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Original Article

Clinical investigation of extracorporeal shock wave therapy combined with kinesitherapy on the treatment of delayed union of tibia and fibula fractures

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Abstract: Objective: To investigate the therapeutic efficacy of extracorporeal shock wave therapy (ESWT) combined with kinesitherapy (KT) for the treatment of delayed union of tibia and fibula fractures. Methods: A total of 68 patients with delayed healing of tibiofibular fractures were enrolled. These patients were divided into three groups: control, ESWT, and ESWT+KT. All patients underwent standard surgical treatment following the fracture. Patients in the ESWT group received shockwave therapy twice a week for 4 months, while those in the ESWT+KT group received additional exercise therapy twice a week over the same duration. The control group did not receive any specific intervention during this period. The pain levels of patients in all three groups were assessed using the Numerical Rating Scale (NRS) before and after treatment. Bone repair and callus formation were evaluated using the Lane-Sandhu and Fernandez-Esteve X-ray grading scales before and after treatment. Additionally, walking ability was assessed using the Functional Ambulation Classification (FAC), Hoffer walking ability grade, and Holden walking ability grade before and after treatment. Results: No significant differences were observed in patient baseline characteristics across the three groups ($P > 0.05$), indicating comparability among groups. Post-treatment, improvements were noted in the NRS, Lane-Sandhu X-ray scale, Fernandez-Esteve X-ray scale, FAC level, Hoffer grade, and Holden grade in all three groups compared to their respective pre-treatment values ($P < 0.05$). Notably, the Lane-Sandhu X-ray scale, FAC level, Hoffer grade, and Holden grade showed significant improvements in the ESWT+KT group after treatment compared to the control group ($P < 0.05$). Additionally, the ESWT group demonstrated significant improvements in FAC level and Holden grade compared to the control group after treatment ($P < 0.05$). Conclusion: ESWT can enhance the walking function in patients with delayed union of tibia and fibula fractures. ESWT combined with KT demonstrates superior efficacy compared to monotherapy, as it not only improves walking function but also promotes bone healing.

Keywords: Delayed healing, fractures, extracorporeal shock wave therapy, kinesitherapy

Introduction

Delayed healing of fractures poses a significant public health challenge globally. Rehabilitation following fractures imposes a substantial clinical burden, leading to reduced mobility and compromised musculoskeletal function. This condition is recognized as a complex musculoskeletal rehabilitation issue. Delayed fracture healing is prevalent in clinical practice, particularly in long bone fractures such as those of the tibia and fibula [1, 2]. Delayed healing of tibiofibular fracture is defined as the absence of significant healing signs at the fracture site three months after fracture. Radiological examinations, such as X-rays, reveal the lack of sclerosis and occlusion of the medullary cavity at the fracture ends, as well as minimal resorption and gaps. The formation of a continuous peripheral bone callus is also not observed. In such cases, natural healing may be difficult, necessitating further therapeutic interventions to promote recovery [3]. Delayed fracture healing can result in long-term pain, activity restriction, and psychological distress, severely affecting patients' life quality, reducing their ability to perform daily activities, and extending hospital stays. Additionally, it increases the risk of reop-

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eration [4] and imposes an economic burden on patients. Despite the inherent self-healing capacity of fractures and the use of traditional surgical or conservative treatment after injury, a proportion of fractures exhibit delayed healing or non-union for unknown reasons [5]. In recent years, advancements in fracture healing techniques have sparked great interest in novel methods, such as shock wave therapy, to address delayed fracture healing. This study investigates the efficacy of combining shock wave therapy with exercise therapy in treating delayed healing of tibiofibular fractures.

Extracorporeal shock wave therapy (ESWT) is a non-invasive modality that utilizes sound waves, commonly employed in urology for lithotripsy of urinary stones. Beyond its application in urology, ESWT has been shown to promote tissue repair and regeneration in rehabilitation settings [6, 7]. Shock waves can elicit new trauma responses at fracture sites, extending the inflammatory phase, stimulating massive inflammatory and vascular reactions, enhancing vascular perfusion, inducing angiogenesis, promoting intramembranous and endochondral osteogenesis, and accelerating fracture healing [8, 9]. Additionally, ESWT facilitates neovascularization, supports the repair and regeneration of non-osseous structures, and alleviates pain [10]. Several studies have demonstrated that ESWT achieves healing rates comparable to surgical intervention in patients with delayed fracture healing [11, 12]. Kinesitherapy (KT), another effective rehabilitation method, can induce local vasodilation through muscle exercise, increase blood flow, and accelerate the reduction of swelling in affected limbs [13]. This process is also essential to promote fracture healing. While both ESWT and KT have demonstrated efficacy in promoting osseous defect reconstruction and improving walking ability in patients with delayed fracture healing, the combined effect of ESWT and KT on delayed fracture healing remains underreported. In this study, the clinical therapeutic effects of ESWT combined with KT were evaluated on patients with delayed union of tibiofibular fractures based on pain indices, callus formation, and ambulatory function.

Materials and methods

Research participants

Patients with delayed healing of tibiofibular fractures who presented to the outpatient clinics of the Department of Rehabilitation Medicine and the Department of Orthopedics at the Affiliated Hospital of Nantong University between September 1, 2021, and December 31, 2023, were enrolled and allocated into three groups: control, ESWT, and ESWT+KT. All patients underwent standard surgical management involving external fixation and/or internal fixation following fracture. Patients in the ESWT group received shockwave therapy twice weekly. Those in the ESWT+KT group received both shockwave therapy and exercise therapy twice weekly.

Inclusion criteria: (1) Patients who had undergone initial fracture surgery and were in the postoperative period. (2) A definitive diagnosis of delayed healing of tibiofibular fractures was confirmed: no obvious sclerosis or occlusion of the medullary cavity at the fracture site over the past three months, no significant resorption or gap at the fracture ends, and discontinuous growth of the surrounding bone callus, with no radiological evidence of fracture healing [14]. (3) Patients with no cognitive dysfunction, who were capable of following commands to complete movements. (4) Patients aged between 8 and 80 years old at the time of injury, with no gender restrictions. Exclusion criteria: (1) Non-union or delayed union of the fracture site, including non-union of infected fractures. (2) Patients with poorly controlled severe diabetes mellitus that affects fracture healing. (3) Patients on steroids, anticoagulants, immunosuppressants, or other medications that may interfere with bone healing. (4) Pregnant women, patients with cardiac pacemakers, pathological fractures, thrombophlebitis, or coagulation disorders. (5) Patients with incomplete examination records or insufficient data. The treatment duration was 4 months, with evaluations conducted both before and after the treatment.

To minimize the influence of confounding factors, this retrospective study ultimately included a total of 68 patients with delayed healing of tibiofibular fractures after verification: 28 in the control group, 24 in the ESWT group, and 16 in the ESWT+KT group.

Extracorporeal shock wave treatment

Patients were treated in a conscious state while maintaining a comfortable position. Before treatment, the affected area was cleaned, and fracture sites were marked using X-ray imaging. During treatment, care was taken to avoid any built-in objects that could obstruct the shock wave energy from reaching the fracture site. A coupling agent was applied to the designated location, and a shock wave therapy device such as the BTL-6000 SWT Topline from BTL Industries Ltd. was used. Depending on the bone thickness, 2 to 3 points along the fracture line were selected as reference points. Treatment parameters included: a shock dose of 2000-3000 impulses per session, a treatment pressure of 2.0 to 3.0 bar, and a frequency of 10 Hz. Patients received treatment twice weekly, with an interval of 3 to 4 days between sessions, and 8 sessions constituted one course of treatment. After 4 courses of treatment, patients' walking ability, pain index, and degree of bone repair were assessed and compared to pre-treatment levels.

Kinesitherapy treatment

The exercise therapy in this study consisted of Muscle Energy Technique (MET), Joint Mobility Training (JMT), Ankle Pump Exercise (APE), and Lower Extremity Weighted Walking Training (LEWWT). Each therapy is designed to enhance muscle function, joint mobility, and walking ability.

MET: This method involves isometric contraction followed by relaxation and reciprocal inhibition. Initially, the patient relaxed, after which the therapist immobilized the thigh with one hand and placed the other hand on the lower end of the calf. The patient performed an isometric contraction against the therapist's resistance. Subsequently, the therapist immobilized the calf with one hand and held the affected foot with the other, instructing the patient to perform an isometric contraction against the therapist's hand at approximately 20% of maximal effort during the first contraction. This contraction was maintained for 5 seconds and repeated, gradually increasing resistance. Throughout the process, the patient is instructed to exert maximum force without experiencing pain. At the end of the treatment, both the patient and therapist collaborated to gradually reduce the force until complete relaxation is achieved.

JMT: The therapist rhythmically rotated the knee and ankle joints through their full range of motion, depending on the severity of joint adhesions, contractures, and pain in the affected limb.

APE: The patient performed two sets of exercises: one for dorsiflexion and one for circumduction. The patient, in a supine or seated position, maximally plantarflexed the ankle for approximately 10 seconds, followed by maximal dorsiflexion with the toes pointing upwards for another 10 seconds. Repeatedly stretching the ankles in this manner helps maintain calf muscle contraction. The ankle joint is also moved in circular motions-plantarflexion, inversion, dorsiflexion, and eversion, alternating between clockwise and counterclockwise directions to improve joint flexibility.

LEWWT: Weight-bearing training can be categorized into partial weight-bearing and touch-weight-bearing. Touch-weight-bearing involves weights ranging from 0-20% of body weight, while partial weight-bearing ranges from 20-50%. During training, an electronic weight scale was utilized in conjunction with guidance from a rehabilitation therapist. The rehabilitation physician determined a safe weight limit for the patient. Initially, the patient placed the healthy lower limb on an isometric pad and the affected limb on the electronic scale. At the beginning of the exercise, the patient's center of gravity is placed entirely on the healthy side. Under the therapist's instructions, the patient gradually shifts the center of gravity toward the affected limb. Upon reaching the predetermined safe weight, the patient holds this position for several seconds to experience the pressure on the soles of the feet. During the self-exercise, the patient can gauge the extent of weight transfer by monitoring the pressure readings on the electronic scale. After adequate training, the patient transitions from using the electronic scale to walking independently with crutches, ensuring proper weight distribution and avoiding injury from excessive weight bearing.

MET, JMT, APE, and LPWWT were performed twice weekly, with a 3 to 4 day interval between sessions. A total of 8 sessions were conducted per course of treatment. After completing 4 sessions, patients were assessed for walking ability, pain index, and bone repair, and the results were compared to their pre-treatment measurements.

Assessment of pain

The Numerical Rating Scale (NRS) is a quantitative visual tool for quantifying pain intensity using an 11-point scale ranging from 0 to 10, where 0 indicates no pain and 10 represents the most severe pain. Patients were instructed to rate their pain intensity based on their personal perception at the time of assessment. The NRS has been shown to provide intuitive results and exhibits high validity [15].

X-ray imaging evaluation

Lane-Sandhu X-ray grading scale is a comprehensive tool for both qualitative and quantitative evaluation of bone repair [16]. It assesses three critical parameters: bone formation, bone connection, and bone contouring. Specifically, bone formation is scored as follows: 0 for no bone formation, 1 for 25% defect filling, 2 for 50% defect filling, 3 for 75% defect filling, and 4 for complete defect filling by new bone. Bone connection is assessed with scores of 0 for a clearly visible fracture line, 2 for a partially visible fracture line, and 4 for complete disappearance of the fracture line. Bone contouring is evaluated as 0 for no restoration of bone shape, 2 for the formation of the medullary cavity, and 4 for complete restoration of the cortical bone structure. The total score ranges from 0 to 12, with higher scores indicating more effective bone defect repair.

Fernandez-Esteve X-ray grading scale evaluates callus formation at the fracture site, classified into five grades [17]. Grade I (0 point): No radiological evidence of callus at the fracture ends; Grade II (1 point): A visible faint callus at the fracture ends; Grade III (2 points): Visible callus on one side of the fracture ends indicated by both anteroposterior and lateral X-rays; Grade IV (3 points): Callus on both sides of the fracture ends; Grade V (4 points): Continuous callus bridging observed. Higher grades of callus formation indicate more effective bone defect repair.

Assessment of walking ability

Functional Ambulation Classification (FAC) [18]: Level 0: the patient is unable to walk or requires assistance from two individuals to ambulate; Level 1: the patient can maintain balance with continuous support from one person, though they may exhibit reduced weight-bearing capacity; Level 2: the patient walks with either continuous or intermittent support from one individual; Level 3: the patient walks independently without direct physical assistance but requires supervision; Level 4: the patient can walk independently on level surfaces but needs assistance for stairs, slopes, or uneven terrain; Level 5: the patient can walk independently in all environments. Higher levels indicate better ambulatory function.

Hoffer's walking ability grade [19]: Grade 1 (non-ambulator): the patient is entirely unable to walk; Grade 2 (non-functional ambulator): the patient can walk indoors with the assistance of devices such as knee-ankle-foot orthoses or canes; Grade 3 (household ambulator): the patient can walk independently within the home using assistive devices like ankle-foot orthoses or canes but cannot sustain prolonged outdoor walking; Grade 4 (community ambulator): the patient can walk and stroll outdoors independently. Higher grades indicate progressively better walking abilities.

Holden's walking ability grade [20]: Level 0: unable to walk, requiring assistance from at least two individuals; Level 1: requires continuous support from one person for balance and weight-bearing while walking; Level 2: requires intermittent support from one person for balance while walking; Level 3: can walk independently but still requires supervision or guidance from others; Level 4: can walk independently but requires assistance when navigating stairs or uneven surfaces; Level 5: can walk independently without difficulty.

Statistical analysis

General admission data, including age, gender, fracture type, fixation mode, delayed healing type, and fracture site, were extracted from the records of 68 patients with delayed healing of tibiofibular fractures. Imaging data were collected and analyzed to evaluate bone formation, osseous junction, bone contouring, and callus growth. Additionally, the pain index was assessed, and the walking ability was evaluated for all patients.

SPSS.V29.0 statistical software was utilized for data analysis and visualization. Descriptive statistics were used to summarize patients' gen-

Table 1. General information of patients

	Total Number of Cases (n=68)			H/χ^2-Score	P-Score
	Control Group (n=28)	ESWT Group (n=24)	ESWT+KT Group (n=16)		
Age (average years)	55.5	57.5	53	0.312	0.856
Gender, n (Male/Female)	16/12	18/5	11/5	1.903	0.392
Type of Fracture, n (%)					
Open Fracture	11 (39.3%)	12 (50%)	7 (43.8%)	0.603	0.740
Closed Fracture	17 (60.7%)	12 (50%)	9 (56.3%)		
Fixation Mode, n (%)					
Internal Fixation	14 (50%)	10 (41.7%)	8 (50%)	5.938	0.192
External Fixation	6 (21.4%)	2 (8.3%)	0 (0%)		
Internal Fixation + External Fixation	8 (28.6%)	12 (50%)	8 (50%)		
Healing Type, n (%)					
Hypertrophic Type	4 (14.3%)	5 (20.8%)	1 (6.3%)	8.135	0.075
Normal Healing	18 (64.3%)	13 (54.2%)	15 (93.8%)		
Atrophic Type	6 (21.4%)	6 (25%)	0 (0%)		
Fracture Site, n (%)					
Upper Segmental	4 (14.3%)	3 (12.5%)	3 (18.8%)	8.091	0.216
Intermediate Segmental	4 (14.3%)	4 (16.7%)	0 (0%)		
Lower Segmental	18 (64.3%)	10 (41.7%)	9 (56.3%)		
Multi Segmental	2 (7.1%)	7 (29.2%)	4 (25%)		

ESWT, Extracorporeal shock wave therapy; ESWT+KT, Extracorporeal shock wave therapy combined with kinesitherapy.

eral information, observational variables, and outcome measures. Non-normally distributed continuous variables were presented as medians with interquartile ranges, while categorical variables were summarized as frequencies and percentages. To assess the significance of differences among multiple groups, one-way ANOVA or Kruskal-Wallis tests were employed as appropriate for analyzing NRS scores, Lane-Sandhu X-ray scale, Fernandez-Esteve X-ray scale, FAC scores, Hoffer walking ability scale, and Holden walking ability scale. For comparisons between the control and treatment groups before and after intervention, independent samples t-tests or Wilcoxon rank-sum tests were used as appropriate. The differences were considered as statistically significant when $P < 0.05$.

Results

General data analysis of patients

A total of 68 patients with delayed healing of tibiofibular fracture were retrospective included in this study, comprising 28 patients in the control group, 24 patients in the ESWT group, and 16 patients in the ESWT+KT group. There were no statistically significant differences in general information among the three groups (**Table 1**).

The mean age of the control group was 55.5 ± 8.75 years, with 16 (57.1%) males and 12 (42.8%) females. Among them, 11 (39.3%) had open fractures, while 17 (60.7%) had closed fractures. The fixation methods included internal fixation in 14 (50.0%) cases, external fixation in 6 (21.4%), and combined internal and external fixation in 8 (28.6%). Delayed healing types were classified as hypertrophic in 4 (14.3%) cases, normal in 18 (64.3%), and atrophic in 6 (21.4%). Fracture locations were distributed as follows: upper segment in 4 (14.3%) cases, middle segment in 4 (14.3%), lower segment in 18 (64.3%), and multiple fractures in 2 (7.1%).

The mean age of the ESWT group was 57.5 ± 7.25 years, with 18 (75%) males and 5 (25%) females. Among the patients, 12 (50%) had open fractures and 12 (50%) had closed fractures. The fixation methods included internal fixation in 10 (41.7%) cases, external fixation in

Table 2. Comparison of NRS scores among three groups of patients before and after treatment

NRS score	Before treatment	After treatment	*Z*-Score	*P*-Score
Control Group Mean (Min, Max)	2 (1, 3)	0 (0, 2)[a]	4.311	< 0.001
ESWT Group Mean (Min, Max)	2 (1, 3)	0 (0, 1)[a]	3.789	< 0.001
ESWT+KT Group Mean (Min, Max)	2 (2, 3)	1 (0, 2)[a]	3.256	0.001
H-Score	0.275	0.697		
P-Score	0.872	0.706		

NRS, Numerical Rating Scale. [a]$P < 0.05$, compared with before treatment. ESWT, extracorporeal shock wave therapy; KT, kinesitherapy.

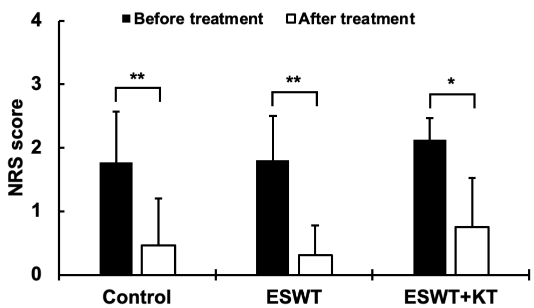

Figure 1. Comparison of Numerical Rating Scale (NRS) scores before and after treatment. NRS scores decreased after treatment in all three groups. *$P < 0.05$, **$P < 0.001$. ESWT, extracorporeal shock wave therapy; KT, kinesitherapy.

2 (8.3%) cases, and combined internal and external fixation in 12 (50%) cases. The fracture types were classified as hypertrophic in 5 (20.8%), normal in 13 (54.2%), and atrophic in 6 (25%) cases. The fracture locations were distributed as follows: upper segmental in 3 (12.5%), middle segmental in 4 (16.7%), lower segmental in 10 (41.7%), and multi segmental in 7 (29.2%) cases.

The mean age of the ESWT+KT group was 53 ± 7.5 years, with 11 (68.8%) males and 5 (31.3%) females. Among the patients, 7 (43.8%) had open fractures and 9 (56.3%) had closed fractures. The fixation methods included internal fixation in 8 (50%) cases and combined internal and external fixation in 8 (50%) cases. Regarding delayed healing types, there was 1 (6.3%) case of hypertrophic delayed healing and 15 (93.8%) cases of normal delayed healing. No atrophic delayed healing cases were observed. Fracture locations were distributed as follows: upper segmental fracture in 3 (18.8%) cases, lower segmental fracture in 9 (56.3%) cases, and multidimensional fracture in 4 (25%) cases. No intermediate segmental fractures were recorded.

Effect of ESWT combined with KT on pain

The NRS scores of patients in all groups decreased post-treatment compared to pre-treatment levels. The mean NRS score was 2 in all three groups before treatment (P=0.872). After treatment, the mean NRS scores reduced to 0-1, and there remained no statistically significant difference among the three groups (P=0.706) (**Table 2**). A significant reduction in NRS scores was observed after treatment in the control group ($P < 0.001$), ESWT group ($P < 0.001$), and ESWT+KT group ($P < 0.05$) compared to their respective pre-treatment scores (**Figure 1**). Prior to treatment, NRS scores for patients with delayed union were generally between 1-3, indicating mild to moderate pain, rather than acute severe pain. After treatment, while all groups showed a reduction in NRS scores, no statistically significant difference was observed between the treatment and control groups. This may be due to the limitations in pain management.

Effect of ESWT combined with KT on X-ray imaging

Before treatment, no statistically significant difference was observed in the Lane-Sandhu X-ray scale scores among the three groups (P=0.125). After treatment, the mean Lane-Sandhu X-ray scale scores increased from 4-6 to 6-8 across all groups. Comparing the three groups, a significant difference was noted in the Lane-Sandhu X-ray scale scores (P=0.036) (**Table 3**). The increase in the Lane-Sandhu X-ray scale scores was statistically significant for all three groups after treatment (all $P < 0.05$). Notably, the ESWT+KT group had significantly higher scores than the control group after treatment (**Figure 2A**).

There was no statistically significant difference in the Fernandez-Esteve X-ray scale scores among the three groups before treatment (P=

Table 3. Comparison of Lane-Sandhu X-ray scales of tibia among three groups of patients before and after treatment

Lane-Sandhu X-ray scale	Before treatment	After treatment	*Z*-Score	*P*-Score
Control Group Mean (Min, Max)	5 (4, 6)	6 (4, 6)[a]	3.317	< 0.001
ESWT Group Mean (Min, Max)	5 (4, 6)	6 (4, 6)[a]	3.162	0.002
ESWT+KT Group Mean (Min, Max)	6 (4, 6)	7 (6, 8)[a,b]	3.162	0.002
H-Score	4.163	6.394		
P-Score	0.125	0.036		

[a]$P < 0.05$, compared with before treatment. [b]$P < 0.05$, compared with control group. ESWT, extracorporeal shock wave therapy; KT, kinesitherapy.

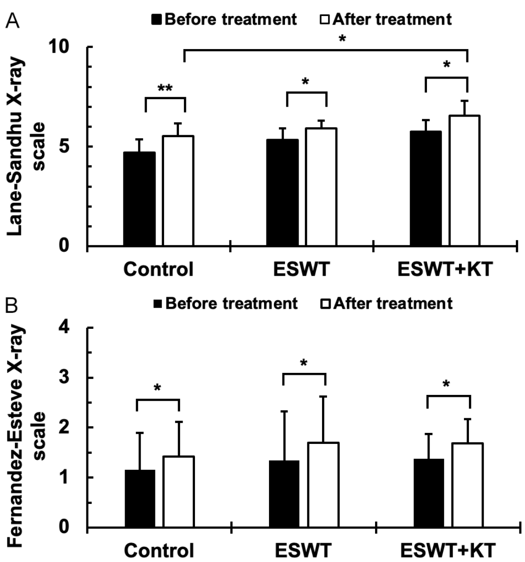

Figure 2. Comparation of the X-ray imaging indexes among three groups of patients before and after treatment. A. Lane-Sandhu's X-ray scale scores increased significantly after treatment in all three groups. There were significant differences between the control and ESWT+KT group after treatment. B. Fernandez-Esteve X-ray scale scores increased significantly after treatment in all three groups after treatment. **$P < 0.001$, *$P < 0.05$. ESWT, extracorporeal shock wave therapy; KT, kinesitherapy.

0.404), with each group having a mean score of 1. After treatment, the mean score increased to 1-2 across all groups. Although there remained no statistically significant difference in the Fernandez-Esteve X-ray scale scores among the three groups after treatment (P=0.309) (**Table 4**), intra-group comparisons revealed a statistically significant increase in scores before and after treatment for the control group, ESWT group, and ESWT+KT group (all $P < 0.05$) (**Figure 2B**).

This study found that both methods for evaluating fracture healing after treatment indicated significant improvement in bone repair. However, the Lane-Sandhu X-ray scale, which evaluates fracture healing from three distinct aspects, demonstrated higher sensitivity compared to the single-aspect evaluation of the Fernandez-Esteve X-ray scale. Consequently, while the Fernandez-Esteve X-ray scale did not detect inter-group differences post-treatment, the Lane-Sandhu X-ray scale revealed that the ESWT+KT group had a notable advantage in fracture repair.

By comparing X-ray images of patients before and after treatment, it was evident that fractures exhibited varying degrees of repair after treatment. Specifically, fractures in the control group showed only slight improvement, whereas those in the ESWT group demonstrated significant repair. The ESWT+KT group displayed markedly superior bone repair compared to the other two groups, accompanied by an increase in muscle mass on the affected side (**Figure 3**).

Effect of ESWT combined with KT on walking ability

Before treatment, the mean FAC levels in the control group, ESWT group and ESWT+KT group were 0, 1, and 0, respectively. There was no statistically significant difference in FAC level among the three groups before treatment (P=0.221). After treatment, the mean FAC levels increased to 1, 2, and 4 in the respective groups. A statistically significant difference was observed in the increase of FAC levels among the three groups after treatment (P=0.018) (**Table 5**). Within-group comparisons revealed a statistically significant increase in FAC levels before and after treatment for all three groups (all $P < 0.001$). There was a significant difference in the increase of FAC levels between the ESWT+KT group and the control group after

Table 4. Comparison of Fernandez-Esteve X-ray scales of tibia among three groups of patients before and after treatment

Fernandez-Esteve X-ray scale	Before treatment	After treatment	*Z*-Score	*P*-Score
Control Group Mean (Min, Max)	1 (0, 2)	1 (0, 2)[a]	2.913	0.004
ESWT Group Mean (Min, Max)	1 (0, 3)	2 (0, 3)[a]	3.000	0.003
ESWT+KT Group Mean (Min, Max)	1 (1, 2)	2 (1, 2)[a]	2.887	0.004
H-Score	1.814	2.349		
P-Score	0.404	0.309		

[a]$P < 0.05$, compared with before treatment. ESWT, extracorporeal shock wave therapy; KT, kinesitherapy.

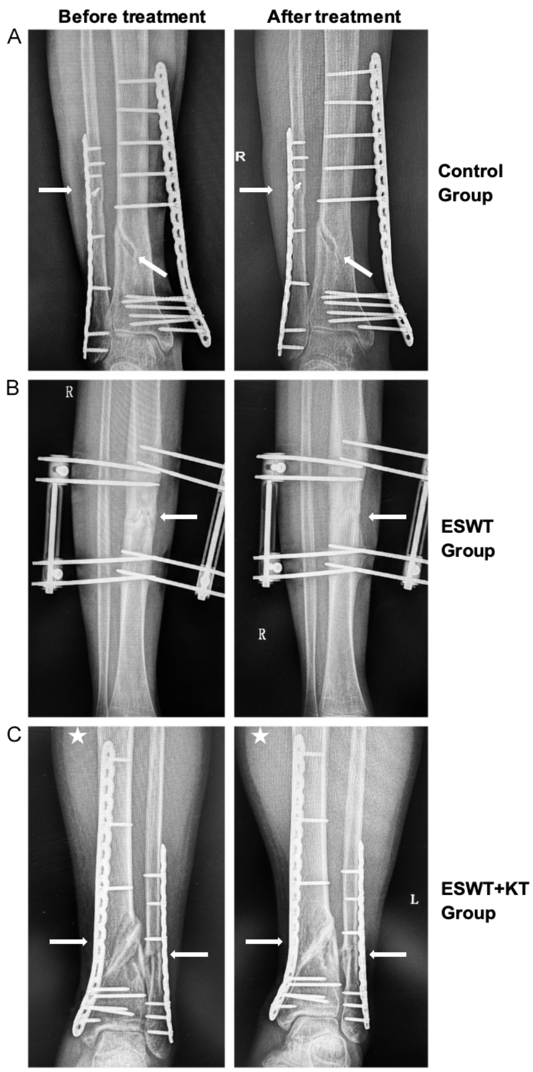

Figure 3. X-ray images of patients before and after treatment (white arrow indicates the fracture site and the star marks the calf muscles). A. Fracture was slightly repaired after treatment compared with that before treatment in the control group. B. Fracture was obviously repaired after treatment compared with that before treatment in the ESWT group. C. After treatment, the fractures in patients were significantly repaired compared to pre-treatment conditions and the calf muscle mass in the ESWT+KT group also increased. ESWT, extracorporeal shock wave therapy; KT, kinesitherapy.

treatment, as well as between the ESWT group and the control group (all $P < 0.05$) (**Figure 4A**).

There was no significant difference in the Hoffer grade among the three groups before treatment (P=0.210). After treatment, the mean Hoffer grades increased from 1-2 to 2-4 across all groups. A statistically significant difference in the Hoffer grade was observed among the three groups after treatment (P=0.003) (**Table 6**). Within each group, there were significant differences in Hoffer grades before and after treatment ($P < 0.05$ or $P < 0.001$). Additionally, a statistically significant increase in the Hoffer grade was noted between the ESWT+KT group and the control group after treatment ($P < 0.05$) (**Figure 4B**).

No statistically significant differences in Holden grade were observed among the three groups before treatment (P=0.227). After treatment, a statistically significant difference was noted in the increase of Holden grades from 0-1 to 1-4 when comparing the three groups (P=0.013) (**Table 7**). Additionally, within-group comparisons revealed a statistically significant increase in Holden grades across the three groups after treatment ($P < 0.001$). The ESWT+KT group exhibited a significantly greater increase in Holden grade compared to the control group after treatment, while similar results were observed between the ESWT group and the control group ($P < 0.001$) (**Figure 4C**).

FAC level and Holden grade are used to evaluate patients' walking ability and independence more directly, while Hoffer grade focuses more on analyzing the activity area of patients to reflect their walking ability. After treatment, the ESWT group showed better independent walking ability than the control group, while compared with the control group, the ESWT+KT group not only improved in independent walking ability but also in walking range, indicating that this treatment plan is more effective.

Table 5. Comparison of FAC levels among three groups of patients before and after treatment

FAC level	Before treatment	After treatment	*Z*-Score	*P*-Score
Control Group Mean (Min, Max)	0 (0, 2)	1 (1, 2)[a]	4.123	< 0.001
ESWT Group Mean (Min, Max)	1 (0, 2)	2 (1, 4)[a,b]	4.193	< 0.001
ESWT+KT Group Mean (Min, Max)	0 (0, 1)	4 (3, 4)[a,b]	3.424	< 0.001
H-Score	3.016	17.383		
P-Score	0.221	0.018		

FAC, Functional Ambulation Classification. [a]$P < 0.05$, compared with before treatment. [b]$P < 0.05$, compared with control group. ESWT, extracorporeal shock wave therapy; KT, kinesitherapy.

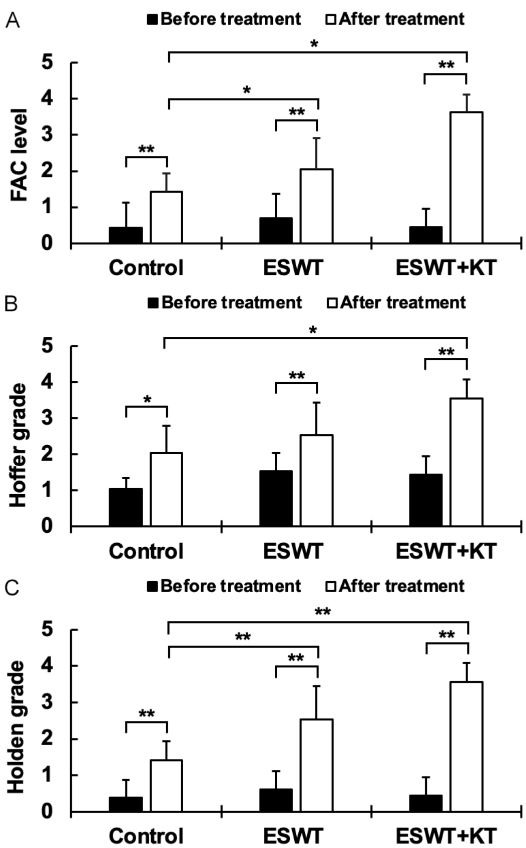

Figure 4. Comparison of walking ability among three groups of patients before and after treatment. A. Functional Ambulation Classification (FAC) level increased after treatment in the control, ESWT and ESWT+KT group. There were significant differences between the control and ESWT+KT group as well as between the control and ESWT group after treatment. B. Hoffer grade increased significantly after treatment in all three groups. Compared with the control group, the grades of the EWST+KT group were significantly increased after treatment. C. After treatment, Holden grade increased significantly. Compared with the control group, the grades of the ESWT and ESWT+KT group were significantly increased after treatment. **$P < 0.001$, *$P < 0.05$. ESWT, extracorporeal shock wave therapy; KT, kinesitherapy.

Discussion

Fractures, as a prevalent traumatic condition, have garnered significant attention from medical practitioners. Despite active treatments, some patients still experience delayed healing or even nonunion. Consequently, interventions for delayed fracture healing holds substantial importance in the field of rehabilitation medicine. In recent years, shock wave therapy has emerged as a promising rehabilitation treatment for various musculoskeletal conditions, including proximal plantar fasciitis [21], lateral epicondylitis of the humerus [22], adhesive capsulitis of the shoulder [23], and osteochondral dislocations of long bone fractures [24]. More recently, shock wave therapy has been applied to treat delayed fracture healing [25-27]. Previous studies have elucidated the potential mechanisms by which shock wave therapy promotes fracture healing. Shock waves can induce microlesions at the fracture site, stimulating and initiating the bone healing process, thereby facilitating effective recovery [28]. Additionally, shock waves generate minuscule bone fragments that can occupy the fracture site and serve as autogenous bone grafts, further enhancing the fracture healing process [29-31]. The application of shock waves can enhance blood circulation to the fracture site, thereby accelerating the healing process [32, 33]. Moreover, shock wave therapy modulates osteoblast and osteoclast activity, while promoting the proliferation, survival, and migration of bone marrow mesenchymal stem cells, which collectively augment bone regenerative capacity [34-36]. The evidence suggests that shock wave therapy is a highly effective and non-invasive method for promoting fracture healing. However, prolonged immobilization following a fracture can induce significant alterations in the morphological structure, biochemi-

Table 6. Comparison of Hoffer grades among three groups of patients before and after treatment

Hoffer grade	Before treatment	After treatment	*Z*-Score	*P*-Score
Control Group Mean (Min, Max)	1 (1, 2)	2 (1, 3)[a]	3.051	0.002
ESWT Group Mean (Min, Max)	2 (1, 2)	3 (1, 4)[a]	3.695	< 0.001
ESWT+KT Group Mean (Min, Max)	1 (1, 2)	4 (3, 4)[a,b]	3.355	< 0.001
H-Score	3.117	11.815		
P-Score	0.210	0.003		

[a]$P < 0.05$, compared with before treatment. [b]$P < 0.05$, compared with control group.

Table 7. Comparison of Holden grades among three groups of patients before and after treatment

Holden grade	Before treatment	After treatment	*Z*-Score	*P*-Score
Control Group Mean (Min, Max)	0 (0, 1)	1 (1, 2)[a]	4.146	< 0.001
ESWT Group Mean (Min, Max)	1 (0, 1)	3 (1, 4)[a,b]	4.164	< 0.001
ESWT+KT Group Mean (Min, Max)	0 (0, 1)	4 (3, 4)[a,b]	3.124	< 0.001
H-Score	2.964	18.062		
P-Score	0.227	0.013		

[a]$P < 0.05$, compared with before treatment. [b]$P < 0.05$, compared with control group. ESWT, extracorporeal shock wave therapy; KT, kinesitherapy.

cal composition, and biomechanical properties of the joint capsule, ligaments, muscles, and other tissues, resulting in impaired joint function and hindering fracture healing. Exercise therapy, as a therapeutic approach, aims to enhance limb function and gait proficiency through systematic and targeted exercise training. This therapy facilitates the restoration of joint mobility, strengthens muscle, improves joint stability, and ultimately optimizes patients' ambulatory capacity, thereby supporting fracture healing [37-39].

In our study, to enhance the efficacy of shock wave therapy and exercise therapy in managing delayed fracture healing, the combination of ESWT and KT was utilized for the treatment of patients with delayed union of tibiofibular fractures, and the clinical efficacy was assessed. The experimental results demonstrated that the ESWT+KT group showed significant improvements in the Lane-Sandhu X-ray scale, FAC level, Hoffer grade, and Holden grade after treatment, compared with the control group. In contrast, the ESWT group only exhibited improvements in the FAC level and Holden grade after treatment. We hypothesize that bone repair may initially manifest as the recovery of walking ability, followed by visible changes on X-rays. The combination treatment of ESWT and KT significantly promotes the recovery of walking ability in patients with delayed union of the tibia and fibula, and markedly improves the repair of bone defects. The ESWT+KT group outperformed the ESWT intervention alone by improving more indicators, demonstrating superior outcomes in both walking ability and bone repair. Therefore, the combination treatment of ESWT and KT is clearly superior.

Currently, limited research has been conducted on the combination of shock wave therapy and exercise therapy for clinical applications. However, existing studies have demonstrated that this approach combined with oral medication is effective in treating low back pain [40]. Whereas our study investigated the impact of this combination therapy on fracture healing and walking function in patients with delayed union, rather than focusing on less severe pain. Undoubtedly, our study possesses certain limitations, including a limited sample size and a restricted observation period. Although the clinical efficacy of this combination therapy has been confirmed, further research is warranted to establish standardized and unified treatment parameters.

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Disclosure of conflict of interest

None.

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