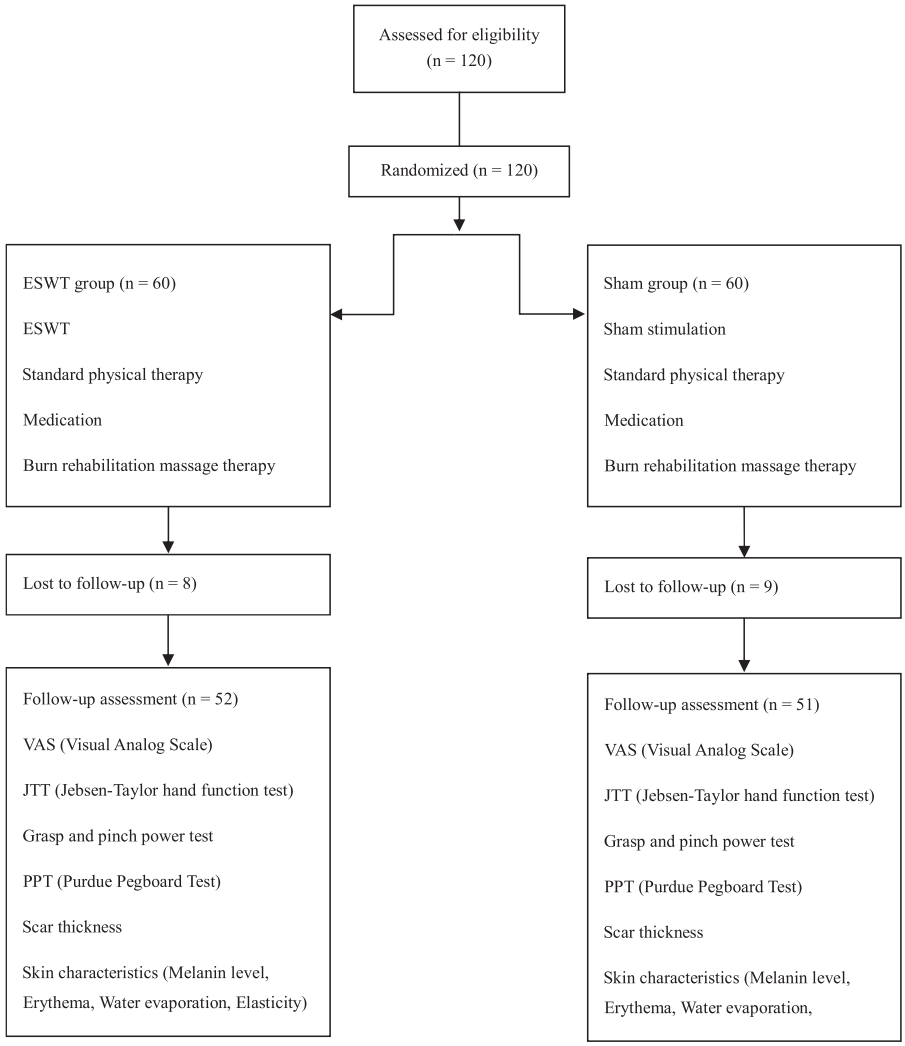

Figure 2. Diagram for subject enrollment, allocation, and follow-up.

Figure 3. The extracorporeal shock wave therapy administered to patients with burns.

ometer (Lafayette Instrument). In the Purdue Pegboard test (PPT), motor function was measured as the number of pins that could be placed on the board in 30 s, with dextrity measured as the number of pins, washers, and collars that could be assembled in 60 s[21]. Scar thickness was objectively quantified using ultrasonography (128 BW1 US system, Medison). Mexameter (MX18, Courage-Khazaka Electronics GmbH) was used to measure the melanin levels and the severity of erythema. Higher values mean more pigmentation and redness. Trans-epidermal water loss (TEWL) was measured using a Tewameter (Courage-Khazaka Electronic GmbH) to evaluate water evapora tion. Sebum in the scars was measured with the Sebumeter (Courage-Khazaka Electronic GmbH). The microprocessor calcu lated the results, which were on display, in mg/cm^2. Distensibility and elasticity were measured using Cutometer SEM 580 (Courage-Khazaka Electronic GmbH, Cologne). Two seconds of negative pressure at 450 mbar was followed by 2 s of recess, which consisted of a complete cycle. Three measurement cycles were conducted, and the average values were obtained. These parameters included the biomechanical skin properties, namely distensibility, elasticity, and viscoelasticity. Distensibility is the

Table 1

Baseline characteristics of the study group.

	ESWT group ($n=52$)	Sham group ($n=51$)	*P*
Male	52	51	
Age (years)	49.08 ± 5.03	46.27 ± 5.88	0.22
Cause of burn			0.08
Flame burn	26	22	
Electrical burn	16	25	
Contact burn	6	4	
Chemical burn	4		
Distribution of nerve injury			0.39
Median	9	9	
Ulnar	4		
Radial	1	4	
Median and ulnar	8	10	
Median and radial	6	8	
Ulnar and radial			
Median, ulnar, and radial	9	8	
Sensory neuropathy	15	12	
Time from injury to treatment (days)	126.08 ± 93.16	171.78 ± 126.42	0.24
TBSA (%)	30.62 ± 20.67	29.39 ± 20.49	0.62
VAS	7.06 ± 1.23	6.98 ± 1.19	0.71
Range of motion (ROM) of hand			
Flexion	814.73 ± 237.41	704.55 ± 225.29	0.98
Extension	−41.38 ± 81.13	−31.76 ± 46.48	0.14
Grasp and pinch power test			
Grip (kg)	6.52 ± 4.30	6.47 ± 4.09	0.82
Tip pinch (kg)	1.28 ± 0.87	0.97 ± 0.79	0.52
Key pinch (kg)	2.52 ± 1.50	1.55 ± 1.56	0.96
Tripod pinch (kg)	1.78 ± 1.16	1.33 ± 1.25	0.83
Jebsen hand function test			
Writing	10.25 ± 5.04	10.14 ± 5.02	0.84
Cards	3.33 ± 2.69	2.94 ± 1.95	0.08
Small	5.48 ± 4.01	4.92 ± 4.05	0.84
Checkers	9.17 ± 3.79	9.08 ± 4.25	0.53
Feeding	9.48 ± 4.20	9.24 ± 4.86	0.09
Light	7.92 ± 3.88	7.02 ± 3.94	0.35
Heavy	7.21 ± 3.60	7.31 ± 4.39	0.50
Purdue Pegboard test			
Affected hand	7.69 ± 4.18	6.88 ± 4.32	0.48
Both hands	5.60 ± 3.26	4.20 ± 3.61	0.10
Assembly	14.88 ± 8.05	14.41 ± 6.64	0.38
Skin characteristics measurement			
Thickness (cm)	0.23 ± 0.10	0.23 ± 0.09	0.43
Melanin (AU)	186.58 ± 65.73	190.00 ± 60.63	0.55
Erythema (AU)	468.85 ± 78.38	418.43 ± 61.90	0.12
TEWL (g/h/m^2)	13.38 ± 4.95	10.92 ± 3.78	0.20
Sebum (μg sebum/cm^2)	8.58 ± 9.44	8.76 ± 10.11	0.09
Skin distensibility R0	0.16 ± 0.04	0.17 ± 0.04	0.72
Biologic skin elasticity R2	35.52 ± 30.19	65.52 ± 31.54	0.18
Gross skin elasticity R7	26.80 ± 23.24	54.87 ± 35.53	0.18
Skin viscoelasticity R6	15.52 ± 32.24	15.16 ± 38.86	0.20

Values are presented as the mean ± SD. *P*-values were calculated using Fisher's exact test or independent *t*-test, as appropriate.

AU, arbitrary units; ESWT, extracorporeal shock wave therapy; TEWL, trans-epidermal water loss; VAS, visual analog scale.

length of the total displacement from the initial position at the maximum negative pressure. Gross elasticity refers to the ability of the skin to return to its initial position after displacement. Biological elasticity refers to the ratio of immediate retraction to total displacement. Viscoelasticity refers to the ratio of delayed distension to immediate distension[14].

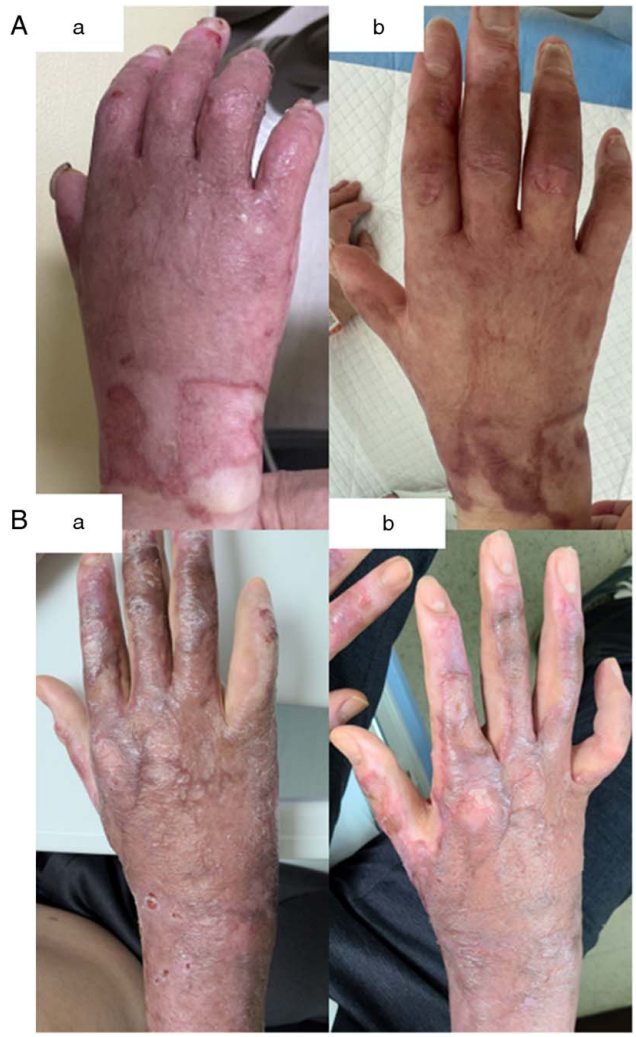

Figure 4. Hands of the extracorporeal shock wave therapy (ESWT) group and the sham stimulation (sham) group before and after 12 weeks of treatments; (A) ESWT group, (a) before treatment, (b) after 12 weeks treatment; (B) Sham group, (a) before treatment, (b) after 12 weeks treatment.

The outcome measurements and data analyses were performed by a trained and blinded outcome assessor who was not involved in the intervention. Possible complications (pain, ecchymosis, skin abrasion, and swelling) were observed.

Statistical analysis

Statistical analyses were performed using SPSS version 23 (IBM Corp.). In order to evaluate homogeneity, the burn type and the nerve injury distribution of the two groups were analyzed using Fisher's exact since an expected frequency of less than 5 was more than 20% of the total. Parametric measurements between the ESWT and sham groups were analyzed using an independent *t*-test after normality testing. To examine the pretreatment homogeneity between the two groups, an independent *t*-test was used for age, TBSA, time from injury to treatment, VAS score, grasp and pinch power scores, JTT parameters, PPT scores, scar thickness, and skin characteristics. A between-group *P*-value <0.05 was deemed significant. The pretreatment to

Table 2

Change of score (pretreatment to post-treatment) in measured outcomes.

	ESWT group ($n=52$)			Sham group ($n=51$)		
	Before training	After training	*P*	Before training	After training	*P*
VAS	7.06 ± 1.23	5.50 ± 1.16	< 0.001*	6.98 ± 1.19	6.43 ± 1.42	< 0.001*
Range of motion (ROM) of hand						
Flexion	814.73 ± 237.41	849.02 ± 252.44	< 0.001*	704.55 ± 225.29	814.90 ± 195.04	< 0.001*
Extension	−41.38 ± 81.13	−28.08 ± 57.74	< 0.001*	−31.76 ± 46.48	−46.67 ± 81.81	< 0.001*
Grasp and pinch power test						
Grip (kg)	6.52 ± 4.30	12.46 ± 8.70	0.002*	6.47 ± 4.09	9.78 ± 7.05	0.56
Tip pinch (kg)	1.28 ± 0.87	1.86 ± 1.21	< 0.001*	0.97 ± 0.79	1.93 ± 1.11	< 0.001*
Key pinch (kg)	2.52 ± 1.50	3.34 ± 1.98	< 0.001*	1.55 ± 1.56	3.01 ± 1.88	< 0.001*
Tripod pinch (kg)	1.78 ± 1.16	2.61 ± 1.60	< 0.001*	1.33 ± 1.25	2.51 ± 1.39	< 0.001*
Jebsen hand function test						
Writing	10.25 ± 5.04	11.31 ± 3.50	0.26	10.14 ± 5.02	10.49 ± 5.29	0.33
Cards	3.33 ± 2.69	4.87 ± 3.09	0.63	2.94 ± 1.95	4.10 ± 3.35	0.25
Small	5.48 ± 4.01	10.79 ± 3.90	0.25	4.92 ± 4.05	6.96 ± 4.34	0.38
Checkers	9.17 ± 3.79	10.02 ± 3.46	0.48	9.08 ± 4.25	10.31 ± 3.48	0.30
Feeding	9.48 ± 4.20	10.79 ± 3.90	0.14	9.24 ± 4.86	11.35 ± 4.41	0.15
Light	7.92 ± 3.88	9.10 ± 2.61	0.78	7.02 ± 3.94	8.80 ± 4.00	0.05
Heavy	6.96 ± 4.13	7.21 ± 3.60	< 0.001*	7.31 ± 4.39	7.27 ± 3.29	0.52
Purdue Pegboard test						
Affected hand	7.69 ± 4.18	9.02 ± 4.75	< 0.001*	6.88 ± 4.32	8.59 ± 3.96	< 0.001*
Both hands	5.60 ± 3.26	7.02 ± 4.07	< 0.001*	4.20 ± 3.61	6.18 ± 3.43	< 0.001*
Assembly	14.88 ± 8.05	19.63 ± 11.32	< 0.001*	14.41 ± 6.64	14.90 ± 8.29	< 0.001*
Skin characteristics measurement						
Thickness (cm)	0.23 ± 0.10	0.26 ± 0.10	0.001*	0.23 ± 0.09	0.24 ± 0.08	0.11
Melanin (AU)	186.58 ± 65.73	163.42 ± 71.74	< 0.001*	190.00 ± 60.63	194.55 ± 134.49	< 0.001*
Erythema (AU)	468.85 ± 78.38	501.10 ± 105.62	0.16	418.43 ± 61.90	457.59 ± 92.82	0.31
TEWL (g/h/m^2)	13.38 ± 4.95	12.54 ± 7.92	< 0.001*	10.92 ± 3.78	11.22 ± 5.59	0.39
Sebum (μg sebum/cm^2)	8.58 ± 9.44	27.96 ± 38.84	0.93	8.76 ± 10.11	23.37 ± 33.28	0.84
Skin distensibility R0	0.16 ± 0.04	0.54 ± 0.64	0.26	0.17 ± 0.04	0.18 ± 0.15	0.17
Biologic skin elasticity R2	35.52 ± 30.19	53.42 ± 21.76	0.60	65.52 ± 31.54	37.07 ± 34.10	0.40
Gross skin elasticity R7	26.80 ± 23.24	29.89 ± 34.01	< 0.001*	54.87 ± 35.53	48.60 ± 32.76	< 0.001*
Skin viscoelasticity R6	15.52 ± 32.24	17.37 ± 45.34	0.24	15.16 ± 38.86	17.35 ± 52.58	< 0.001*

*Statistically significant $p < 0.05$.

Values are presented as the mean ± SD. *P*-values were calculated using paired *t*-test, as appropriate.

AU, arbitrary units; ESWT, extracorporeal shock wave therapy; TEWL, trans-epidermal water loss; VAS, visual analog scale.

post-treatment scores were evaluated between the two groups using the paired *t*-test after normality testing, with a *P*-value < 0.05 deemed significant. Parameters between the two groups after treatment were analyzed using an independent *t*-test after the normality test. A between-group *P*-value < 0.05 was deemed significant.

Results

No significant intergroup difference was noted in the initial evaluations ($P > 0.05$) (Table 1). We found statistically significant improvements (pretreatment to post-treatment) in VAS score ($P < 0.001$), joint total ROMs (flexion and extension) ($P < 0.001$ and $P < 0.001$), the grasp and pinch power test results (grip, tip pinch, key pinch, and tripod pinch) ($P = 0.002$, $P < 0.001$, $P < 0.001$, and $P < 0.001$), the JTT scores (heavy) ($P < 0.001$), the PPT scores (affected hand, both hand, and assembly) ($P < 0.001$, $P < 0.001$, and $P < 0.001$), and skin characteristics (melanin, TEWL, and gross skin elasticity) ($P < 0.001$, $P < 0.001$, and $P < 0.001$) in the ESWT group (Fig. 4). Scar thickness increased in the ESWT group ($P < 0.001$). No significant improvement (pretreatment to post-treatment) in any other measurement, including the JTT scores (writing, cards, small, checkers, feeding, and light) and skin characteristics (erythema, sebum level, skin distensibility, biological elasticity, and skin viscoelasticity) was seen ($P > 0.05$) (Table 2). We found statistically significant improvements (pretreatment to post-treatment) in VAS score ($P < 0.001$), joint ROMs (flexion and extension) ($P < 0.001$ and $P < 0.001$), grasp and pinch power test results (tip pinch, key pinch, and tripod pinch) ($P < 0.001$, $P < 0.001$, and $P < 0.001$), the PPT scores (affected hand, both hands, and assembly) ($P < 0.001$, $P < 0.001$, and $P < 0.001$), and skin characteristics (melanin, gross skin elasticity, and skin viscoelasticity) ($P < 0.001$, $P < 0.001$, and $P < 0.001$) (Fig. 4) in the sham group. No significant improvement (pretreatment to post-treatment) was seen in any other measurement, including the grip power test results, JTT scores (all sub-scores), scar thickness, and skin characteristics (erythema, TEWL, sebum level, skin distensibility, and biologic elasticity) ($P > 0.05$) (Table 2 and Table 3).

More significant improvements were found in the ESWT group than in the sham group in terms of the VAS score ($P = 0.004$), extension ROMs ($P = 0.02$), the JTT scores (writing, small, and light) ($P < 0.001$, $P < 0.001$, and $P = 0.002$), and skin characteristics (melanin, skin distensibility, and biologic skin elasticity) ($P = 0.004$, $P < 0.001$, and $P < 0.001$) (Fig. 4). The participants complained of pain during ESWT but were able to continue

Table 3

Scores of the measured outcomes after intervention.

	ESWT group ($n=52$)	Sham group ($n=51$)	P
VAS	5.50 ± 1.16	6.43 ± 1.42	0.004*
Range of motion (ROM) of hand			
Flexion	849.02 ± 252.44	814.90 ± 195.04	0.73
Extension	−28.08 ± 57.74	−46.67 ± 81.81	0.02*
Grasp and pinch power test			
Grip (kg)	12.46 ± 8.70	9.78 ± 7.05	0.16
Tip pinch (kg)	1.86 ± 1.21	1.93 ± 1.11	0.15
Key pinch (kg)	3.34 ± 1.98	3.01 ± 1.88	0.18
Tripod pinch (kg)	2.61 ± 1.60	2.51 ± 1.39	0.10
Jebsen hand function test			
Writing	11.31 ± 3.50	10.49 ± 5.29	< 0.001*
Cards	4.87 ± 3.09	4.10 ± 3.35	0.38
Small	10.79 ± 3.90	6.96 ± 4.34	< 0.001*
Checkers	10.02 ± 3.46	10.31 ± 3.48	0.86
Feeding	10.79 ± 3.90	11.35 ± 4.41	0.70
Light	9.10 ± 2.61	8.80 ± 4.00	0.002*
Heavy	6.96 ± 4.13	7.27 ± 3.29	0.10
Purdue Pegboard test			
Affected hand	9.02 ± 4.75	8.59 ± 3.96	0.30
Both hands	7.02 ± 4.07	6.18 ± 3.43	0.20
Assembly	19.63 ± 11.32	14.90 ± 8.29	0.14
Skin characteristics measurement			
Thickness (cm)	0.26 ± 0.10	0.24 ± 0.08	0.29
Melanin (AU)	163.42 ± 71.74	194.55 ± 134.49	0.004*
Erythema (AU)	501.10 ± 105.62	457.59 ± 92.82	0.33
TEWL (g/h/m^2)	12.54 ± 7.92	11.22 ± 5.59	0.10
Sebum (μg sebum/cm^2)	27.96 ± 38.84	23.37 ± 33.28	0.65
Skin distensibility R0	0.54 ± 0.64	0.18 ± 0.15	< 0.001
Biologic skin elasticity R2	53.42 ± 21.76	37.07 ± 34.10	< 0.001
Gross skin elasticity R7	29.89 ± 34.01	48.60 ± 32.76	0.86
Skin viscoelasticity R6	17.37 ± 45.34	17.35 ± 52.58	0.39

*Statistically significant $p < 0.05$.

Values are presented as the mean ± SD. *P*-values were calculated using independent *t*-test, as appropriate.

AU, arbitrary units; ESWT, extracorporeal shock wave therapy; TEWL, trans-epidermal water loss; VAS, visual analog scale.

treatment. No complication, such as ecchymosis, skin abrasion, or scar deterioration, requiring discontinuation of treatment, was observed during the study.

Discussion

Researchers evaluated the effectiveness of ESWT in improving hand function and explored its treatment mechanisms. The therapeutic effects were evaluated based on changes in joint ROM, grasp power, hand dexterity, scar thickness, and skin characteristics (erythema, pigmentation, sebum level, and skin dryness). ESWT for hypertrophic scarring and nerve injury after burns in hands provided significant benefits in improving joint ROM, grasping power, hand function, and scar characteristics (pigmentation, skin distensibility, and biological elasticity).

The clinical outcomes of ESWT for hypertrophic scars following burns have been widely studied in the field of regenerative medicine. The regenerative mechanisms of ESWT strengthen angiogenesis in repaired tissues, release various growth factors for neovascularization, modulate inflammatory responses, change mechanotransduction, and cause other cellular changes[22]. The neovascularization and regulated inflammation result in rapid epithelialization in the early stages of wound healing, promoting extracellular matrix (ECM) remodeling. ESWT affects various cells (fibroblasts, keratinocytes, and macrophages) involved in the wound-healing process during the proliferative and remodeling phases of the wound[11,23], improving scar characteristics and inhibiting scar formation[24]. In a meta-analysis on the effect of ESWT in patients with burns, a significant improvement in the symptoms of pain and pruritus, as well as in scar characteristics and thickness, was confirmed[25]. Improvement in aspects related to the skin protective barrier, pigmentation, and erythema was found to be related to the effect of ESWT on cell regeneration in the epidermis and dermis[11]. ESWT changes the nanostructure and properties of collagen fibers[26,27]. Improvements in distensibility and elasticity are due to the regeneration of collagen fibers and proteoglycan matrix[14,26,28].

The researchers confirmed the clinical effect of ESWT in improving joint ROMs, muscle strength, and hand function in patients who developed decreased hand function and pain after nerve injuries caused by burn. ESWT has been reported to reduce the pain caused by damage to the musculoskeletal system due to overload, enable a quick return to sports activities, and improve function overall by shortening the recovery time[7,10]. The pain suppression mechanism is explained by gate control, nerve regeneration through the sensory input of hyperstimulation, and degeneration of calcitonin gene-related peptide (CGRP) – and substance P (SP)-positive nerve fibers related to neuroinflammation[29–31]. The increase in muscle strength is explained by the reduction in pain caused by ESWT and the increase in proliferation and synthesis of the ECM. ESWT has been reported to effectively reduce pain and improve function in musculoskeletal pain disorders[32].

In particular, the clinical effectiveness of ESWT for hand dysfunction accompanied by nerve injury has been confirmed. Although several mechanisms for recovery after nerve injury have been discovered, no clear solution to the functional decline caused by incomplete and delayed reinnervation is available yet. One approach for accelerating peripheral nerve regeneration is to stimulate the physiological processes that occur following nerve injury. Early nerve regeneration allows early reinnervation of the target muscles, preventing muscle atrophy or functional decline. ESWT induces locomotor recovery by regenerating motor axons[16]. During the proliferative phase, Schwann cells provide structural guidance and trophic support to regeneration axons[33]. In subjects who underwent ESWT, early improvement in motor function, an increase in nerve fiber number, and regulation of inflammatory markers of Schwann cells were observed during Wallerian degeneration[15,34]. In animal experiments, ESWT improved sensory-motor coordination and tactile response thresholds. In an in-vivo study, ESWT promoted axonal regrowth and myelination[34]. The axonal fibers of the peripheral nerve accumulated on Schwann cells and perineural fibroblasts and underwent regeneration in response to mechanotransductive signals, such as ESWT[34]. Another treatment mechanism for ESWT could be via the promotion of regeneration by increasing cell-to-cell communication through the secretion of extracellular vesicles[17]. Intracellular signaling pathways establish interrelationships among various cell types (fibroblasts, satellite cells, Schwann cells, and macrophages) to facilitate nerve growth[35]. Electron microscopic analysis revealed faster clearance of the regenerating nerves, which displayed fewer fibroblasts and less

endoneurial collagen. This phenomenon can be interpreted as improving the reorganization of the injured nerve and reducing endoneurial scarring[16].

The current study required a cautious interpretation of the data, considering the small sample size, short follow-up period, the diversity of wound healing phases, and the absence of electromyography after treatment. Based on the results of this study, if follow-up electromyography tests that can objectively confirm nerve regeneration and research on the effects of ESWT according to the wound healing phases are conducted, it is expected that more objective evidence for the clinical effects of ESWT will be confirmed. In future studies, we plan to confirm the clinical effects by tracking a larger sample size over a longer period; in-vivo studies would be required to reveal the treatment mechanism.

Conclusion

ESWT has a positive effect on improving joint ROM, hand function, and muscle strength in case of hand burns accompanied by nerve damage. Positive effects on skin characteristics, such as scar distensibility, elasticity, and pigmentation, were also confirmed in the study. Overall, the results are expected to influence the use of ESWT for nerve and skin scar regeneration.

Ethical approval

The study protocol was approved by the Institutional Review Board and Ethics Committee of Hangang Sacred Heart Hospital (approval no. HG2023-024.

Consent

Written informed consent was obtained from all patients. All procedures were conducted in accordance with the relevant guidelines and regulations.

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Author contribution

S.Y.J.: conceived and designed the study; S.Y.L.: analyzed, interpreted the data, and wrote the manuscript; J.S.: collected and assembled the data and performed the experiments; Y.S.C. and C.H.S.: revised the manuscript. All authors have reviewed the results and approved the final version of the manuscript.

Conflicts of interest disclosure

The authors declare no conflicts of interest.

Research registration unique identifying number (UIN)

1. Our study was registered in the Clinical Trials.
2. Unique identifying number or registration ID: NCT06438224, https://clinconnect-io/trials/NCT06438224.

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Data availability statement

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

Provenance and peer review

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