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ORIGINAL ARTICLE

Clinical effectiveness of multi-wavelength photobiomodulation therapy as an adjunct to extracorporeal shock wave therapy in the management of plantar fasciitis: a randomized controlled trial

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Abstract

The goal of our study was to investigate the cumulative effect of combining medium-energy extracorporeal shock wave therapy (ESWT) and photobiomodulation therapy (PBMT), as well as to compare between their relative effectiveness in the management of plantar fasciitis (PF). One hundred twenty participants with chronic PF, more than 6 months with failure to respond to conservative treatment, were randomly assigned into four equal groups. Participants received either ESWT with PBMT, ESWT (once a week), PBMT (three times a week), or sham-PBMT (three times a week) for three consecutive weeks. A home exercise program was also included for all four groups. Outcome measures included pressure pain threshold (PPT), visual analogue scale (VAS), and functional foot index disability subscale (FFI-d) that were collected prior to the first treatment session and at the end of the 3-week treatment period, as well as at a follow-up session, 12 weeks after the final treatment session. There were statistically significant improvements in post-intervention and follow-up PPT, VAS, and FFI-d values in all treatment groups ($P < 0.0001$). As for the sham-PBMT, no significant difference was found between the pre-, post-intervention and follow-up values ($P > 0.05$). Bonferroni correction test revealed that there was a significant difference between all the four groups in PPT, VAS, and FFI-d values ($P < 0.0001$). All active treatment groups maintained the treatment effect at the 12-week follow-up. Both ESWT and PBMT were effective in increasing PPT values, decreasing pain and increasing functional ability. Additionally, application of PBMT after ESWT was shown to be superior over ESWT and PBMT alone, and ESWT was superior over PBMT in terms of reducing pain sensitivity and increasing function.

Level of Evidence II.

Keywords Photobiomodulation therapy · Extracorporeal shock wave therapy · Plantar fasciitis

Introduction

Plantar fasciitis (PF), inflammation of the plantar fascia, is one of the common reasons for foot pain [1]. Ten percent of the general population may experience PF somewhere in their life time [1, 2]. While the exact etiology of PF remains unclear, it is undoubtedly multifactorial [2]. The root cause of PF is assumed to be of mechanical source, where overloading the plantar foot muscles originating at the volar calcaneus (adductor hallucis, quadratus plantae, flexor digitorum brevis, and abductor digiti minimi quinti) can lead to inflammation [3], consequent pain, and tenderness inferiorly at the calcaneal medical tuberosity where the plantar fascia originates [2].

The diagnosis of PF is usually clinical. Typical symptoms denote inferior throbbing or piercing pain around the medial calcaneal tuberosity, especially on weight bearing with the first few steps in the morning and after periods of extended sitting [1]. Pain often improves after further ambulation but worsens with continued activity which may persist for months to years, limiting daily activities [4]. Plantar fascia pain is especially clear upon dorsiflexion of the patients pedal phalanges, which further stretches the plantar fascia; windlass mechanism [5]. Consequently, any activity that places excessive compressive or traction forces that flattens the foot's longitudinal arch and increases stretch of the plantar fascia (such as walking barefoot without any arch support, climbing stairs, or toe walking) can cause repeated microtraumas and

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inflammation that results in fibrosis and degeneration at the plantar fascia origin and exacerbates pain [6]. Hence, therapy for PF aims on either lessening the muscle tightness that causes the original injury or decreasing the inflammation that aggravates the injury [7].

PF often responds to a wide range of therapies that is predominantly conservative [8]; however, there is no single universally accepted way of treating this condition [9]. Physical therapy modalities most commonly utilized include heat/cold massage, electrotherapy, ultrasound, and photobiomodulation therapy (PBMT) with stretching exercises [8–11]. PBMT has achieved recognition over the past 30 years in the management of soft-tissue, musculoskeletal, and open-wound injuries, as well as various painful conditions [12, 13], although scientific support remains rather mixed. PBMT irradiation is claimed to enhance cellular metabolism, augment protein synthesis, improve wound healing, and boost immune response, hence speeding the healing process of soft-tissue injuries and decreasing pain levels [14]. Despite its numerous benefits, efficacy of PBMT in the management of PF still remains contentious.

Extracorporeal shock wave therapy (ESWT) is an alternative treatment modality that has been shown to be of benefit for PF since the 1990s [15]. Shock waves are purported to produce a controlled micro-disruption of tissue resulting in neovascularization and hence promoting healing by releasing local growth factors [16, 17]. Recently, the Orthopedic Section of the American Physical Therapy Association recommended a multimodal treatment approach for the management of PF [18]. While several randomized controlled trials of ESWT and PBMT on PF have suggested benefit with different magnitudes [17–25], comparing various treatment methods in order to find the most effective therapy for PF is compulsory. To date, no consensus exists concerning the repeated use of medium-energy ESWT with or versus PBMT. Therefore, the aim of the present study was to investigate the cumulative effect of combining medium-energy ESWT and PBMT, as well as to compare between their relative effectiveness in reducing pain and increasing functional ability in patients suffering from PF.

Methods

Sample and study design

A single-blind, randomized, placebo-controlled trial was conducted at a private orthopedic outpatient clinic in Heliopolis, Cairo, Egypt, between September 2017 and April 2018. This study conforms to all CONSORT guidelines and reports the required information accordingly (see Supplementary Checklist). One hundred twenty participants, 56 men and 64 women, with ages ranging from 40 to 70 years were enrolled from the outpatient clinic of the School of Physical Therapy at Cairo University and were diagnosed as having PF by medical doctors. Entry criteria included (1) unilateral plantar heel pain, with a participant self-assessment of pain having a score 5 cm on a 10-cm visual analogue pain scale (VAS) mainly during the first few steps upon arising in the morning; (2) duration of pain of more than 6 months with failure to respond to conservative treatment (not including PBMT in their treatment program); (3) tenderness at the insertion site of the plantar aponeurosis, on the medial calcaneal tubercle, which increased with dorsal flexion of the toes; (4) "normal" (20–24.9) and "overweight" (25–29.9) body mass indexes (BMIs). Participants were excluded if they had (1) diffuse or bilateral plantar pain; (2) a history of recent trauma or foot surgery; (3) received any therapeutic interventions for heel pain 6 weeks prior to the study; (4) received PBMT in any of their conservative treatment programs; (5) previous diagnosis of rheumatoid arthritis, hemophilia, coagulopathies, calcaneal stress fracture, osteomyelitis, plantar fascia neoplasm, plantar aponeurosis rupture, or neurological abnormalities; and (6) BMI of class II ("severely obese") or III ("very severely obese"). Participants were randomly assigned in blocks to one of four groups (ESWT with PBMT group (combined group), ESWT group, PBMT group, or sham-PBMT control group), with 30 participants in each group. Additionally, all four groups received a home exercise program. All participants provided written informed consent to participate in our study (see Supplementary Checklist). A flow chart (Fig. 1) demonstrates the assignment of participants into groups. Ethical approvals were obtained from the Board Council of Higher Education of the School of Physical Therapy, the Institutional Review Board of Higher Education and Research of Cairo University, and the Supreme Council of Universities in Egypt. The study is prospectively registered with the Australian New Zealand Clinical Trials Registry (ACTRN12617000761369).

Physical examination and outcome measure

The primary outcome measure was pressure pain threshold (PPT) measured by an electronic algometer (Force One gauge-model FDI; Wagner Instruments, Greenwich, CT, USA) which was applied by a single trained assessor. With the participant in prone lying position, an ankle splint was used to maintain the ankle in an anatomically neutral position. Algometry consisted of a 1-cm^2 probe that was placed perpendicular at the most painful site on the painful foot (usually the medial tubercle of the calcaneum). Steady downward pressure was then applied, where participants were informed to say "STOP" when the sensation initially shifted from pressure to pain. The digital display denoted the PPT value in kilogram-force (kgf). Three successive measurements were taken 20 s apart, and the mean was considered in the analysis [26–28]. To ensure standardization of relocating the precise location of the

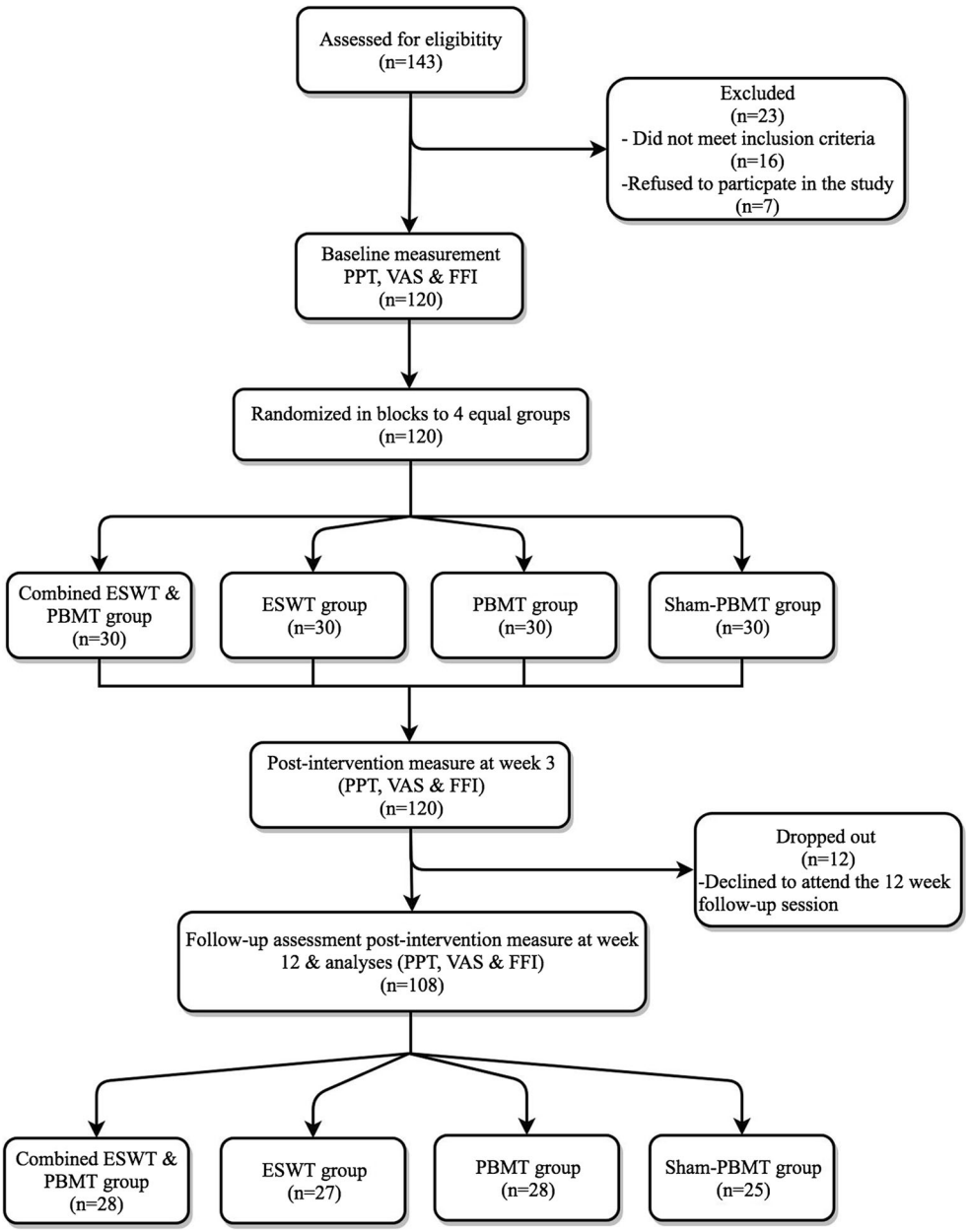

Fig. 1 Methodology flowchart

most tender spot, it was marked with a permanent marker. A plastic scale was then placed over the heel, and the contour of the participant's foot as well as the painful spot was plotted on the scale. This plastic scale was then used in each treatment session as well as in re-evaluation [28]. Intraclass correlation coefficient (ICC) was utilized to ensure intra-rater reliability of the pressure algometer. On three different occasions, the same examiner took three PPT measurements on 15 participants. Secondary outcome measures included heel pain elicited by passive stretch. Prior to the test, participants were given 10 min of rest before any measurement. The participant was then placed in prone lying with the knee flexed 90°, while the assessor applied passive dorsiflexion at the ankle with extension of the big toe to the full passive end ranges. The participant was then asked to describe the intensity of the stretching pain on a 10-cm line VAS scale, with "no pain" to the left and "worst pain ever felt" to the right [29]. The minimal clinically important difference was estimated as the percentage of participants having more than 8% VAS decrease of pain from the baseline to follow-up [30]. FFI-d subscale was also used. It is a reliable and valid scale for measuring disability on daily life function in patients with PF [31, 32]. Since our study used PPT and VAS scale as measures of pain, we only used the disability subscale of FFI for this study. The FFI disability subcategory consists of nine items that measures difficulty performing various functional activities in standing, walking, ascending and descending activities, and running. Participants scored their difficulty encountered while

performing functional activities over the preceding week, on a scale ranging from 0 (no difficulty) to 10 (so difficult unable to do) [32]. Total score ranging from 0 (minimum) to 90 (maximum) was calculated by summing up the number score in each item. The minimal clinically meaningful change of FFI-d subscale has been reported as a seven-point increase/decrease in total score [33]. Negative scores denoted improved foot function. Outcome measures were collected prior to the first treatment session and at the end of the 3-week treatment period. Additionally, all participants, including the sham, attended a follow-up session 12 weeks after the final treatment session, where outcome measures were collected again.

Intervention

For the ESWT treatment, an electromagnetic ESWT (Intelect Focus Shockwave; DJO Global, UK) device was used. It can generate up to 0.55 mJ/mm^2 energy level shock waves. Treatment parameters were set on the lowest energy level of 0.02 mJ/mm^2 that was then increased to reach the maximum tolerable intensity of participants, which was between 0.22 and 0.28 mJ/mm^2; hence, belonging to the medium energy category. The frequency of these pulses was gradually increased to 4 Hz to reach 240 pulses per minute with a total of 2000 shock waves per treatment, once a week for three consecutive weeks [34]. The mean (SD) dose of ESWT treatment was 1286.43 (332.92) mJ/mm^2. For the ESWT application, participants were placed in a prone lying position with an ankle splint to anatomically place its neutral position. The plastic scale with the plotted tender spot was placed on the heel, and the most tender spot was marked. Ultrasound gel was then applied to provide a good transmission of shock waves that was continuously monitored. Details of any adverse effects were recorded and pain (using VAS) was scored immediately after ESWT.

For the PBMT, a class 3B infrared laser treatment device (Vectra Genisys Laser 2784; Chattanooga DJO Global, UK) was used in the study. PBMT was administered with a 33-diode gallium–aluminum–arsenide (GaAlAs) cluster laser applicator with a total power density of 0.046 W/cm^2 and a contact area of 31.2 cm^2. It contains five laser diodes of 850 nm power output and a spot area of 0.06 cm^2 each. Additionally, it has 28 light-emitting diodes (LEDs) of multiple wavelengths, 12 diodes of 670 nm with a spot area 1.92 cm^2, 8 diodes of 880 nm, as well as another 8 diodes of 950 nm with a spot area of 1.28 cm^2 for each diode (Top Y, personal communication 27/8/2018). Similar to the ESWT application, participants were placed in a prone position with the foot hanging out of the treatment table and a splint to maintain the ankle in neutral. The contact method was used, where the center of laser applicator was applied over the most tender spot; the origin of the plantar fascia on the medial calcaneal tubercle. PBMT treatment parameters consisted of a laser/LED continuous mode, a total power density output of 0.046 W/cm^2 (the laser device has a built-in sensor for autocalibration of the optical output before each application), and 31.2 cm^2 total contact area. A total radiant energy dose of 86.4 J (2.8 J/cm^2) for 60 s was applied per session [35]. As for the sham-PBMT control group, the timer and the laser power density were set to zero. PBMT, sham-PBMT as well as the combined group received laser treatment three times per week for three consecutive weeks. As for the combined group, PBMT was applied directly after the ESWT (that was applied once per week).

Participants in all four groups were all instructed to practice a supervised home exercise program only for the 3-week treatment period. They were first trained on the exercises and then subsequently given an exercise form that demonstrated each exercise and for marking the exercise dates and sessions. The home exercise program involved stretching of Achilles tendon and plantar fascia from sitting and gastrocnemius and soleus muscles from standing. Participants were instructed to perform these exercises two times per day (at the morning and at night) with 10 repetitions for three consecutive weeks [10].

Side effects

In all participants, temporary reddening occurred after shock wave application. Thirty-seven of 60 participants receiving ESWT reported pain (average of 7 on VAS) during its application. Apart from these minor findings, no clinical relevant side effect was found.

Sample size

The sample size was calculated using PASS 14 (version 14.0.8) power and sample size software. It was established based on an estimated 37% decrease in VAS scores after ESWT exposure from preceding studies [34]. Presuming a mean of 5 and 2 on a 10-point VAS, a two-tailed test, an alpha level of 0.05, and an estimated power (β) of 95%, an estimated sample size was 25 participants per group. Allowing a dropout rate of 20%, the number of participants required was estimated to be 30 per group.

Randomization

Using SPSS software (IBM, USA), a computer-generated block random list was created prior to data collection by the study biostatistician. Block size with equal numbers for all four groups within the block was calculated. Individual and sequentially symboled index cards were secured in opaque envelopes. Each participant was given a hand-picked envelope and was relocated accordingly to the treatment group.

Blinding

A biostatistician blinded to the study approach generated the concealed block randomization and allocation sequence and relocated participants to the four groups. A certified manual physical therapist (blinded to treatment allocations) with more than 12 years of experience executed the physical assessment, marked the location of the most tender spot on the plastic scale, assured its relocation, and collected measurement outcome. Lastly, four certified physical therapists with experience ranging from 3 to 4 years managed each group individually. All therapists responsible for carrying out the intervention were blinded to the sequence allocation, physical assessment, and measurement outcome.

Data analysis

Statistical analysis was computed using SPSS for Windows version 20 (SPSS, Inc., Chicago, IL). Descriptive statistics was used to describe the means and standard deviations of the participants' characteristics. A 4 × 3 mixed model analysis of variance (MANOVA) was used to compare within and between differences in the three treatment groups versus the control group. Moreover, Bonferroni correction test was used to compare between the groups. The *P* value was set at 0.05.

Results

Table 1 lists the general physical characteristics of the 120 (56 male and 64 female) participants in our study. A total of 108 participants completed the study where 12 participants declined to attend the 12-week follow-up assessment. There was no significant difference in the mean values of age, gender, weight, height, and BMI among the four groups as revealed by the one-way analysis of variance, with a *P* value > 0.05. The ICC for intra-rater reliability of the pressure algometer on tender spots was 0.96, which indicates high reliability.

Table 2 represents the within-group comparison, where multiple pairwise comparison tests revealed that there was a significant increase in post-intervention (3 weeks) PPT, VAS, and FFI-d values as well as in the 12-week follow-up for the combined group (ESWT + PBMT), ESWT, and PBMT when compared to their baseline values ($P < 0.0001$). However, as for the sham-PBMT, there was no significant difference between the pre-/post-intervention and 12-week follow-up PPT, VAS, and FFI-d values ($P > 0.05$). Furthermore, the 4 × 3 mixed-design MANOVA indicated that there were significant overall effects of combined group (ESWT + PBMT), ESWT, and PBMT on PPT, VAS, and FFI-d scores, with values of $F = 235.403$, 85.454, and 49.76, respectively ($P < 0.0001$; Table 3).

Among group comparison, Bonferroni correction test revealed that there was a significant difference between all four groups in PPT and VAS values at 3-week post-intervention as well at the 12-week follow-up periods ($P < 0.0001$; Tables 4 and 5). Additionally, at week 3, significant difference between all groups was found in the FFI-d scores except for the ESWT and PBMT groups ($P > 0.05$). At the 12-week follow-up period, our results revealed a significant difference among all four groups in FFI-d scores (Table 6). Mean differences between groups also showed that the combined group (ESWT + PBMT) yields the highest scores in PPT, VAS, and FFI-d scores, followed by the ESWT alone, then PBMT alone (Tables 4, 5, and 6).

Discussion

The goal of our study was twofold: first, to investigate the combined effect of ESWT and PBMT in PF; and second, to compare their relative effectiveness in decreasing pain and increasing PPT. According to our results, when comparing

Table 1 General characteristics of the participants

	ESWT + PBMT ($n = 30$)	ESWT ($n = 30$)	PBMT ($n = 30$)	Sham-PBMT ($n = 30$)	*F* value	*P* value
Age (years)	56.03 ± 9.4	53.7 ± 10.1	54.1 ± 8.7	56 ± 10.3	0.48	0.69 (NS)
Gender						
Female	17 (65.7%)	13 (43.3%)	19 (63.3%)	15 (50%)	$\chi^2 = 2.67$	0.44 (NS)
Male	13 (43.3%)	17 (65.7%)	11 (36.7%)	15 (50%)		
Weight (kg)	79.06 ± 18.7	82.5 ± 19.4	82.8 ± 18.3	84.16 ± 19.5	0.30	0.82 (NS)
Height (m)	1.65 ± 0.09	1.6 ± 0.1	1.6 ± 0.14	1.6 ± 0.16	0.36	0.77 (NS)
BMI (kg/m^2)	28.6 ± 4.5	30.3 ± 5.1	31.15 ± 7.3	29.7 ± 4.8	1.08	0.36 (NS)

Data are expressed as mean (SD) or number (%)

χ^2 chi-square test, *NS* not significant ($P > 0.05$), *ESWT* extracorporeal shock wave therapy, *PBMT* photobiomodulation therapy, *Sham-PBMT* sham-photobiomodulation therapy

Table 2 Mean (SD) differences and percentage of change within groups

Measurement outcome	Baseline—week 0				Intervention period—week 3				Follow-up period—week 12			
	ESWT + PBMT	ESWT	PBMT	Sham-PBMT	ESWT + PBMT	ESWT	PBMT	Sham-PBMT	ESWT + PBMT	ESWT	PBMT	Sham-PBMT
VAS	7.4 (1.4)	7.8 (1.5)	7.6 (1.4)	7.8 (1.4)	1.8 (1.2) 75.6%↓	3.3 (1.2) 57.6%↓	6.2 (1.01) 8.06%↓	8.2 (1.3) 5.1%↑	0.7 (0.8) 90.5%↓	1.7 (1.02) 48.48%↓	5.7 (2.04) 18.4%↓	8.1 (1.2) 3.8%↑
PPT	0.85 (0.11)	0.91 (0.16)	0.89 (0.24)	0.92 (0.24)	4.4 (0.38) 417.6%↑	3.15 (0.4) 246.1%↑	1.38 (0.38) 15.9%↑	1.01 (0.25) 9.7%↓	4.75 (0.52) 458.8%↑	4.3 (0.91) 36.5%↑	1.6 (0.71) 55.05%↑	0.86 (0.3) 6.5%↓
FFI_{DS}	44.6 (7.08)	41.8 (5.2)	41.6 (5.8)	43.8 (5.2)	28.3 (3.9) 36.5%↓	35.4 (5) 15.3%↓	35.4 (4.4) 14.9%↓	44.9 (5.7) 2.5↑	19.5 (4.2) 56.2↓	28.9 (5.5) 30.8↓	31.4 (4.3) 24.5↓	43.5 (5) 0.6%↑

Data are expressed as mean ± standard deviation. % of improvement = post-value – pre-value/pre-value × 100

ESWT extracorporeal shock wave therapy, *PBMT* photobiomodulation therapy, *Sham-PBMT* sham-photobiomodulation therapy, *PPT* pain pressure threshold, *VAS* visual analogue scale, FFI_{DS} foot function index disability subscale

Table 3 Mean differences within groups and overall size effect on PPT, VAS, and FFI_{DS}

Measurement outcome	Differences within groups												Differences between groups		
	Week 3–week 0				Week 12–week 0				Week 12–week 3				Overall effect[a]		
	ESWT + PBMT	ESWT	PBMT	Sham-PBMT	ESWT + PBMT	ESWT	PBMT	Sham-PBMT	ESWT + PBMT	ESWT	PBMT	Sham-PBMT	F[b]	P value[c]	Effect size[d]
VAS	− 5.6	− 4.5	− 1.4	0.4	− 6.7	− 6.1	− 1.9	0.3	− 1.3	− 1.6	− 0.5	− 0.16	85.454	0.0001*	0.68
PPT	3.6	2.2	0.49	0.09	3.9	3.4	0.71	0.15	0.29	1.16	0.22	0.06	235.403	0.0001*	0.85
FFI_{DS}	16.3	6.4	6.1	1.1	25.6	12.3	10.1	0.2	8.7	6.4	4	1.3	49.76	0.0001*	0.56

Data are expressed as mean differences within and between groups

ESWT extracorporeal shock wave therapy, *PBMT* photobiomodulation therapy, *Sham-PBMT* sham-photobiomodulation therapy, *PPT* pain pressure threshold, *VAS* visual analogue scale, FFI_{DS} foot function index disability subscale

[a] 3 × 2 analysis of variance

[b] Mixed-design analysis of variance F ratio, representing interaction effect of time by group on dependent variable

[c] Significant P value < 0.05

[d] Partial η^2 : small > 0.01, medium > 0.06, large > 0.14

Table 4 Bonferroni tests and mean difference between the groups for VAS

	VAS			
	Intervention—3 weeks		Follow-up—12 weeks	
	Mean difference (CI 95%)	*P* value	Mean difference (CI 95%)	*P* value
ESWT + PBMT vs. ESWT	− 1.5 (− 2.12 to − 0.87)	0.0001*	− 0.93 (− 1.6 to − 0.22)	0.01*
ESWT + PBMT vs. PBMT	− 4.4 (− 5.08 to − 0.38)	0.0001*	− 5 (− 5.7 to − 4.2)	0.0001*
ESWT + PBMT vs. Sham-PBMT	− 6.4 (− 7.08 to − 5.8)	0.0001*	− 7.3 (− 8.04 to − 6.6)	0.0001*
ESWT vs. PBMT	− 2.9 (− 3.5 to − 2.3)	0.0001*	− 4.06 (− 4.7 to − 3.3)	0.0001*
ESWT vs. Sham-PBMT	− 4.9 (− 5.5 to − 4.3)	0.0001*	− 6.4 (− 4.11 to − 5.6)	0.0001*
PBMT vs. Sham-PBMT	− 2 (− 2.6 to − 1.3)	0.0001*	− 2.3 (− 3.04 to − 1.6)	0.0001*

Data are expressed as mean difference and confidence interval (95% CI)

ESWT extracorporeal shock wave therapy, *PBMT* photobiomodulation therapy, *Sham-PBMT* sham-photobiomodulation therapy, *VAS* visual analogue scale

*Significant *P* value < 0.05

within the four groups, both groups receiving ESWT yield improvements in PPT, VAS, and FFI-d scores ($P < 0.0001$) within the 3-week treatment period and was sustained at the 12-week follow-up.

PF is a difficult clinical entity to treat particularly when symptoms persist for over 6 months with failure to respond to conventional physical therapy modalities [36]. For these chronic symptoms, ESWT has been recommended before operative treatment choices [37]. Recently, results of numerous randomized controlled studies have supported the beneficial effects of ESWT in the management of chronic PF. Rompe et al. concluded that three treatments (once weekly) with ESWT was efficient at reducing morning heel pain when compared with a control group [21]. Konjen et al. reported a significant drop in VAS pain scores after ESWT was administered six times at weekly intervals [20]. Furthermore, Lohrer et al. reported significant improvement in functional tasks after the application of three sessions of ESWT at weekly intervals [19]. Ogden et al. reported a 47% improvement with a single application of 1500 high-energy shocks [17]. Similarly, Kudo et al. confirmed that a single application of 3800 high-energy shock waves produced significant improvements in terms of pain and function that was sustained up to 3 months after treatment [38].

Fundamental to its effectiveness, the exact analgesic mechanism of ESWT is yet immensely debated. ESWT is thought to produce extracellular cavitations resulting in needle-shaped hemorrhages in the tissues, thus producing chemical effects that interfere with the transmission of pain signals [21]. It has also been hypothesized that micro-disruption and hemorrhages may initiate the early expression of angiogenesis-related growth factors and a healing response within the fascia [39]. It is thought that this response promotes revascularization, which improves blood supply and increases cell proliferation and eventual tissue regeneration [40].

In contrast to our findings, Haake et al. reported that approximately three fourths of their PF patients had a good outcome 1 year after intervention irrespective of sham or ESWT. They concluded that the reasons for the observed improvement could have been due to the self-limiting natural history and spontaneous resolution of PF symptoms or additional conservative treatment that some patients received after the intervention [41]. Moreover, both groups, sham and ESWT, received local anesthesia prior to the application of the intervention. Similarly, Speed et al. examined 88 patients who had suffered PF for at least 3 months. Sham and ESWT were introduced once every month for three consecutive months. By the end of the 6-month course of the study, no statistical

Table 5 Bonferroni tests and mean difference between the groups for PPT

	PPT			
	Intervention—3 weeks		Follow-up—12 weeks	
	Mean difference (CI 95%)	*P* value	Mean difference (CI 95%)	*P* value
ESWT + PBMT vs. ESWT	1.3 (1.1–1.4)	0.0001*	− 0.43 (0.09–0.76)	0.01*
ESWT + PBMT vs. PBMT	3.06 (2.8–3.2)	0.0001*	3.09 (2.7–3.4)	0.0001*
ESWT + PBMT vs. Sham-PBMT	3.4 (3.2–3.6)	0.0001*	3.8 (3.5–4.2)	0.0001*
ESWT vs. PBMT	1.7 (1.5–1.9)	0.0001*	2.6 (2.3–2.9)	0.0001*
ESWT vs. Sham-PBMT	2.1 (1.9–2.3)	0.0001*	3.4 (3.1–3.7)	0.0001*
PBMT vs. Sham-PBMT	0.36 (0.18–0.55)	0.0001*	0.79 (0.46–1.1)	0.0001*

Data are expressed as mean difference and confidence interval (95% CI)

ESWT extracorporeal shock wave therapy, *PBMT* photobiomodulation therapy, *Sham-PBMT* sham-photobiomodulation therapy, *PPT* pain pressure threshold

*Significant *P* value < 0.05

significance was found between sham and ESWT groups in terms of pain [42]. This may account to that their study treatment protocol differed from ours, in terms of a single dose of low-energy ESWT delivered monthly, not weekly. Buchbinder et al. used ultrasound-guided ESWT on 166 patients suffering from PF for at least 6 weeks. They found no evidence that ESWT provided greater benefit than placebo in terms of pain and function [29]. This may be due to the placebo group that received low-energy shock waves (100 per treatment at energy 0.02 mJ/mm^2 and total dose 6.0 mJ/mm^2) which may have interfered with their results and produced a minor improvement. Furthermore, Buchbinder et al. applied ESWT on the area of maximal thickness of plantar fascia and did not focus on the area of maximal pain as in the current study.

In the current study, within-group comparison also revealed that the PBMT group showed profound improvement in PPT and FFI-d scores mainly on the 12-week follow-up (55.05 and 24.5%) than that at 3-week post-intervention (15.9 and 14.9%). Additionally, no statistical significance was found in the sham-PBMT group both in the 3-week post-intervention and 12-week follow-up periods ($P > 0.05$). Jastifer et al. investigated the effect of PBMT application twice weekly for three consecutive weeks on PF. VAS and Foot Function Index (FFI) were evaluated at baseline, 2 weeks post-procedure, and 6 and 12 months post-procedure. They found significant improvement post-intervention; however, the most benefit was achieved several months after PBMT application [43]. These findings come in line with our results, where at 12-week follow-up profound improvement in PPT, VAS, and FFI-d scores were found in the PBMT group than that at the 3-week post-intervention.

Over the last decade, PBMT has been used in the treatment of numerous musculoskeletal disorders [12, 13]. It is thought that PBMT may boost bio-stimulation effects that promote tissue healing through the enhancement of leukocyte infiltration, macrophage activity, collagen deposition, cellular proliferation, and neovascularization [44–47]. These effects were likely responsible for the profound clinical improvement at 12-week follow-up seen in our study: local tissue healing and remodeling. Similarly, Kiritsi et al. investigated the effect of 6-week PBMT application on PF by measuring planter fascial thickness via ultrasonography. They found significant change in planter fascial thickness after PBMT; they suggested that PBMT may have contributed to PF healing, serving as a cell stimulator and possibly accelerating the healing process [48].

To our knowledge, no previous trials have explored the effects of ESWT in conjunction with PBMT. In the current study, when comparing among all groups, our results revealed that ESWT combined with PBMT showed greater reduction in

Table 6 Bonferroni tests and mean difference between the groups for FFI disability subscale

	FFI_{DS}			
	Intervention—3 weeks		Follow-up—12 weeks	
	Mean difference (95% CI)	*P* value	Mean difference (95% CI)	*P* value
ESWT + PBMT vs. ESWT	7.06 (9.4–4.6)	0.0001*	9.4 (11.8–6.9)	0.0001*
ESWT + PBMT vs. PBMT	7.1 (9.5–4.6)	0.0001*	11.8 (14.3–9.4)	0.0001*
ESWT + PBMT vs. Sham-PBMT	16.5 (18.9–14.1)	0.0001*	23.9 (26.4–23.5)	0.0001*
ESWT vs. PBMT	0.03 (2.4–2.3)	0.97	2.4 (4.9–0.007)	0.04*
ESWT vs. Sham-PBMT	9.4 (11.9–7.07)	0.0001*	14.5 (17.02–12.1)	0.0001*
PBMT vs. Sham-PBMT	9.4 (11.8–7.04)	0.0001*	12.1 (14.5–9.6)	0.0001*

Data are expressed as mean difference and confidence interval (95% CI)

ESWT extracorporeal shock wave therapy, *PBMT* photobiomodulation therapy, *Sham-PBMT* sham-photobiomodulation therapy, FFI_{DS} foot function index disability subscale

*Significant *P* value < 0.05

pain sensitivity and FFI-d scores (458.8 and 56.2%, respectively) than ESWT (246.1 and 30.8%, respectively) and PBMT (55.05 and 24.5%, respectively) alone. This can be explained by the coupled effect that might have augmented during the application of ESWT prior to PBMT. The purpose of ESWT is to activate a controlled micro-disruption of plantar fascial tissue, which initiates a healing response within the fascia [21]. Additionally, at a cellular level, ESWT may produce free radicals through cavitation which in return may alter the cellular antioxidative defense status or even damage the cell membranes [40]. On the other hand, application of PBMT after creating such an environment of micro-disruption and needle-shaped hemorrhages in the tissues may accelerate the healing process through its bio-stimulation effects. Furthermore, PBMT may advocate pain reduction through its potential effect on serotonin metabolism, thereby acting as a pain suppressor [48], hence the coupled effect.

Recently, Cinar et al. compared the effectiveness of ESWT and PBMT in relieving pain in patients with PF. Their treatment protocol included lower energy levels of radial ESWT at 0.02 mJ/mm^2 applied for three sessions once a week and a PBMT wavelength of 850 nm, dose of 5.6 J/cm^2 with 5 to 7 min exposure/session for a total of 10 sessions. They found that PBMT was more effective than ESWT in reducing pain in PF at 3-week and 3-month follow-up [49]. These results come in contrast to our findings, where at week 3 post-intervention ESWT was found to have a significant effect on pain sensitivity when compared to PBMT. However, at the same time, there were no significant differences between ESWT and PBMT with regard to function. Additionally, at the 12-week follow-up, ESWT was found to have a significant effect on both pain sensitivity and function when compared to PBMT. This may account to that their study treatment protocol in both ESWT and PBMT differed from ours. In the current study, medium-energy ESWT with energy level between 0.22 and 0.28 mJ/mm^2 was used, and a lower the PBMT dose (2.8 J/cm^2) was applied for only 60 s. Additionally, Cinar et al. outcome measure included only pain measures (FFI-pain subscale and numerical rating scale for pain) with no functional nor activity measures [49].

Limitation

Limitations of the present study include the fact that the study lasted for 15 weeks only; the longer-term effects of ESWT and PBMT in the management of PF require further investigation. However, it would have been either expensive or impossible to recruit the participants for so long, without more dropouts.

Further work needs to focus on the physiological responses produced by combining both ESWT and PBMT subsequently, and identify the mechanisms involved. Future research is also required to investigate the effects of multimodal treatment approaches in the management of PF.

Conclusion

In conclusion, ESWT and PBMT are both effective in reducing pain sensitivity in PF. However, combining PBMT with ESWT in a multimodal treatment session was found to produce superior effects in reducing pain and increasing function in PF. Additionally, ESWT was found to be more effective than PBMT in reducing pain and improving function in PF at short-term follow-up.

Compliance with ethical standards

Ethics approval The Board Council of Higher Education of the School of Physical Therapy, the Institutional Review Board of Higher Education and Research of Cairo University, and the Supreme Council of Universities at Egypt approved this study. The study is prospectively registered with the Australian New Zealand Clinical Trials Registry (ACTRN12617000761369). All participants gave written informed consent before data collection began.

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