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Immediate effects of ultrasound therapy on pain and plantar pressure in individuals with subacute ankle sprains: a randomized controlled trial

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Abstract

Introduction. Despite the fact that ultrasound (US) therapy is not advised for acute ankle sprains, its therapeutic effects may be beneficial for other stages of ankle sprains, such as a subacute ankle sprain. There is, however, a lack of evidence regarding the effects of US on pain relief and functional improvement in subacute ankle sprains. Therefore, this study aimed to determine the immediate effects of US on pain and plantar pressure in individuals with unilateral subacute ankle sprains.

Methods. Fifty-four participants with unilateral subacute ankle sprains (aged 16–55 years) were recruited and randomly allocated into a treatment group (n = 27) and a control group (n = 27). The treatment and control groups received a single intervention session of US and an ineffectual US, respectively. Pain intensity during weight-bearing and static and dynamic plantar pressures were assessed before and after receiving the intervention.

Results. In both groups, pain intensity was statistically reduced ($p < 0.05$) and clinically relevant. Although the maximum plantar pressure in the hindfoot during static conditions was statistically higher in the control group (p = 0.024), the values were still lower than MDC_{95}.

Conclusions. A single treatment of US could clinically reduce pain, but it had no effect on altering plantar pressure in individuals with unilateral subacute ankle sprains.

Key words: ankle, sprains, ultrasound, weight-bearing, pain

Introduction

Lateral ankle sprains are the most frequent type of ankle injury experienced during sports and exercise (85% of all cases), which commonly involve an injury to the anterior talofibular ligament (ATFL; about 70% of cases) [1]. Individuals with ankle sprains return to daily life activity in an average of 28 to 33 days after injury. Unfortunately, more than 40% of improperly healed ankle sprains progress to chronic ankle dysfunctions, which cause pain during weight-bearing activity on the affected foot, recurrent swelling, and recurrent injuries [2], thus impacting daily life activities [3]. It is critical to prevent this progression.

To avoid the development of chronic ankle dysfunction, appropriate interventions should be implemented to eliminate the symptoms during the subacute phase [4]. In this phase, soft tissue repair takes place as fibroblasts begin to be synthesized at the affected area and produce collagen. This period usually appears within 4 days after injury and tends to last for 10 to 14 days [5].

Due to its therapeutic effects, one physical therapy modality frequently used to treat ankle sprain is ultrasound (US) therapy [6, 7]. The thermal effects of US can enhance blood flow and the extensibility of tissues while minimizing pain [6, 8]. Most studies reported pain improvement after several sessions of thermal US [9]. However, a single session of thermal US would reduce pain in musculoskeletal conditions as it would affect nociceptive information [10]. In addition, the non-thermal effects can promote intracellular calcium, cell membrane permeability, and protein synthesis [11–14]. Moreover, US has direct effects on the viscoelastic properties of collagen [15]. A recent systematic review concluded that US does not appear to help with pain and swelling or standing on the affected foot in acute ankle sprains, thus, it is not recommended for the treatment of acute ankle sprains [9]. Furthermore, the literature lacks detailed information on US parameters. To our knowledge, however, no study has focused on the effectiveness of US on pain relief in subacute ankle sprains.

Meanwhile, there is a lack of evidence showing whether US can relieve pain as well as improve weight-bearing in individuals with subacute ankle sprains. Therefore, this study aimed to investigate the immediate effects of a single US treatment in individuals with unilateral subacute ankle sprains. US parameters in this study were set primarily based on the thermal effect. We hypothesized that a single applied US treatment with a specific parameter setting for pain relief could reduce pain and improve weight bearing in individuals with unilateral subacute ankle sprains.

Subjects and methods

Participants

Participants were recruited from local physical therapy clinics in the provinces of Nakon Nayok and Pathum Thani, Thailand, between April 2020 and December 2020.

Participants diagnosed with unilateral lateral ankle sprains (grades 1–2) by a physician at least 4 days and up to 14 days

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after injury were recruited for this study. All participants met the inclusion criteria, including having pain during weight-bearing for at least 30 mm of a 100-mm visual analog scale (VAS), and the ability to communicate and use a VAS. Exclusion criteria were redness and warmth at the area of the ankle sprain, numbness of the lower extremity, vestibular problems confirmed by medical history, and having any contraindications to US.

The sample size was calculated using G*power version 3.1.9.4 with a significance level of 0.05, desired power of 0.80, and effect size of 0.80. The estimation of effect size was based on previous studies related to musculoskeletal pain [16, 17]. The estimated required sample size was calculated to be at least 52 participants. Therefore, the sample size was at least 26 per group. However, we decided to protect against drop out of participants in the instance they have adverse effects from US. Therefore, the sample size was included to be 54 and separated into each group to be 27 per group.

Procedure

We conducted a double-blind randomized, controlled trial. The participants were unaware of the group assignment. Investigator 1 recruited participants and performed treatment sessions. Investigator 2 evaluated outcome measurements at baseline and after treatment and was unaware of group assignments. In addition, the outcome assessments and treatment sessions were conducted in a separate room.

Fifty-four participants were divided into 2 groups, including a treatment group and a control group by investigator 1, following a stratified randomization procedure based on the incidence of the ankle sprain found in adolescents and adults [18]. The stratified random sampling methods were performed to balance gender and age between the groups. Participants were randomly allocated into the treatment and control groups by using opaque sealed envelopes.

Outcomes measures

Baseline evaluation included demographic and clinical characteristic data, including age, gender, height, weight, body mass index, duration of injury, side of injury, the severity of the injury, and pain intensity during weight-bearing (see Table 1).

All participants were assessed for outcome measures, including pain intensity during weight-bearing, static and dynamic plantar pressure distribution before and after intervention. Static and dynamic maximum plantar pressure (kPa) measurements were analyzed for the three regions, including the forefoot, midfoot, and hindfoot. These outcome measurements were assessed by investigator 2, who was trained and had high reliability in pain intensity measurements ($ICC_{(3, 1)}$ = 0.99) and good to high test-retest reliability of maximum plantar pressures ($ICC_{(2,1)}$ were 0.72, 0.85, and 0.85 for the forefoot, midfoot, and hindfoot, respectively). The test-retest minimal detectable change with 95% confidence (MDC_{95}) for pain was 5.04 mm [19], and MDC_{95} for maximum plantar pressures were 15.40, 19.22, and 45.24 kPa for forefoot, midfoot, and hindfoot, respectively.

To measure the outcomes, we asked participants to step down on the affected side once. Pain intensity during weight-bearing was measured using 100-mm VAS. Then, static and dynamic plantar pressure distributions were measured using a plantar pressure platform system (DIERS International GmbH, Germany) with a sampling rate of 200 Hz. To measure static plantar pressure, participants were instructed to stand with their feet apart on the platform. Data were recorded for 15 seconds. Then, the dynamic plantar pressure of the affected side was measured by having the participants stand at a distance, after which they would take two steps before striking the platform with the affected side. Participants were allowed 2–3 trials to familiarize themselves with the protocol. Data for one trial of each static and dynamic task was used for data analysis. In addition, participants were allowed to take a rest at their request.

Interventions

For intervention sessions, participants maintained a supine position until the end of the session. Investigator 1 used a Sonopuls 490 US device (Enraf-Nonius, Lisburn, UK) equipped with a US transducer with an effective radiation area of 5.0 cm^2 and a beam non-uniform ratio of 1:6. The US transducer was calibrated before applying it to the participants. The treatment area was estimated at approximately 10 cm^2 and marked by using a bendable wire circle and pen. The US was applied to the painful area on the lateral aspect of the ankle.

In the treatment group, participants received US according to the therapeutic purpose (thermal effect) [20]. US treatment intensity was set at 0.25 W/cm^2 with a duty cycle of 100%, a spatial average-temporal average (SATA) of 0.25 W/cm^2, and a frequency of 3 MHz. A circular stroke technique was applied and the treatment time was set for 6 minutes [7, 21]. In the control group, participants received the ineffectual US, which was set at minimal energy. US treatment intensity was set at 0.05 W/cm^2 with a duty cycle of 5%, SATA of 0.0025 W/cm^2, and the same frequency, treatment duration, and techniques used in the treatment group. After finishing the intervention sessions, participants were reassessed for all outcome measures (Figure 1).

Statistical analysis

Statistical analysis was performed using SPSS version 22 (IBM). The Shapiro–Wilk test was used to test the normality of data. All data were normally distributed. Independent *t*-tests were used to determine the differences between the treatment and control groups. Paired *t*-tests were used to determine the differences before and after the intervention within each group. Statistical significance was set at $p < 0.05$.

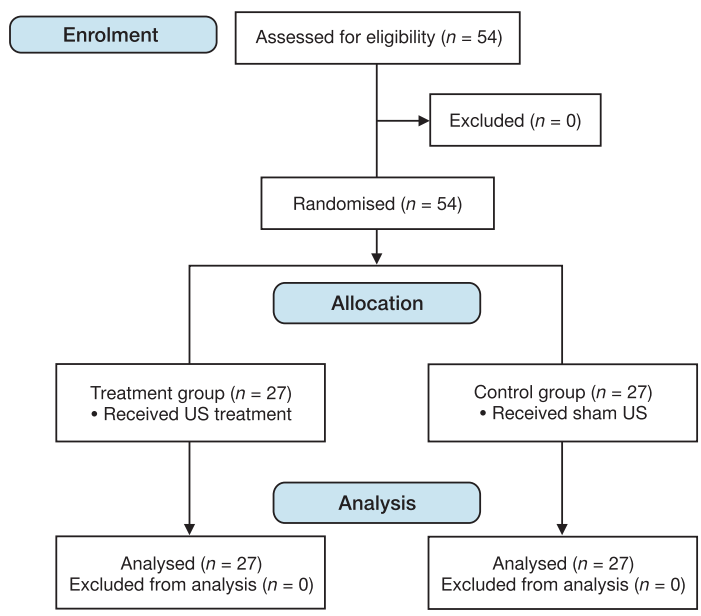

Figure 1. Flow diagram for the study

Results

There were no significant differences in characteristics between the treatment and control groups (Table 1).

Before receiving an intervention, there were no significant differences in pain intensity during weight-bearing and static and dynamic maximum plantar pressures between the treatment and control groups ($p > 0.05$). After receiving an intervention, pain intensity significantly decreased in both groups ($p < 0.01$). However, this decreased pain intensity did not differ significantly between groups ($p > 0.05$; Table 2).

For static plantar pressure measurements, only the control group displayed an increased maximum plantar pressure in the hindfoot after interventions ($p = 0.024$). However, there was no significant difference between the groups ($p > 0.05$, Table 3).

Table 1. Demographic and clinical characteristic data of the treatment and control groups (values are mean ± *SD* unless otherwise indicated)

Variables	Treatment group ($n = 27$)	Control group ($n = 27$)	$p^{\dagger}$
Gender, *n* (%)			
male	22 (82)	22 (82)	–
female	5 (18)	5 (18)	–
Age (years)	26.04 ± 11.03	26.07 ± 10.26	0.990
Height (cm)	169.44 ± 7.85	170.04 ± 8.98	0.797
Weight kg)	66.31 ± 9.70	70.04 ± 13.20	0.242
BMI (kg/m^2)	23.05 ± 2.65	24.29 ± 4.79	0.243
Duration of injury (days)	7.00 ± 3.70	6.33 ± 2.87	0.463
Side of injury (*n*; %)			
right	16 (59.30)	14 (51.90)	–
left	11 (40.70)	13 (48.10)	–
Severity of the injury, *n* (%)			
grade 1	5 (18.50)	6 (22.20)	–
grade 2	22 (81.50)	21 (77.80)	–
VAS scores (mm)			
weight-bearing	49.54 ± 15.37	44.85 ± 14.11	0.249

BMI – body mass index, VAS – visual analog scale
† Independent *t*-test compares the mean difference between treatment and control groups

For dynamic plantar pressure measurements, no variables showed significant differences between groups or within each group ($p > 0.05$, Table 4).

Discussion

We aimed to investigate the immediate effect of single-treatment US in individuals with unilateral subacute ankle sprains. We found statistically significant improvement in pain intensity in both treatment and control groups. However, weight-bearing in terms of plantar pressure did not show any obvious improvement.

Both groups reported significant pain reduction during weight-bearing after receiving an intervention. The mean pain intensity after treatment decreased by 19.28 mm and 12.56 mm in the treatment and control groups, respectively, with large effect sizes of 1.10 and 1.15. In addition, the pain intensity of both groups met the minimal detectable change of 5.04 mm, which was reported in a previous study [19]. Even though, VAS showed variability of pain intensity, pain reduction in both groups was sufficient to allow a meaningful effect that indicated clinically significant changes, confirming the analgesic effect.

The US parameters used were set according to the therapeutic purpose, which was the thermal effect. Appropriate US parameter settings can significantly affect treatment outcomes [20]. Besides parameter setting, the types of lesions treated (e.g., muscle, tendon, or ligament) should be considered [20]. The rate of temperature increase in a participant's tendons was greater than that in their muscles, as the tendons showed poor blood circulation [22–24]. Furthermore, a recent systematic evaluation of US therapy in acute ankle sprains discovered a non-identified objective of US parameter setting as well as a risk of bias due to a lack of blinding of care providers, patients, or outcome assessments [9]. Therefore, considering US parameters, lesion type, and risk of bias can further improve the measured outcomes.

Previous studies reported that the thermal effect of US could reduce pain by increasing local blood circulation [6, 25], the pain threshold, and enzymatic activity, as well as accelerate the metabolic rate, change nerve conduction velocities, increase the extensibility of collagen fibers [26, 27], and decrease nitric oxide synthesis [28]. US-induced antinociception involved the attenuation of the inflammatory response, as seen by lower levels of spinal proinflammatory cytokines, as well as changes in neuronal excitability, membrane permeability, and immune cell activity in the joints [10]. For a single session of US treatment, the short-term antinociception caused by US was associated with changes in nerve conduction velocity, cell membrane permeability, and possibly cell excitability. These changes would last for one hour [10]. Thus, pain

Table 2. Within and between-group comparisons of pain intensity during weight-bearing in individuals with unilateral subacute lateral ankle sprains for the treatment and control groups

Variables	Baseline mean ± *SD*	After treatment Bangkok, Thailand	Mean difference (95% CI)	$p^{\dagger}$	Effect size‡	$p^{\ddagger}$	Effect size‡
VAS scores (mm)							
treatment group ($n = 27$)	49.54 ± 15.37	28.78 ± 18.77	19.28 (14.75, 26.77)	0.000*	1.10	0.949	0.462
control group ($n = 27$)	44.85 ± 14.11	32.30 ± 21.60	12.56 (8.25, 16.89)	0.000*	1.15		

VAS – visual analog scale
* significant differences ($p < 0.05$)
† paired *t*-test was compared between baseline and after treatment for each treatment and control group
‡ independent *t*-test comparing the mean difference between treatment and control groups after the treatment

Table 3. Within and between-group comparisons for maximum plantar pressure (kPa) at the forefoot, midfoot, and hindfoot under static conditions in the treatment and control groups

Variable	Baseline mean ± *SD*	After treatment mean ± *SD*	Mean difference (95% CI)	$p^{\dagger}$	Effect size†	$p^{\ddagger}$	Effect size‡
Forefoot maximum plantar pressure (kPa)							
treatment group (*n* = 27)	46.40 ± 16.32	50.10 ± 17.24	3.63 (–0.11, 7.36)	0.056	0.384	0.407	0.064
control group (*n* = 27)	51.10 ± 17.31	52.57 ± 17.76	1.47 (–2.29, 5.23)	0.428	0.155		
Midfoot maximum plantar pressure (kPa)							
treatment group (*n* = 27)	34.7 ± 13.45	35.83 ± 11.83	1.07 (–2.60, 4.75)	0.554	0.115	0.277	0.302
control group (*n* = 27)	34.20 ± 19.71	38.43 ± 20.72	4.23 (–0.39, 8.85)	0.071	0.362		
Hindfoot maximum plantar pressure (kPa)							
treatment group (*n* = 27)	92.52 ± 36.13	97.45 ± 33.33	4.93 (–2.27, 12.12)	0.171	0.271	0.452	0.065
control group (*n* = 27)	86.57 ± 37.30	95.34 ± 34.10	8.77 (1.25, 16.29)	0.024*	0.461		

* significant difference ($p < 0.05$)
† paired *t*-test is compared between baseline and after treatment in each treatment and control group
‡ independent *t*-test compared the mean differences between treatment and control groups after treatment

Table 4. Within and between-group comparisons of maximum plantar pressure (kPa) at the forefoot, midfoot, and hindfoot under dynamic conditions in treatment and control groups

Variable	Baseline mean ± *SD*	After treatment mean ± *SD*	Mean difference (95% CI)	$p^{\dagger}$	Effect size†	$p^{\ddagger}$	Effect size‡
Forefoot maximum plantar pressure (kPa)							
treatment group (*n* = 27)	101.03 ± 35.13	105.21 ± 32.66	4.18 (–4.76, 13.12)	0.345	0.384	0.291	0.064
control group (*n* = 27)	107.35 ± 31.41	105.76 ± 28.83	–1.60 (–8.23, 5.04)	0.625	0.155		
Midfoot maximum plantar pressure (kPa)							
treatment group (*n* = 27)	65.14 ± 25.15	62.95 ± 22.05	–2.19 (–10.50, 6.13)	0.593	0.115	0.161	0.302
control group (*n* = 27)	65.93 ± 32.25	70.96 ± 31.55	5.03 (–1.30, 11.36)	0.114	0.362		
Hindfoot maximum plantar pressure (kPa)							
treatment group (*n* = 27)	137.02 ± 53.58	140.80 ± 42.98	3.78 (–10.96, 18.52)	0.602	0.271	0.934	0.065
control group (*n* = 27)	153.71 ± 41.47	156.78 ± 42.00	3.07 (–6.47, 12.62)	0.514	0.461		

† paired *t*-test comparing baseline and after treatment within each treatment and control group
‡ independent *t*-test comparing mean differences between treatment and control groups after treatment

reduction after a single session of US could not be maintained over time. Although US has been demonstrated to promote inflammation and is not suggested for application in the inflammatory phase [9], it has been shown to be beneficial during the proliferative phase. It stimulates fibroblasts, endothelial cells, and myofibroblasts [6]. This study found that thermal US has an advantageous effect on pain relief in subacute ankle sprains. As a result, the biophysical properties of thermal US after the acute period would be favorable to ligament damage. Good outcomes for US therapy have been reported in patients with epicondylitis [29], carpal tunnel syndrome [30], calcific tendinitis of the shoulder [31], and chronic varicose ulcers [32].

Even though our study found a reduction in pain intensity in the control group, it was not influenced by thermal US because the settings were set at 0.0025 W/cm^2 with a duty cycle of 5% and frequency of 3 MHz, resulting in a minimal energy of 0.45 J/cm^2. However, this dose was unable to deliver a therapeutic effect of thermal US as it has been shown to have a therapeutic effect at energies ranging from 30–180 J/cm^2 [21]. The reduction of pain intensity in this group could be explained by the placebo effect. Previous studies have reported that control groups can demonstrate effectiveness equal to or superior to treatment groups in various areas, such as knee osteoarthritis [16], delayed-onset muscle soreness [33], and plantar fasciitis [17]. The physiological mechanisms

of the placebo effect depend on the physical and psychological factors of the individuals. A participant's positive expectations could activate the endogenous opioid system, which can affect pain relief via analgesic mechanisms [34, 35]. The opioid-driven response is a part of placebo analgesia stimulated by a descending pain modulation pathway involving the rostral anterior cingulate cortex, orbitofrontal cortex, periaqueductal grey matter, pons, and medulla [35]. These pathways use opioids to increase inhibition at the dorsal horn of the spinal cord. Consequently, they can reduce the number of nociceptive signals reaching the brain.

In addition, moving US transducers over the area of treatment may act as a local massage, which induces tactile analgesia and increases lymphatic blood flow and drainage in both groups. Tactile analgesia can be explained by the gate control theory [36]. The nerve impulses from mechanoreceptor stimulation by moving the transducer along the afferent nerves block impulses from pain fibers at the dorsal horn of the spinal cord. Then, pain information cannot be transmitted up to the higher centers [37]. However, pain reduction by the gate control theory has immediate effects of less than one hour [38, 39].

Even though maximum plantar pressure in the hindfoot was increased by 8.77 kPa in the control group, the changes in maximum pressure did not meet the MDC_{95} value of 45.24 kPa. The use of a single US treatment only slightly decreased the intensity of pain during weight-bearing, and plantar pressure parameters changed inconclusively. Therefore, the application of US in individuals with unilateral subacute lateral ankle sprains may need to be conducted with more than a single treatment session to yield improved functional activity.

Limitations

The limitation of the study included objective measurements of pain intensity such as PPTs were not collected. Moreover, this study did not assess swelling, foot types (e.g., flat foot, high arch), and the dominant limb of participants that could affect plantar pressure measurements. Furthermore, the frequency, types, and duration of regular exercise, as well as occupational activities that could be associated with pain and weight-bearing were not investigated in this study. Therefore, further studies with PPT, swelling measurements, and identifying the types of foot, dominant limb, and routine physical activity should be conducted. In addition, the full US treatment program should be done with after-treatment follow-up.

Conclusions

In this study, a single US treatment demonstrated an immediate effect on pain, but no improvement in plantar pressure outcomes. A complete program of US treatment should be investigated further to determine whether additional treatment sessions would influence weight-bearing and improve functional ability.

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Ethical approval

The research related to human use has complied with all relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Research Ethics Review Committee for Research Involving Human Research Participants, Group I, Chulalongkorn, Thailand (approval No.: COA No.079/2020) and were registered at ThaiClinicalTrials.org (TCTR registration No. TCTR20200423002).

Informed consent

Informed consent was obtained from all individuals included in this study.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflicts of interest

The authors state no conflicts of interest.

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