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Effects of Extracorporeal Shock Wave Therapy on Ankle Function, Range of Motion, and Dynamic Balance in Patients with Chronic Ankle Instability

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Purpose: This study investigated the short-term effectiveness of extracorporeal shock wave therapy (ESWT) on pain, the ankle instability, the ankle function, dorsiflexion range of motion (ROM), and dynamic balance in patients with chronic ankle instability (CAI).
Methods: Eighteen participants were divided into an experimental ($n=9$) and control group ($n=9$). The ESWT in the experimental group was applied to the lateral collateral ligament in combination with the tibialis anterior whereas the ESWT was applied to the lateral collateral ligament of the ankle alone in the control group. Pain, the ankle instability, the ankle function, dorsiflexion ROM, and dynamic balance were measured using the Visual analog scale, Cumberland ankle instability tool, American Orthopedic Foot and Ankle Society ankle-hindfoot score, weight-bearing lunge, and Y-balance test, before and after ESWT intervention.
Results: Significant interactions (group × time) and time effects were observed in the dorsiflexion ROM and dynamic balance. Bonferroni's post-hoc analysis showed that the experimental group revealed a more significant change in dorsiflexion ROM and dynamic balance than the control group. There was a significant time effect in the pain, the ankle instability, and the ankle function, but no significant interaction (group × time) was observed.
Conclusion: The ESWT could improve the pain, ankle instability, ankle function, dorsiflexion ROM, and dynamic balance in patients with CAI. Furthermore, the ESWT combined with lateral ankle ligaments and tibialis anterior more improves the dorsiflexion ROM and dynamic balance.

Keywords: Extracorporeal shock wave therapy, Chronic ankle instability, Dorsiflexion range of motion, Dynamic balance

INTRODUCTION

An acute ankle sprain is the most common musculoskeletal injury[1] and occurs by forced plantar flexion and inversion as the body's center of gravity rolls over the ankle.[2] These forces commonly damage the nerve and musculotendinous tissue of the ankle joint, particularly the lateral collateral ligament complex, consisting of the anterior talofibular ligament, the posterior talofibular ligament, and the calcaneofibular ligament.[3] A substantial proportion of individuals who have experienced an ankle sprain tend to develop chronic ankle instability (CAI).[4] CAI is an encompassing term used to describe an individual who presents with mechanical and functional ankle instability following an initial lateral ankle sprain.[5] Mechanical ankle instability is defined by reduced ligament stiffness and arthrokinematics changes, whereas functional ankle instability is characterized by recurrent ankle instability due to an impairment of the proprioception and neuromuscular systems.[6] Impairments in sensorimotor control affect various functional deficits,[7] including decreased static[8,9] and dynamic balance,[10] decreased strength, and altered gait patterns.[11] For examples, patients with CAI show lower dorsiflexion angle and higher plantar flexion angle during gait than non-CAI.[12,13] It may reduce the ability to absorb impact and modulate vertical ground reaction force appropriately during heel strike.[14] In addition, patients with CAI demonstrated different muscle activation pattern of lower extremity during gait in the tibialis anterior and peroneus longus.[13,15,16] Changes in the activation patterns of tibi-

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alis anterior and peroneus longus could induce a more supinated foot position during the stance phase,[15] which could result in repeated ankle instability, recurrent sprains, a feeling of the "giving away," and pain.[3,17] Thus, appropriate coupling of tibialis anterior and peroneus longus activity is crucial for facilitating the neutral position that controls the load during the stance phase of gait.[15]

Both functional deficit and pain are important considerations in the rehabilitation goal-setting process. Conventional treatment for patients with CAI consists of mobilization, weight-bearing, strength, balance, and ROM exercises to address functional ankle instability and pain.[18] Extracorporeal shock wave therapy (ESWT) has recently been used in treatment approaches to reduce pain in musculoskeletal conditions.[19,20] When ESWT was applied to patients with chronic Achilles tendinopathy, the pain decreased and the functionality of the ankle joint improved.[21-24] Although the precise mechanism has not been determined and the outcomes vary depending on the dosage and treatment regimes, the rationale for this effectiveness is to stimulate soft tissue healing, reduce calcification, inhibit pain receptors, and induce denervation.[25,26] In addition, extracorporeal shock waves could increase maximal dorsi flexion and a dorsiflexion/plantar flexion torque ratio in patients with plantar fasciopathy.[27] These improvements contribute to quality of life,[27] static and dynamic balance.[28,29]

Based on these findings, ESWT can help improve the pain and function in patients with soft tissue disease of the ankle joint. However, there is currently a lack of evidence of its effects to patients with CAI. Hence, the tibialis anterior plays a crucial function in maintaining dorsiflexion and avoiding excessive plantar flexion during gait to prevent recurrent ankle sprain in patients with CAI.[15] It is necessary to understand whether and how ESWT affects patients with CAI when an extracorporeal shock wave is applied to the tibialis anterior in order to determine the most effective intervention method. Therefore, this study examined the effects of ESWT on pain, ankle instability, ankle function, dorsiflexion ROM, and dynamic balance when ESWT is applied in combination with the tibialis anterior and the lateral ankle ligaments in patients with CAI.

METHODS

1. Participants

Twenty patients with CAI were recruited for this study. The participants were allocated randomly to either the experimental or control group. The ESWT in the experimental group was applied to the lateral collateral ligament of the ankle and tibialis anterior whereas the ESWT was applied to the lateral collateral ligament of the ankle alone in the control group. There was one dropout in each experimental and control group caused by an error in data collection. The inclusion criteria of participants were as follows: 1) diagnosed with CAI through an anterior drawer test, 2) a score <24 on the Cumberland Ankle Instability Tool (CAIT),[30] 3) a score ≥4 on the visual analog scale (VAS), 4) diagnosed with a lateral ligament injury through radiographs, 5) no wounds in the ankle joint and calf. Participants had no history of ankle joint injuries or surgical procedures within the last year and injection treatment around the ankle joint within six months. All participants provided written informed consent in accordance with the Declaration of Helsinki. This study was approved by the Institutional Review Board of Dankook University (DKU 2022-02-035-001).

2. Measurements

1) Pain

The pain intensity was evaluated using a VAS. The participants were asked to define their present pain intensity by marking a perpendicular line on a 10 cm horizontal line (no pain = 0, worst pain possible = 10). The VAS has high validity and reliability (ICC = 0.97).[31]

2) Ankle instability

CAIT was used to evaluate the functional ankle instability. The CAIT is a self-reported nine-item questionnaire to evaluate the severity of functional ankle instability. The total score ranged from zero to 30, with lower scores indicating more severe instability. The scores ≥28 could be considered as non-affected ankle while <24 indicated CAI.[32] The CAIT test-retest reliability and validity were high (ICC = 0.979).[33]

3) Ankle function

The ankle function was evaluated using an American Orthopedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Score. The AOFAS is a 100-point scoring system based on a questionnaire that evaluates the ankle function by combining subjective and objective components. It evaluates the pain (40 points), function (50 points), and alignment (10 points).[34]

4) Dorsiflexion ROM

Weight-bearing lunges were used to measure the ankle dorsiflexion ROM. This was performed standing, with the second toe, the center of the heel, and the knee kept in a plane perpendicular to the wall. The participant then performed a lunge forward by bending the hip and knee joints until

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Figure 1. Extracorporeal shock wave therapy intervention. (A) extracorporeal shock wave therapy to tibialis anterior, (B) extracorporeal shock wave therapy to lateral collateral ligament.

the anterior knee contacted the wall. When participants completed the weight-bearing lunge, the dorsiflexion angle was obtained without lifting the heel from the ground using a goniometer. The average values of ankle dorsiflexion ROM were calculated over the three trials. The reliability of the weight-bearing ankle dorsiflexion showed high inter and intra-rater reliability with an ICC value of 0.80–0.99 and 0.65–0.99, respectively (ICC = 0.96).[35,36]

5) Dynamic balance

The Y-balance test was used to assess the dynamic postural stability in three-reach directions: anterior, posteromedial, and posterolateral. The goal of the Y-balance test was to reach as far as possible with one leg in three directions while maintaining balance with the contralateral limb. The participants stand at a central point and reach as far as possible forward with the un-affected leg while maintaining balance with the affected leg. The participants then return to a bilateral stance, while maintaining their balance. This procedure was repeated with measurements for the posteromedial and posterolateral directions. The composite score was calculated by dividing the sum of the maximum reach distance in the anterior, posteromedial, and posterolateral directions by three times the limb length of the participant and then multiplying the value by 100.[37] The Y-balance showed excellent intra-tester (0.85-0.89) and inter-tester (0.97-1.00) reliability.[38]

3. Procedure

The baseline outcome measurements were taken, including VAS, CAIT, AOFAS, ankle dorsiflexion ROM, and Y-balance test. Both groups performed ESWT for four sessions at two-three day intervals by one physical therapist. The extracorporeal shock waves were delivered using SALUS-FSWT (REMED, Daejeon, Korea) with 2,500 shockwave impulses (6 Hz), which was effective in improving pain and functional abilities in patients with musculoskeletal diseases.[39-41] The intensity of extracorporeal shock waves was adjusted according to the patients' degree of tolerance to the pain. In the experimental group, the extracorporeal shockwave was applied to the anterior talofibular ligament, posterior talofibular ligament, calcaneofibular ligament, and tibialis anterior muscle (Figure 1). In the control group, the extracorporeal shockwave was delivered to the anterior talofibular ligament, posterior talofibular ligament, and calcaneofibular ligament (Figure 1). A post-test was measured the day after ESWT.

4. Data analysis

Data analysis was performed using SPSS software (version 25.0, SPSS, Chicago, IL, USA). The Shapiro-Wilk test was used for the normality test among the measurements. The independent t-test (age, height, weight, VAS, and CAIT) and chi-square test (sex) were performed to analyze the general characteristics between groups. Two-way repeated measures analysis of variance (ANOVA) was performed to analyze the changes in pain, ankle instability, ankle function, dorsiflexion ROM, and dynamic balance of CAI patients between two groups and over time. A Bonferroni adjustment was used for post-hoc analysis. The null hypothesis of no difference was rejected when p-values were < 0.05.

RESULTS

The demographic characteristics of the participants are shown in Table 1. No significant differences were observed based on sex, age, height, weight, VAS, and CAIT between the two groups ($p > 0.05$)(Table 1).

As shown in Table 2, there was a significant difference in the VAS scores between the groups and over time ($p < 0.05$), but no significant interaction (group × time) was observed ($p > 0.05$)(Table 2, Figure 2). In addition, there were significant differences in CAIT and AOFAS over time ($p < 0.05$), but no significant main effects of the group and interaction between time and group ($p > 0.05$)(Table 2, Figure 2).

The ankle dorsiflexion ROM and Y-balance composite score revealed a significant main effect of time ($p < 0.05$) and interaction between time and group ($p < 0.05$)(Table 2, Figure 2). However, there were no significant main effects of group ($p > 0.05$)(Table 2). The post-hoc analysis results showed that the experimental group observed a significantly greater change in the ankle dorsiflexion ROM and Y-balance composite score than the control group ($p < 0.05$)(Table 2, Figure 2).

DISCUSSION

This study examined the effects on the pain, ankle instability, ankle function, dorsiflexion ROM, and dynamic balance when ESWT was applied to the lateral collateral ligament in combination with the tibialis anterior. To the best of our knowledge, this is the first study to examine the effectiveness of ESWT, which was applied to the lateral ligament combined with the tibialis anterior in CAI patients. The main findings of this study were as follows: 1) VAS score was decreased significantly after ESWT in both groups, 2) CAIT and AOFAS scores, ankle dorsiflexion ROM, and Y-balance composite score were significantly increased after ESWT in both groups, 3) the changes in ankle dorsiflexion ROM and Y-balance composite score were significantly greater in the experimental group than in the control group. These results indicate that pain, ankle instability, ankle function, dorsiflexion ROM, and dynamic balance can be improved via ESWT in CAI patients. Furthermore, ESWT applied to the lateral collateral ligament combined with tibialis anterior was more effective for ankle dorsiflexion ROM and dynamic balance than ESWT applied to the lateral collateral ligament alone.

In the present study, the dorsiflexion ROM was increased significantly in both groups. These findings are consistent with those from previous studies which showed that ESWT leads to an improvement in the ROM, but the intervention periods and intensity differed between studies.[42] Indeed, previous studies reported that short-term ESWT could increase dorsiflexion ROM in patients with plantar fasciitis[43] and Achilles tendinosis.[42] This improvement was associated with reduced pain from the changes in the metabolism of cells and the penetrability of endothelial tissues[44] and reduced protective muscle tone at the end range positions.[43]

Table 1. The general characteristics

	Experimental Group (n=9)	Control Group (n=9)	p
Sex (M/F)	4/5	5/4	0.637
Age (yr)	19.0±8.0	21.5±10.1	0.561
Height (cm)	161.7±11.7	163.9±8.9	0.656
Weight (kg)	54.11±10.6	55.4±8.0	0.768
VAS (score)	6.11±0.78	6.67±0.50	0.091
CAIT (score)	9.67±1.66	9.44±1.94	0.797

Data are presented as Mean±SD.
VAS: Visual analog scale, CAIT: Cumberland ankle instability tool.

Table 2. Comparison of the dependent variable within/between the groups

	Experimental group	Control Group	Time	Group	Time × Group
VAS (score)					
Pre	6.11±0.78	6.67±0.50	F = 551.54	F = 4.52	F = 0.09
Post	1.77±0.83	2.44±0.73	p = <0.001*	p = 0.049*	p = 0.764
CAIT (score)					
Pre	9.66±1.65	9.44±1.94	F = 123.95	F = 3.238	F = 2.692
Post	21.77±3.52	18.44±3.84	p = <0.001*	p = 0.091	p = 0.12
AOFAS (score)					
Pre	44.22±9.09	49.44±11.39	F = 171.58	F = 0.67	F = 1.302
Post	78.55±6.21	78.55±4.00	p = <0.001*	p = 0.425	p = 0.271
Dorsiflexion ROM (degree)					
Pre	28.33±12.24	30.66±8.66	F = 100.00	F = 0.782	F = 11.93
Post	48.88±7.81	40.00±7.50	p = <0.001*	p = 0.39	p = 0.003*
Y-balance composite score (cm)					
Pre	66.93±11.67	69.28±7.51	F = 291.63	F = 0.056	F = 9.469
Post	90.66±14.99	85.76±11.68	p = <0.001*	p = 0.817	p = 0.007*

Data are presented as Mean±SD.
VAS: Visual analog scale, CAIT: Cumberland ankle instability tool, AOFAS: American orthopedic foot and ankle society, ROM: Range of motion.
*p<0.05.

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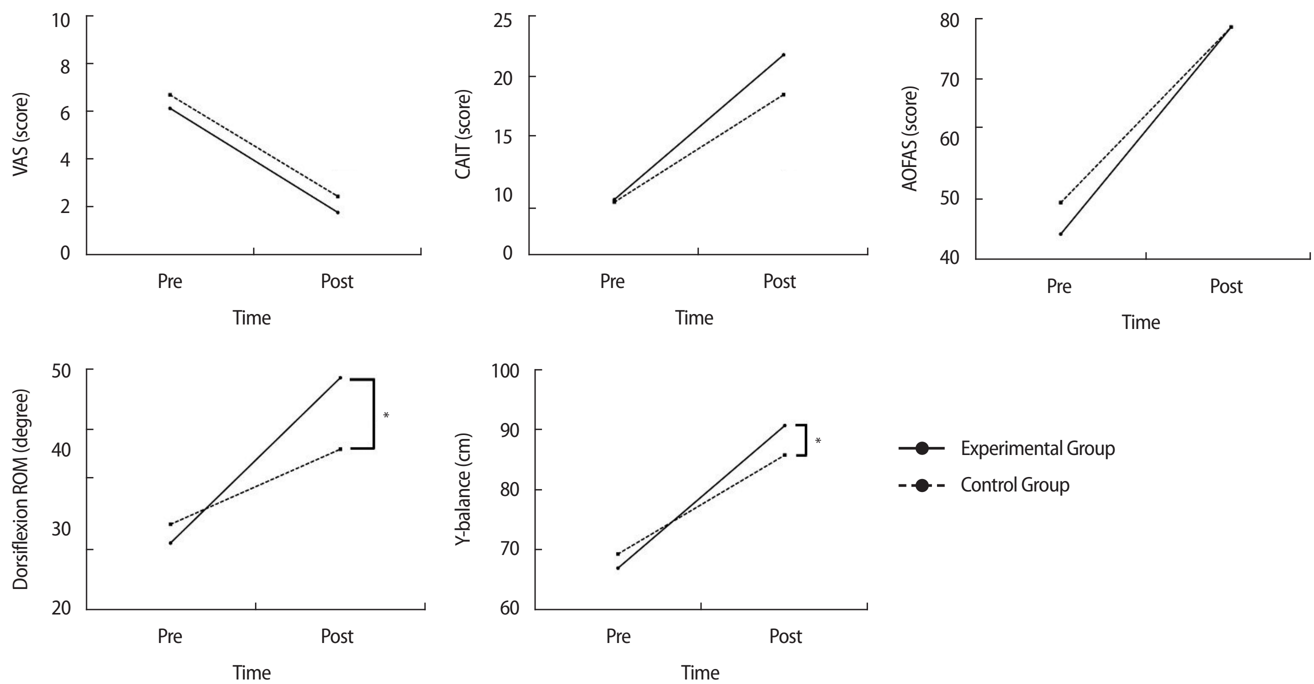

Figure 2. Measurement outcomes. Data are presented as the Mean±SD. CAIT: Cumberland ankle instability tool, AOFAS: American orthopedic foot and ankle society, ROM: range of motion. *Indicates statistical differences as confirmed by Bonferroni post hoc test ($p < 0.05$).

Post-hoc analysis showed that the change in ankle dorsiflexion ROM was significantly greater in the experimental group. ESWT on muscle could reduce the intrinsic stiffness and increase the extensibility of the muscle.[45] In addition, previous studies reported that the elasticity, muscular tone, and muscular recruitment of the muscle were increased after ESWT.[46] Based on these studies, our findings suggest that ESWT could improve the dorsiflexion ROM in CAI patients, and this effect is enhanced when ESWT is delivered in conjunction with the lateral collateral ligament and tibialis anterior.

We also found that the dynamic Y-balance composite score was increased significantly in both groups. This result can be explained via two perspectives. First, it may be associated with improvement of proprioception after ESWT. The CAI is attributed to proprioceptive deficits, manifesting as dynamic postural control impairment.[47] Proprioception is the ability to integrate the sensory inputs to retain balance and to enable dynamic movements.[48] Indeed, previous studies reported that ESWT could improve proprioception.[40] This improvement is associated with the vibration and high-intensity pressure wave of an extracorporeal shock wave stimulating proprioception.[40] Second, this may be associated with increased dorsiflexion ROM after ESWT. Increased dorsiflexion ROM could enhance dynamic balance in healthy adults[28] and in patients with CAI.[29] Thus, ESWT might enhance proprioception and improve dorsiflexion ROM, consequently improving dynamic balance. Post-hoc analysis showed that the change in Y-balance composite score was significantly greater in the experimental group than in the control group. As mentioned above, the dorsiflexion ROM was improved more when ESWT was applied in the lateral collateral ligament complex in combination with the tibialis anterior than lateral collateral ligament complex alone. Previous studies showed that the weight-bearing dorsiflexion ROM had a significant moderate correlation with the dynamic posture stability in healthy adults[28] and patients with CAI.[29] Thus, as the dorsiflexion ROM more increases, the dynamic balance in patients with CAI is further improved. Based on these previous studies, our results indicate that when ESWT is applied to patients with CAI, applying an extracorporeal shock wave to the lateral ankle ligament in conjunction with the tibialis anterior is more effective in improving the dynamic balance by increasing the dorsiflexion ROM more than applying it only to the lateral ankle ligament.

In the present study, both groups showed a decrease in the VAS scores and an increase in the CAIT and AOFAS after ESWT. Recurrent sprains and repeated instability in patients with CAI increase the risk of injury to the lateral collateral ankle ligaments, specifically the anterior talofibular ligament and the calcaneofibular ligament.[49,50] In addition to the lateral collateral ligaments, the soft tissue structures at risk include the peroneal tendons, peroneal retinaculum, and talofibular ligament. Injury of these structures may lead to hypertrophic scar tissue and impingement in the anterolateral gutter, which is primarily responsible for the persistent pain.[51] Previous studies have reported that ESWT leads to an improvement in pain. This may have been due to the repetitive shock waves stimulating neovascularization, improving blood supply to the tissue,[52] and suppressing the nociceptors, thereby alleviating the pain.[53] Pain relief could affect the CAIT and AOFAS scores because the scoring system for these assessments included a pain component. The CAIT is a self-reported questionnaire that assesses pain and instability, and the AOFAS evaluates pain, function, and alignment. The effects of ESWT, which include pain relief, enhancement of proprioception, and increased dynamic postural stability and dorsiflexion ROM, could alleviate the ankle instability and improve the ankle function. Based on these previous studies, our results indicate that ESWT is effective for reducing pain and instability and improving ankle function in patients with CAI. However, no significant interaction between time and group for the VAS, CAIT, and AOFAS. These results suggest that the effect of ESWT on pain, instability, and ankle function in patients with CAI is independent of whether the tibialis anterior muscle is applied or not.

The present study showed that ESWT could improve pain, ankle instability, ankle function, dorsiflexion ROM, and dynamic balance in patients with CAI. Furthermore, the improvement of the dorsiflexion ROM and dynamic postural stability is more effective when ESWT is applied to the lateral collateral ligament complex in conjunction with the tibialis anterior than when applied to the lateral collateral ligament alone. However, there are limitations concerning the concluding remarks. First, our findings cannot be generalized due to the sample size. Second, the duration of the intervention was short, and there was no follow-up. Third, we could not include a placebo group because of ethical concerns. Therefore, further studies should be conducted with an appropriate sample size and intervention period, follow-up, and placebo control group.

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