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Article

Effects of low-level laser therapy and functional exercises in the treatment of chronic ankle sprain: A randomized controlled trial

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Abstract: Objective: Chronic ankle sprains can be described as a failure of the lateral ankle joint complex following an acute or recurrent ankle injury. It is estimated that 80% to 85% of ankle sprains and lateral ankle complex failures can be successfully treated with a functional ankle rehabilitation program. However, most previous functional training has focused on enhancing local ankle function, with less attention paid to the damaged tissue cells and to the systematic consideration of the human lower limb kinetic chain. The more comprehensive approach to combined therapy requires further research. The purpose of this study is to investigate whether low-level laser therapy (LLLT) combined with functional exercise, is more effective than functional exercise alone in treating chronic ankle sprain. At the same time, to observe the dose-response relationship of LLLT in the treatment of chronic ankle sprains. **Methods:** Thirty-three patients with chronic ankle sprains were randomly divided into three groups: exercise alone, low-dose laser plus exercise, and high-dose laser plus exercise, with eleven patients in each group. Two "laser groups" received laser irradiation at an intensity of 398 mW/cm^2 and 796 mW/cm^2 (doses of 119 J/cm^2 and 239 J/cm^2), respectively, which were applied to two acupoints of Ki 3 (Taixi) and Bl 60 (Kunlun), and two pain points of the ankle. The functional exercise program consisted of ankle resistance exercises, resistance kinematic chain exercises, heel raise exercises, and BOSU ball exercises. All patients received five treatments per week for four weeks. At the end of this treatment and at baseline, observing the changes in ankle pain, range of motion (ROM), muscle strength, and balance postural control, and evaluating the curative effects. **Results:** After the 4-week intervention, all groups showed significant improvement in outcomes ($P < 0.05$). The high-dose laser irradiation combined with functional exercise resulted in more significant improvements in the primary outcomes than the other two regimens ($P < 0.05$). However, there were no significant differences ($P > 0.05$) between the low-dose laser irradiation combined with functional exercise and functional exercise alone. **Conclusion:** 1) Systematic functional exercise can significantly reduce the pain of patients with chronic ankle sprains, meanwhile improves the ROM, muscle strength, and balance control of the ankle joint. 2) LLLT enhances the efficacy of functional exercise in the treatment of chronic ankle sprains. 3) The therapeutic effect of LLLT on chronic ankle sprains is related to the irradiation intensity, and the effects of 796 mW/cm^2 irradiation being more effective than 398 mW/cm^2 irradiation.

Keywords: chronic ankle sprain; functional exercise; low-level laser therapy; intensity-effect relationship

1. Introduction

Chronic ankle sprain is commonly caused by an acute ankle sprain. According to the research, it illustrates that 40% to 70% of acute ankle sprains may turn to chronic ankle sprains [1]. Patients with chronic ankle sprain typically experience pain during weight-bearing activities, instability when walking on uneven surfaces, and limited ankle mobility. This not only imposes a significant burden on patients' quality of life and finances, but also increases the risk of developing osteoarthritis in the ankle joint [2]. Currently, conservative treatments are the first line of approach for managing patients with a chronic ankle sprain. These may include manipulation, acupuncture, Chinese herbal fumigation, and physiotherapy, among others [3–5]. If conservative treatments fail or if the ankle ligaments are completely torn, surgical intervention such as ligament reconstruction may be necessary. Unfortunately, single-treatment modalities often result in poor recovery outcomes, low healing rates, and high recurrence rates, and therefore, more comprehensive and systematic treatment options are needed.

Functional exercise, as a widely applicable exercise rehabilitation method, has been widely used for functional recovery after ankle sprains. It typically includes strength training, balance training, and proprioception training [6,7]. Moreover, the effectiveness of functional exercise has been affirmed [8–12]. Its mechanism of action is primarily reflected in the following aspects. First, functional exercises improve the dynamic stability of the joint and reduce the risk of re-injury by strengthening the muscles around the ankle. Second, functional exercises help restore joint proprioception and improve joint position sense and motor control, thereby reducing secondary injuries caused by instability. In addition, by gradually increasing the ROM of the joint, functional exercises help restore flexibility and mobility to the ankle. Finally, functional exercises enhance postural stability and the responsiveness of the ankle joint by improving neuromuscular control, helping patients regain motor function in daily activities. However, recent studies have found that patients with chronic ankle sprains not only have weak ankle joint muscles, proprioception loss, and neuromuscular control changes, but also have delayed peroneal reaction time during exercise and changes in lower limb kinematics during exercise [13,14]. Previous studies on the treatment of chronic ankle sprains have mostly focused on improving local ankle joint function, but lack of attention to the lower limb kinetic chain. Therefore, a whole-comprehensive functional exercise approach needs to be further studied.

On the other hand, LLLT has been widely used as a rehabilitation method for ankle sprain recovery because of its significant role in promoting tissue inflammation resolution, tissue cell regeneration, and accelerating blood circulation, etc. [15–17]. Research has reported that LLLT promotes an increase in ATP levels [18]. The improvement of ATP reserves in the body contributes to muscle strength growth. If laser irradiation is targeted at the mitochondria, it can enhance the production of cyclic adenosine monophosphate and deoxyribonucleic acid, stimulate the release of growth factors within the cells, and promote the repair of ankle injury tissues, providing a physiological foundation for functional exercise. Additionally, LLLT has the potential to suppress inflammatory responses, reduce neuronal degeneration, induce glial cell proliferation, enhance neuronal metabolism, and improve the ability to generate myelin [19,20]. These effects increase neural signal sensitivity and transmission efficiency, which are critical for practicing BOSU ball exercises in functional training programs. In previous ankle sprain studies, LLLT has shown significant efficacy and a certain dose-response related-relationship [21–23]. However, the dose-response relationship of LLLT in chronic ankle sprain treatment has not been published, and the therapeutic effect, intensity, and dosage required for chronic ankle sprain patients still need to be further investigated.

Therefore, the intention of this study is to use LLLT combined with functional exercise to treat patients with chronic ankle sprains. 1) To explore more reasonable rehabilitation exercises for chronic ankle sprain; 2) To observe whether low laser irradiation can improve the therapeutic effect of functional exercise on chronic ankle sprain; 3) To understand the different effects of different intensities of low-level laser that combined with functional exercise in the treatment of chronic ankle sprain. Additionally, to observe the relationship between the intensity of LLLT and efficacy when combined with functional exercise in the treatment of chronic ankle sprain.

This paper is structured as follows: Section 1 provides a detailed overview of the background, current status, and objectives of the study. Section 2 describes the experimental design in detail. Section 3 presents the experimental results, reported impartially. Section 4 offers an objective analysis of these results, comparing and summarizing them with existing literature. Finally, section 5 presents the conclusions.

2. Materials and methods

The study protocol was approved by the Ethics Committee of the Faculty of South China Normal University (SCNU-SPT-2021-104), Guangzhou, China. Written informed consent was obtained from each participant prior to the start of treatment.

2.1. Participants

Thirty-three patients with chronic ankle sprains aged 18–28 years were enrolled in this study. All patients were undergraduate students studying at the School of South China Normal University (**Table 1**). The study was conducted at the Laboratory of Laser Sports Medicine of South China Normal University in Guangzhou in April and May 2021. Inclusion criteria: (1) a self-reported history of at least one substantial ankle sprain with associated inflammatory symptoms; (2) pain caused by the sprains lasting for more than a month; (3) patients with inversion ankle sprain; and (4) no history of other lower-extremity injuries or neuromuscular deficits. Exclusion criteria: (1) fracture or dislocation of the ankle joint; (2) mechanical instability of the ankle joint; (3) other lower limb disorders that may affect training (**Figure 1**).

Table 1. General characteristics of the subjects ($N = 33$).

	E group (n = 11)	**LE1 group (n = 11)**	**LE2 group (n = 11)**
Age	22.10 ± 1.84	21.10 ± 1.87	20.90 ± 1.51
Sex (M/F)	8/3	8/3	8/3
Affected limb (L/R)	5/6	4/7	5/6
Duration of ankle pain (months)	6.45 ± 4.52	6.00 ± 3.82	4.73 ± 2.90
VAS score	51.36 ± 15.18	49.09 ± 14.97	51.82 ± 12.70

M: male; F: female; L: left; R: right; VAS: visual analogue scale.

2.2. Experiment groups

The grouping methodology experimented in our experiment was stratified random grouping. Male subjects were randomly divided into eight subgroups based on their visual analogue scale (VAS) scores, each subgroup consisting of three individuals. Subsequently, one subject was randomly selected from each subgroup to be assigned to the experimental groups, including the exercise group (E group), the low-dose laser + exercise group (LE1 group), and the high-dose laser + exercise group (LE2 group). The same grouping procedure was repeated for female subjects. So that each experimental group contains 11 individuals (8 males subjects and 3 females subjects). During the grouping process, all patient numbers were replaced with the initials of the patients' names, and no information was exchanged between the staff member who measured the experimental indicator and the staff member who grouped the patients.

The E group received functional exercise therapy alone. The LE1 and LE2 groups were treated with laser irradiation at dose of 119 J/cm^2 and 239 J/cm^2, respectively, along with functional exercises. The trial implemented a single-blinded design, in which all participants were unaware of their group allocation and the intensity of the treatment they received. The functional training program concealed the load and duration of the exercises, while LLLT obscured the numerical values displayed on the treatment device screen (**Figure 1**).

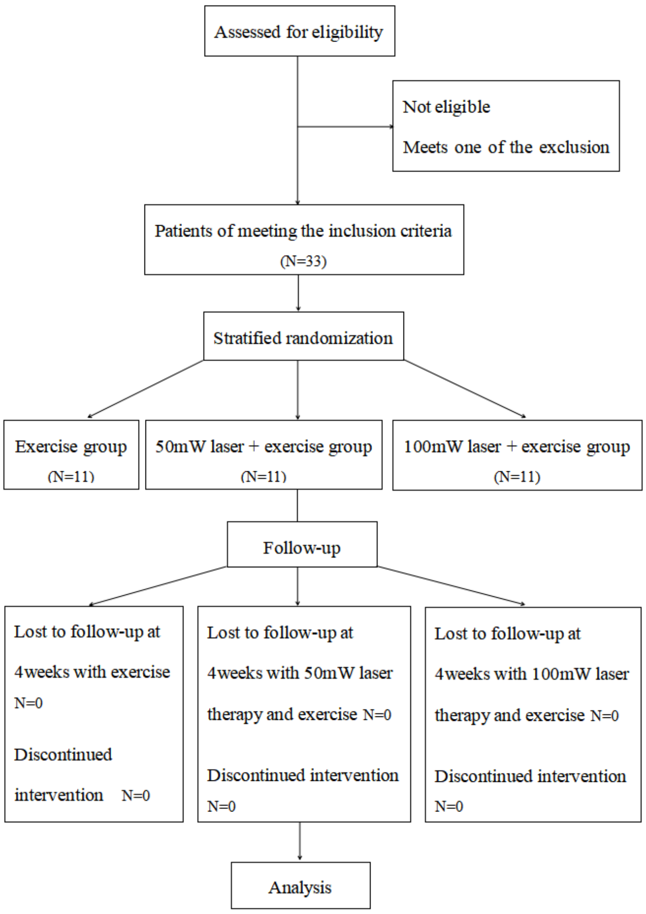

Figure 1. Flow chart of trial participants. Treatment was given during weeks 1–4; outcomes were assessed pre- and post-treatment.

2.3. Functional exercise program

Each subject completed four dynamic tasks, including ankle resistance exercises, resistance kinematic chain exercises, heel raise exercises, and BOSU ball exercises. The ankle resistance exercises were used to develop the strength of the muscles around the ankle joint [24]. The resistance kinematic chain exercises were used to develop the strength of the femoral adductor muscle group and to enhance the strength of the ankle eversion muscles by using the closed kinematic chain of the lower extremity. The heel raise exercises were used to develop the strength of the triceps surae muscle group [8]. The BOSU ball exercises were used to improve the neuromuscular function of the ankle joint, to increase the sensitivity of the proprioceptors and to enhance postural balance control [9]. The program was progressive, with the intensity of the exercises increasing gradually, and some modifications being added every week, as detailed in **Table 2**. Functional training should be performed once daily, for a duration of approximately 30 minutes each time. It should be done 5 times per week, continuously for 4 weeks.

Table 2. Description of the functional exercise program.

Exercise	Description	Sets × Repetitions
Resistance-Band Protocols	Week 1: Exercises were performed in 4 directions (dorsiflexion, plantar flexion, inversion, and eversion) with tan resistance band.	3 × 12
	Week 2: Exercises with red resistance band.	3 × 12
	Week 3: Exercises with blue resistance band.	3 × 12
	Week 4: Exercises with silver resistance band.	3 × 12
Resistance Kinematic Chain Exercises	Week 1: Squatting with hip adduction exercises against yellow resistance band.	3 × 12
	Week 2: Exercises with green resistance band.	3 × 12
	Week 3: Exercises with black resistance band.	3 × 12
	Week 4: Exercises with gold resistance band.	3 × 12
Heel raise	Week 1: Standing on the toes, change from the toe forward to the inward and outward, then return to the initial position, and finally, the heels land, and practice in a cycle at medium speed.	3 × 40 s
	Week 2: Heel raise on the injured ankle.	3 × 40 s
	Week 3: Heel raise on the injured ankle.	3 × 1 min
	Week 4: Heel raise on the injured ankle with weight-bearing (5-kg).	3 × 1 min
Balance-Exercise Protocol	Week 1: Maintain proper balance in a single limb stance on the BOSU.	3 × 30 s
	Week 2: Standing position in a single limb stance combined with foam roller swing like rowing.	3 × 30 s
	Week 3: Standing position in a single limb stance combined with badminton racket smashing.	3 × 30 s
	Week 4: Standing position in a single limb stance combined with ball throwing and catching.	3 × 15

2.3.1. Resistance band protocols

During this exercise, the subject assumes a seated position on a foam cushion with the injured leg fully extended. One end of the Thera-Band is secured while the other end is applied to the metatarsal region. The subject then performs dorsiflexion, plantarflexion, inversion, and eversion movements against the resistance of the elastic band while maintaining consistent tension throughout each repetition (**Table 2**).

2.3.2. Resistance kinematic chain exercises

In the initial position, the subjects stood barefoot, with feet shoulder-width apart and hands on their waist. The elastic band was fixed 2.5 cm above the knee joints and pulled out with medium tension on both sides (**Figure 2**). Then, the subjects performed a squat with hip adduction to 90° knee flexion and returned to the initial position. Each week, the subjects progressed by changing the color of the band resistance (**Table 2**).

(a)

(b)

Figure 2. Resistance kinematic chain exercises: Squatting with hip adduction (knee valgus, ankle eversion) exercises against resistance bands. **(a)** Start; **(b)** end.

2.3.3. Heel raise exercise

In the first week of the exercise, the subjects were instructed to maintain a standing position on their tiptoes. During the exercise, they slowly transitioned from a forward-facing position to a position where their toes pointed inward or outward in a gradual manner before returning their toes to the forward-facing position. Finally, they slowly lowered their heels to the ground until touch it and then raised their heels back to the starting position. In the second, third, and fourth weeks, the subjects engaged in a single-leg heel raise exercise by gradually increasing the level of difficulty each week (**Table 2**).

2.3.4. Balance exercise protocol

The balance training program used in this survey is a modified version of the procedure originally described by McKeon et al. [11]. Subjects performed the exercises on the BOSU ball and were asked to maintain balance on the affected leg. A brief description of each exercise, the required number of repetitions per training session, and the progression of the difficulty levels are listed in **Table 2**.

2.4. Laser irradiation procedure

A Ga-Al-As laser (Model LD-1, Guangzhou, China) with an 810 nm wavelength, 0–500 mW adjustable and continuous power output, and a 0.4 cm beam diameter was used. The subjects in the LE1 group and the LE2 group were treated with the laser at doses of 119 and 239 J/cm^2 (power: 50 and 100 mW; intensity: 398 and 796 mW/cm^2; irradiation time: 5 min/point, 20 min in total), respectively, five times per week for four weeks. The following points on the injured ankle were irradiated: Ki 3 (Taixi), Bl 60 (Kunlun), and two pain points of the ankle. The acupuncture points and the pain points of the subjects were identified via palpation and marked prior to administration of the laser treatment. Laser irradiation was applied directly to the skin of the points with a perpendicular beam at the end of the exercise program (**Figure 3**). Those in the E group did not receive laser irradiation.

Figure 3. Masking of laser power during treatment.

2.5. Outcome measures

Perceived pain, ROM, muscle strength, and postural control were observed at baseline and at the end of treatment, and the curative effects were evaluated after treatment.

2.5.1. Perceived pain

Perceived ankle pain was measured using the VAS. Subjects made a mark on the 100-mm line to rate their overall perceived ankle pain at that moment. The VAS has been shown to produce reliable and valid estimates of pain intensity [12].

2.5.2. ROM

Measurements of the sprained ankle were taken with a goniometer. The subject lies on the examination table with the ankle joint in a neutral position. To test ankle dorsiflexion and plantarflexion ROM, the axis of the goniometer is placed approximately 2.5 cm below the midpoint of the lateral malleolus, with the fixed arm parallel to the fibular axis and the moving arm parallel to the fifth metatarsal. To test ankle inversion ROM, the axis of the goniometer is placed on the lateral aspect of the calcaneus, with the fixed arm parallel to the tibial axis and the moving arm parallel to the plantar surface of the heel. To test ankle eversion ROM, the axis of the goniometer is placed at the midpoint of the medial aspect of the tarsometatarsal joint, with the fixed arm parallel to the tibial axis and the moving arm parallel to the plantar surface of the foot. During testing, the subject is instructed to actively move their ankle without experiencing pain. The measurement values are recorded in degrees, and the testing is repeated three times. The maximum value is taken as the subject's ankle joint mobility [25].

2.5.3. Muscle strength

The maximum isometric muscle strength of the ankle's dorsiflexion, plantarflexion, inversion, and eversion movements was assessed using the Micro FET3 muscle strength tester. The subtalar joint was maintained in a neutral position during the test, while the lower leg was secured to the testing bed using straps to prevent additional movements. The dynamometer was positioned on different areas of the metatarsals depending on the ankle joint movement. During the test, the subject applied gradual force against a fixed position, while keeping the ankle stationary against the dynamometer at all times. The subject maintained maximum force against the dynamometer for a period of 3 seconds. The test was repeated three times with a 10-second break between each repetition, and the maximum isometric strength was recorded from the three tests. The dynamometer was positioned just distal to the base of the fifth metatarsal head for eversion, just proximal to the first metatarsal head for inversion, on the plantar aspect of the metatarsal heads for plantar flexion, and on the dorsum of the foot just proximal to the metatarsal heads for dorsiflexion [26].

2.5.4. Postural control

The Star Excursion Balance Test (SEBT), as previously described, was performed with the subjects standing barefoot in the middle of a grid formed by eight tape measures extending out at 45° from each other [27]. The stance foot was centered on the grid, aligned with the anterior and posterior directions. Verbal instructions were given to each subject before the test. Subjects were asked to maintain a single stance on the injured ankle while reaching with the contralateral leg to touch lightly as far as possible along the selected direction, and then return to a bilateral stance. A standardized protocol of 3 practice trials followed by 3 test trials was performed in each of the eight directions [15]. Reach distances were measured by the same researcher by making a mark on the tape measure. The maximum values of the three test trials normalized for the length of the stance leg was used for analysis. The subjects' legs were measured with the subject lying supine from the anterior superior iliac spine to the distal tip of the medial malleolus using a standard tape measure [16]. The SEBT composite score was calculated by dividing the sum of the 8 reach distances by 8 times the limb length of the individual, and then multiplying by 100.

2.5.5. Curative effect

The criteria of a curative effect were defined as follows: ① Markedly effective: the pain in the ankle joint disappeared, and the joint function returned to normal; ② Effective: the pain in the ankle joint was alleviated, and the joint function remained limited; ③ Ineffective: there was no alleviation in pain or recovery of function in the ankle joint. The clinical cured rate was defined as follows: Clinical cured rate = (Cases of clinical cured/Total number of cases) × 100%.

2.6. Statistical analysis

Data are expressed as the mean ± standard deviation. Paired t-tests were used to analyze differences between before and after treatment in each group. Differences between group were analyzed using one-way ANOVA. Clinical cured rates after treatment were analyzed using the chi-squared test. The statistical level of significance was set at $P < 0.05$. SPSS 20.0 statistical software was used for the statistical analysis.

3. Results

3.1. Pain outcomes

There were no significant differences in the VAS score at baseline between the groups (**Table 3**). After four weeks of the intervention, all of the groups exhibited significant pain reductions ($P < 0.01$). The mean VAS scores in the E group, the LE1 group, and the LE2 group were reduced by 30, 33.64, and 51.82 points (percent reductions: 58.4%, 68.5%, and 100%), respectively.

The proportion of patients who became pain-free was 1/11 (9%) in the E group, 1/11 (9%) in the LE1 group, and 11/11 (100%) in the LE2 group after four weeks. The decrease in the VAS score in the LE2 group was significantly greater than that in the other two groups ($P < 0.01$). There was no significant difference in the VAS score after treatment between the E and LE1 groups, as shown in **Table 3**.

Table 3. Descriptive statistics of means and standard deviations for all dependent variables.

Outcome	E group			LE1 group			LE2 group		
	Pre	**Post**	**Change**	**Pre**	**Post**	**Change**	**Pre**	**Post**	**Change**
VAS (′)	51.36 ± 15.18	21.36 ± 12.47*	30.00 ± 13.78	49.09 ± 14.97	15.45 ± 12.74*	33.64 ± 16.90	51.82 ± 12.70	0.00 ± 0.00*	51.82 ± 12.70$^{\bigstar\blacktriangle}$
ROM (°)									
DF	9.82 ± 4.36	15.73 ± 3.41*	5.91 ± 3.30$^{\bigstar}$	9.91 ± 4.21	19.55 ± 4.30*	9.64 ± 2.46$^{\blacktriangle}$	11.36 ± 4.13	27.27 ± 4.76*	15.91 ± 2.47$^{\bigstar\blacktriangle}$
PF	36.52 ± 7.93	38.73 ± 8.46*	2.36 ± 1.91	35.91 ± 7.50	38.09 ± 6.19$^{\#}$	2.18 ± 2.52	37.27 ± 8.36	41.09 ± 6.19*	3.82 ± 3.13
IV	22.64 ± 8.37	32.18 ± 7.63*	9.55 ± 2.88	21.64 ± 7.22	32.64 ± 8.19*	11.00 ± 3.61	25.73 ± 6.78	41.09 ± 5.77*	15.36 ± 4.97$^{\star\blacktriangle}$
EV	13.09 ± 3.15	18.55 ± 4.50*	5.45 ± 3.17	11.36 ± 2.91	19.27 ± 3.29*	7.91 ± 2.39	14.45 ± 4.63	28.18 ± 4.58*	13.73 ± 3.74$^{\bigstar\blacktriangle}$
MS (N)									
DF	21.92 ± 5.32	28.56 ± 5.13*	6.64 ± 2.83	21.30 ± 5.39	30.07 ± 5.89*	8.77 ± 3.96	21.63 ± 5.31	36.28 ± 6.12*	14.66 ± 4.08$^{\bigstar\blacktriangle}$
PF	47.31 ± 10.78	56.39 ± 10.28*	9.08 ± 5.53	48.89 ± 9.73	63.20 ± 10.80*	14.31 ± 9.82	42.81 ± 13.73	68.03 ± 14.59*	25.22 ± 9.80$^{\bigstar\blacktriangle}$
IV	18.78 ± 3.40	26.66 ± 3.72*	7.87 ± 2.66	20.92 ± 5.16	27.76 ± 5.38*	6.85 ± 2.41	18.31 ± 4.62	34.01 ± 5.20*	15.70 ± 2.39$^{\bigstar\blacktriangle}$
EV	18.52 ± 3.70	25.09 ± 4.19*	6.57 ± 3.17	19.02 ± 4.89	26.26 ± 5.11*	7.25 ± 2.47	15.87 ± 4.07	33.06 ± 4.79*	17.18 ± 4.01$^{\bigstar\blacktriangle}$

Table 3. (*Continued*).

Outcome	E group			LE1 group			LE2 group		
	Pre	Post	Change	Pre	Post	Change	Pre	Post	Change
SEBT (′)									
ANT	77.80 ± 3.01	83.74 ± 2.52*	5.94 ± 3.21	76.87 ± 4.53	84.63 ± 5.62*	7.76 ± 2.46	75.60 ± 5.52	92.78 ± 7.45*	17.18 ± 4.85★▲
AMED	67.29 ± 5.78	74.59 ± 4.69*	7.30 ± 5.99	65.04 ± 8.25	74.09 ± 4.78*	9.05 ± 4.44	70.07 ± 8.48	86.25 ± 7.58*	16.18 ± 7.49☆▲
LAT	53.41 ± 8.09	58.27 ± 6.72*	4.86 ± 2.38	56.07 ± 7.51	61.22 ± 7.23*	5.15 ± 1.80	59.84 ± 8.24	68.75 ± 9.06*	8.90 ± 4.55
PMED	80.32 ± 9.45	88.90 ± 7.39*	8.57 ± 4.19	77.23 ± 9.85	90.56 ± 5.27*	13.33 ± 5.40	84.34 ± 11.65	102.72 ± 10.85*	18.38 ± 6.72☆▲
POST	93.96 ± 8.31	102.69 ± 6.70*	8.73 ± 4.75☆	87.64 ± 6.81	100.70 ± 5.33*	13.06 ± 4.07△	93.43 ± 10.37	115.32 ± 8.41*	21.89 ± 5.25★▲
PLAT	92.22 ± 8.31	102.50 ± 9.81*	10.28 ± 5.35	88.50 ± 5.98	101.67 ± 4.96*	13.17 ± 5.18	89.73 ± 13.46	114.62 ± 8.78*	24.89 ± 10.28★▲
MED	84.02 ± 5.05	94.83 ± 6.36*	10.81 ± 3.59	82.85 ± 4.75	95.25 ± 5.66*	12.40 ± 3.67	82.78 ± 12.00	105.34 ± 8.58*	22.56 ± 13.06△
ALAT	82.44 ± 4.27	89.38 ± 4.14*	6.94 ± 3.33	81.08 ± 3.56	89.66 ± 5.00*	8.58 ± 3.70	78.21 ± 7.49	100.07 ± 7.74*	21.86 ± 7.45★▲
CS	78.93 ± 4.20	86.86 ± 3.48*	7.93 ± 2.58	76.91 ± 4.49	87.22 ± 3.80*	10.31 ± 2.31	79.06 ± 5.05	98.23 ± 5.79*	19.17 ± 4.08★▲

VAS: visual analogue scale; ROM: range of motion; MS: muscle strength; SEBT: the star excursion balance test. DF: dorsiflexion; PF: plantar flexion; IV: inversion; EV: eversion; ANT: anterior; AMED: anteromedial; LAT: lateral; PMED: posteromedial; POST: posterior; PLAT: posterolateral; MED: medial; ALAT: anterolateral; CS: composite score. Crosses indicate significant differences from pretreatment (# $p < 0.05$; * $p < 0.01$). Triangles indicate significant differences from the T group (△ $p < 0.05$; ▲ $p < 0.01$). Asterisks indicate significant differences from the LT1 group (☆ $p < 0.05$; ★ $p < 0.01$).

3.2. ROM outcomes

At baseline, no significant ($P > 0.05$) differences were found among the three groups in any study outcome (**Table 3**). After four weeks of the intervention, there was a significant difference ($P < 0.05$) between the pretest and posttest scores for ankle ROM (dorsiflexion, plantar flexion, inversion, eversion) in the three groups, with greater posttest scores. In all cases, the effect size comparing posttest to pretest was the largest in the LE2 group.

The LE2 group showed a significantly greater improvement in dorsiflexion, inversion, and eversion than the other two groups ($P < 0.05$), but there was no significant difference in plantar flexion after treatment between the LE2 group and the other two groups. There was a significant difference in dorsiflexion alone ($P < 0.01$) between the LE1 and E groups, as shown in **Table 3**.

3.3. Strength outcomes

At baseline, there were no significant differences in ankle strength (dorsiflexion, plantar flexion, inversion, eversion) among the groups (**Table 3**). After four weeks of the intervention, the mean ankle strength in all directions exhibited significant improvements in all three groups ($P < 0.01$).

The LE2 group showed a significantly greater improvement in all directions than the other two groups ($P < 0.01$), but there were no significant differences ($P > 0.05$) between the LE1 and E groups, as shown in **Table 3**.

3.4. Functional outcomes

Compared with the previous experiment, the SEBT scores in all directions of the 3 groups were significantly better than before the experiment ($P < 0.01$).

Compared with groups E and LE1, the effect size of group LE2 was better in the anterior, anterolateral, posterolateral, posterior, posteromedial, and anteromedial directions ($P < 0.05$). The effect size of LE1 group was moderate in all directions, and the posterior effect size of LE1 group was better than that of E group ($P < 0.05$). However, there was no significant difference in the effect size in the lateral direction among the three groups ($P > 0.05$), as shown in **Table 3**.

3.5. Curative effect

After four weeks of the intervention, the clinical cured rate in the E, LE1, and LE2 groups was 9%, 9%, and 81%, respectively. The curative rate was significantly greater in the LE2 group than in the other two groups ($P < 0.01$). There was no significant difference in the curative rate after the treatment between the E and LE1 groups ($P > 0.05$), as shown in **Table 4**.

Table 4. Comparison of curative effects among the three groups after treatment.

Group	No. of cases	Invalid	Effective	Cured	Cured rate
E group	11	0	10	1	9%
LE1 group	11	0	10	1	9%
LE2 group	11	0	2	9	81%
X^2					17.455
P-value					0.002

4. Discussion

Based on the study of the mechanism of chronic ankle sprain, a targeted exercise plan has been designed to strictly implement and monitor rehabilitation exercises during training, enabling patients to recover their restricted function. It has been proven that chronic ankle sprain patients have several problems such as weakened ankle joint muscle strength, decreased body coordination, and reduced proprioception. Based on the pathological mechanisms of ankle joint functional decline, scholars have designed specific training methods for muscle strength, proprioception, balance, and other training, which have achieved excellent results [9,28,29]. However, recent studies on the pathological mechanisms of chronic ankle sprain have found that chronic ankle sprain patients not only have pathological changes such as foot muscle strength decline and reduced proprioception, but also have weakened overall lower limb muscle activity, abnormal hip and knee joint ROM, and insufficient neural control of muscle groups. The above studies indicate that chronic ankle sprain not only affects local activity of the ankle joint but also affects the overall function of the lower limb. Currently, if rehabilitation research on chronic ankle sprain still focuses mainly on local rehabilitation exercises of the ankle joint and neglects the functional changes in the overall lower limb movement chain, it will not be conducive to the recovery of chronic ankle sprain patients. The functional exercise plan used in this study consists of ankle joint resistance training, lower limb movement chain training, heel raise exercise, and standing on a Bosu ball exercise. Unlike previous rehabilitation exercises that only focused on single exercises such as strength, balance, or posture, this plan emphasizes comprehensive limb functional training to promote dynamic functional recovery of the limbs.

Resistance training using elastic bands could increase the strength of the anterior and posterior muscles of the tibia and the calf muscles through dorsiflexion and plantar flexion exercises. In addition, inversion and eversion exercises can enhance the strength of the peroneus longus, tibialis anterior muscles, and stretch the medial and lateral ligaments of the ankle joint. Specifically, the primary source of ankle strength is the calf muscles and the flexor and extensor muscle groups of the foot. Therefore, calf raises can improve the strength of the posterior muscles of the lower leg, and enhancing the control of the lower limb muscles over the ankle joint. Furthermore, using a Bosu ball to improve the neuromuscular control of the ankle joint in dynamic movement patterns, increase the coordination and cooperation among ankle muscle groups, and to enhance proprioceptive sensitivity and dynamic balance. Currently, most rehabilitation exercises for ankle sprain patients focus on muscle strength or proprioception training for the ankle joint. However, if exercises only target specific joint functions, it may lead to imbalanced development of the limbs and have adverse effects on future sports or daily activities, making it difficult to prevent injury recurrence. Research indicates that the recurrence rate of ankle sprains can be as high as 70% [30]. Therefore, reducing the risk of recurrent ankle sprains is crucial for patients. Lower limb kinetic chain exercises can enhance the strength of hip adductor muscles and ankle inversion muscle groups during dynamic training, improve the efficiency of lower limb muscle force transmission, increase the muscle strength and coordination of joints such as the hip and knee, improve ankle stability, and prevent excessive inversion movement of the ankle joint, thereby reducing the incidence of ankle inversion sprains.

Ankle joint stability is maintained by the complex interplay between static and dynamic mechanisms. The ligaments provide static ankle joint stability, while dynamic ankle joint stability is coordinated by muscle groups. Most ankle sprains are lateral ligament sprains caused by inversion combined with plantar flexion movements. The functional instability of the ankle joint caused by relaxation of the ligaments, weakening of the peroneal muscles, and damage to the proprioceptors can be restored by functional exercises [31]. Hall et al. [10,26] reported the effects of strength training on chronic ankle injury patients' strength, dynamic balance, functional performance, and perceptual stability through multiple experiments. After six weeks of the intervention, the results showed significant improvements in strength, VAS scores, balance error scoring system, star balance test results, and functional performance in the strength exercise and balance exercise groups. In addition, studies have shown that balance exercises can significantly improve static and dynamic postural function in patients with chronic ankle sprains. Schaefer et al. [25] treated chronic ankle injury with dynamic balance exercises. After a 4-week exercise program, all patients in the exercise group showed improvements in dynamic postural, ROM, and pain. Other related studies have also shown that a 4-week balance exercise program can improve static and dynamic postural function in patients with chronic ankle injury [11,32]. In this study, chronic ankle sprains were treated with a comprehensive functional exercise program that included strength exercises, proprioceptive exercises, and balance exercises. After 4-weeks of the intervention, the VAS score in the E group decreased by an average of 30 points, and the comprehensive balance ability of the lower limbs improved by 7.93 points. Meanwhile, the balance ability, ankle ROM, and muscle strength were also improved. However, patients still felt pain during exercise. There were significant limitations in force generation and deficits in their sports performance. Therefore, the question of the inadequacy of functional exercise alone in the treatment of chronic ankle sprains arises when evaluating the efficacy of treatment.

Suppressing swelling and edema is an important issue in the healing of wounds and associated fractures. Asagai et al. [33] found that when LLLT was applied to these areas, the skin temperature fell in the high-temperature zone but rose in the low-temperature zone to approximately normal temperature in both zones, suggesting improvement in the circulation of blood and lymph. Clinically, the reduction in local swelling and edema was considered to have led to an improvement in blood and lymph flow. Additionally, relieving pain caused by the inflammatory response is another essential problem in treating soft tissue injuries. Izukura et al. [22] selected 17 patients with chronic foot and ankle pain as complaints. The patients underwent Ga-Al-As semiconductor laser irradiation at a wavelength of 830 nm, power density of 667 mW/cm^2, and energy density of 20 J/cm^2. Patients were irradiated at four points on each foot twice a week for four weeks. The results showed that LLLT significantly improved chronic ankle pain after treatment ($P < 0.01$). The authors believe that improvements in the pain threshold and blood flow and ankle joint cartilage regeneration were the main contributing factors. Similarly, after four weeks of intervention, all of the groups in this study exhibited significant pain reductions ($P < 0.01$). The mean VAS score in the E group, LE1 group, and LE2 group was reduced by 30, 33.64, and 51.82 points (percent reduction: 58.4%, 68.5%, and 100%), respectively. The LE2 group showed a significantly greater improvement in pain than the other two groups ($P < 0.05$). This may be related to the fact that a LLLT can reduce inflammation and promote the synthesis of collagen fibers and soluble collagen. Dong et al. [34] administered electroacupuncture at the St 36 (Zusanli) and Bl 60 (Kunlun) acupoints in rats with adjuvant arthritis and found that electroacupuncture could reduce the expression of TLR4, MYD88, and NF-kB, which play important roles in adjuvant arthritis. In this study, the Ki 3 (Taixi) and Bl 60 (Kunlun) were selected as irradiation points in the LE1 and LE2 groups. Compared with the E group, the LE2 group showed more significant pain reduction ($P < 0.01$), indicating a better therapeutic effect. Our results show that LLL irradiation of the Bl 60 (Kunlun) and Ki 3 (Taixi) acupoints may achieve the same therapeutic effect as needle acupuncture, but the underlying mechanism is still unclear.

The irradiation dose is a key factor in whether laser therapy causes an inhibitory or excitatory effect. The size of the dose varies depending on the structure and function of different tissues and the wavelength of the laser. We observed a dose-response relationship in LLLT for chronic ankle sprains in this study. Based on data from several trials of Ga-Al-As laser therapy, we adopted doses of 119 and 239 J/cm^2 to conduct LLLT research [22,33,35]. Irradiations at 239 J/cm^2 significantly reduced all of the performance measures which compared with exercise alone, whereas irradiation at 119 J/cm^2 did not significantly reduce any of the performance measures. However, there were no significant differences in any of the performance measures between the LE1 and LE2 groups. Among the three doses, the higher dose of 239 J/cm^2 appeared to be the most efficient. Low-dose laser irradiation has a cumulative effect, meaning that the biological effects caused by a high dose of laser irradiation are roughly the same as the total dose of multiple low doses of laser irradiation [36]. The results in this study show that patients treated with 50 mW (119 J/cm^2) gained some beneficial effects in terms of the VAS score, joint ROM, muscle strength, and balance ability which in the middle and late stages of clinical treatment. However, whether these effects are due to the cumulative effect of the laser or due to the patient's healing is unclear. This issue needs further investigation.

5. Conclusion

1) Systematic functional exercise could significantly reduce the pain of patients with chronic ankle sprains and improve the ROM, muscle strength, and balance control of the ankle joint.

2) LLLT increases the efficacy of functional exercise in the treatment of chronic ankle sprains.

3) The therapeutic effect of LLLT on chronic ankle sprains is related to the irradiation intensity; and the therapeutic effect of 796 mW/cm^2 irradiation was better than that of 398 mW/cm^2 irradiation.

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Ethical approval: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of the Faculty of South China Normal University (SCNU-SPT-2021-104). Informed consent was obtained from all subjects involved in the study.

Data availability: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interest: The authors declare no conflict of interest.

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