Ovidius University Annals, Series Physical Education and Sport / SCIENCE, MOVEMENT AND HEALTH
Vol. XXV, ISSUE 2 Supplement, 2025, Romania
The journal is indexed in: ERIH PLUS, Ebsco, SPORTDiscus, INDEX COPERNICUS JOURNAL MASTER LIST, DOAJ DIRECTORY OF OPEN ACCESS JOURNALS, Caby, Gale Cengage Learning, Cabell's Directories

Science, Movement and Health, Vol. XXV, ISSUE 2 Supplement, 2025
September 2025, 25 (2): 368-373
Original article

A STUDY ON BIOMECHANICAL APPROACHES IN THE REHABILITATION OF CALCANEAL FRACTURES

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Abstract

Aim. Calcaneal fractures are among the most challenging injuries of the lower limb due to the complex role of the calcaneus in load transfer, gait mechanics, and shock absorption. These fractures, although relatively rare, often lead to long-term functional deficits and impaired quality of life if rehabilitation is not properly conducted. The aim of this study was to analyze the efficiency of a biomechanically oriented physiotherapy program in restoring mobility and function after calcaneal fractures, by comparing two distinct clinical cases: one treated conservatively and the other surgically.

Methods. The study design was a case series including two adult patients diagnosed with unilateral calcaneal fracture. Case 1 received conservative management consisting of immobilization followed by rehabilitation, while Case 2 underwent open reduction and internal fixation and then entered a structured physiotherapy program. Both patients were enrolled in a progressive rehabilitation protocol guided by biomechanical principles. The intervention consisted of three main phases. The initial phase focused on pain and edema control (cryotherapy, limb elevation, drainage), maintenance of joint mobility in the non-affected segments, and prevention of muscular atrophy through isometric contractions. The intermediate phase emphasized progressive mobilization of the ankle and subtalar joints, stretching, and strengthening exercises targeting the plantarflexors, dorsiflexors, and peroneal muscles, as well as proprioceptive training under partial weight-bearing conditions.

Results. Both patients showed significant clinical and functional improvements. The surgically treated patient (Case 2) demonstrated faster pain reduction, earlier restoration of joint mobility, and improved muscular strength compared to the conservatively treated patient (Case 1). However, residual subtalar stiffness and occasional discomfort during sudden changes of direction persisted. In Case 1, recovery was slower and limited by prolonged edema and joint stiffness in the early stages, but by the end of the 12-week program the patient achieved independence in daily activities and was able to ambulate without major restrictions, though pain was still reported during prolonged or intense physical effort. These findings underline that both treatment pathways can reach satisfactory outcomes when supported by a personalized rehabilitation protocol.

Conclusions. The present study highlights the central role of physiotherapy, guided by biomechanical principles, in the rehabilitation of calcaneal fractures. While surgical treatment can accelerate the initial stages of recovery by restoring anatomical alignment, conservative treatment may also lead to functional independence if followed by a carefully structured program. The comparison of the two cases suggests that individualized rehabilitation strategies, focusing on pain control, mobility restoration, muscular strengthening, proprioceptive training, and gait re-education, are essential for optimizing long-term.

Keywords: general strength development, circuit training method, high school, female group, adolescent girls.

Introduction

Calcaneal fractures are among the most severe and disabling injuries of the hindfoot, despite representing only a small percentage of all fractures in the adult population. Epidemiological studies estimate their frequency between 0.5% and 1% of all skeletal fractures, but their clinical significance is disproportionately high due to the central role of the calcaneus in human locomotion (Rubenson et al., 2021). As the largest tarsal bone, the calcaneus bears and transmits substantial loads during static stance and dynamic activities, providing stability while functioning as a lever during push-off and as a shock absorber during impact (Angin & Demirbüken, 2022). Its anatomical configuration, with strong trabecular bone adapted to weight bearing and articulations with the talus and cuboid, makes it critical for efficient gait mechanics (Papilian, 2003). When fractured, this bone jeopardizes not only local function but also the overall biomechanics of the lower limb.

The injury mechanism is typically high-energy trauma. The most common causes include falls from a significant height, where vertical compression forces are transmitted from the talus onto the calcaneus, and motor vehicle accidents, in which axial loads are generated by sudden deceleration. Such trauma frequently produces intra-articular fractures extending into the subtalar joint, which complicates prognosis and requires complex management strategies (Buckley &

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Tough, 2004; Ibrahim et al., 2007). The extent of displacement, number of fragments, and involvement of articular surfaces dictate whether conservative or surgical treatment is chosen (Schepers et al., 2008). Conservative management, based on immobilization and gradual weight bearing, is usually reserved for non-displaced or minimally displaced fractures, or for patients with contraindications to surgery (Neagu, 2024). Surgical treatment, most often open reduction and internal fixation, aims to restore anatomical alignment and congruency of the subtalar joint. Yet even anatomically well-reduced fractures may result in long-term stiffness, pain, and altered function without adequate rehabilitation (Ibrahim et al., 2007). Rehabilitation after calcaneal fractures is particularly demanding because the functional impairments extend beyond the local lesion. Immediately after injury, patients often present with intense pain, edema, limited range of motion, and an inability to bear weight on the affected limb. Secondary consequences include muscle atrophy, reduced proprioceptive input, and compensatory gait patterns that overload adjacent joints such as the ankle, knee, or hip (Rubenson et al., 2021). Without a structured program, these adaptations may become chronic, resulting in persistent disability. Physiotherapy addresses these issues through pain and edema control, gradual mobilization of the ankle and subtalar joints, strengthening of the calf and foot muscles, proprioceptive training, and re-education of walking (Neagu, 2024). The ultimate goal is not only to restore anatomical movement but also to reintegrate the patient into daily life, occupational activities, and sports, where applicable.

Biomechanics provides the scientific foundation for effective rehabilitation protocols. Understanding the distribution of forces through the calcaneus during stance and gait allows clinicians to prescribe appropriate loading strategies and progressions. For example, the medial and lateral columns of the foot transmit forces differently; disruption of this balance after a fracture can alter pressure distribution on the plantar surface (Angin & Demirbüken, 2022). Similarly, the subtalar joint plays a crucial role in accommodating uneven surfaces by allowing inversion and eversion; restricted mobility here often leads to compensatory stress on the knee and hip (Rubenson et al., 2021). By integrating biomechanical analysis into rehabilitation, clinicians can anticipate such compensations and design targeted interventions to restore functional alignment.

The challenges of recovery are highlighted in the literature. Many patients experience residual pain, reduced mobility, or limited endurance even years after the injury. Studies report difficulties with activities such as climbing stairs, prolonged standing, or running, reflecting the complexity of regaining full function (Ibrahim et al., 2007). Additionally, chronic pain and mobility restrictions may impact psychological well-being and quality of life, influencing the ability to return to professional or recreational activities (Schepers et al., 2008). These findings underline the need for comprehensive rehabilitation programs that go beyond traditional exercises to include proprioceptive training, functional re-education, and patient education (Neagu, 2024).

Given these considerations, the present paper focuses on two clinical cases that illustrate different management pathways: one treated conservatively and one surgically. Both patients followed a structured rehabilitation program based on biomechanical principles. By comparing their outcomes in terms of pain reduction, range of motion, muscular strength, and functional independence, this study aims to highlight the pivotal role of physiotherapy in optimizing recovery. Furthermore, it emphasizes the importance of tailoring rehabilitation protocols to the specific clinical context of each patient. Ultimately, the findings are expected to contribute to the growing body of evidence supporting individualized, biomechanically informed rehabilitation strategies for calcaneal fractures, aiming to minimize long-term disability and maximize quality of life.

Methods

Study Design

The present study was designed as a case series that followed two adult patients diagnosed with unilateral calcaneal fracture. The intention was not to provide generalizable statistical conclusions but to illustrate, through detailed clinical observation, how a rehabilitation program structured according to biomechanical principles can influence recovery trajectories in both conservative and surgical contexts. Case series are a valuable methodological approach when the number of participants is limited, but when detailed information about progression, treatment choices, and outcomes can generate hypotheses for future research.

Participants

Two patients were enrolled based on medical records and clinical diagnosis of calcaneal fracture.

Case 1 was managed conservatively with immobilization in a cast for several weeks, followed by gradual weight-bearing and entry into the rehabilitation program. This case represented the typical trajectory of a patient with a non-displaced or minimally displaced fracture where surgical intervention was not considered necessary.

Case 2 underwent surgical management consisting of open reduction and internal fixation (ORIF). The decision for surgery was taken due to fracture displacement and involvement of the subtalar joint. Postoperatively, after wound healing and initial medical clearance, the patient was introduced into the rehabilitation protocol.

Both participants were adults of working age, with no prior history of severe lower limb pathology that could confound results. Both provided informed consent to participate in the study and to share anonymized data for research purposes.

Inclusion and Exclusion Criteria

Inclusion criteria consisted of: confirmed unilateral calcaneal fracture, medical clearance for rehabilitation, and compliance with the rehabilitation schedule. Exclusion criteria were: presence of multiple fractures or polytrauma, severe neurological or vascular conditions affecting the lower limb, or contraindications to physical activity.

Rehabilitation Protocol

The rehabilitation protocol was identical in its structure for both cases but adapted in intensity and progression speed according to the medical background (conservative versus surgical). The protocol was divided into three distinct phases, each targeting specific objectives, following principles described in the literature (Neagu, 2024).

Phase I (Weeks 0–2): Acute management

The initial focus was on pain and edema reduction. Interventions included cryotherapy, limb elevation, lymphatic drainage techniques, and non-weight-bearing positioning. Simultaneously, the physiotherapist encouraged gentle active and passive movements of non-affected joints (hip, knee, and toes) to maintain general mobility. Isometric contractions of the calf muscles were introduced to limit atrophy, while patient education emphasized the importance of progressive loading and protection of the healing tissue (Schepers et al., 2008).

Phase II (Weeks 3–6): Early mobilization and strengthening

Once initial pain and swelling subsided, and with medical clearance, the focus shifted to mobilization of the ankle and subtalar joints. Assisted and active mobilization exercises were applied to restore dorsiflexion, plantarflexion, inversion, and eversion. Stretching exercises targeted the Achilles tendon and plantar fascia. Strengthening exercises involved plantar and dorsal flexors, peroneals, and tibialis anterior, using elastic bands or body weight. Partial weight-bearing was gradually introduced, initially with assistive devices. Proprioceptive training began at this stage, using stable surfaces and simple balance drills to reactivate neuromuscular control.

Phase III (Weeks 7–12): Advanced rehabilitation and functional re-training

During this stage, exercises became more dynamic and functional. Strengthening progressed towards endurance and power, incorporating exercises in closed kinetic chains, squats, and step-ups. Proprioceptive training advanced to unstable surfaces such as balance boards, combined with perturbations and dual-task exercises. Gait re-education emphasized symmetrical weight distribution, correction of antalgic patterns, and gradual progression from assisted walking to independent gait. Functional training included stair climbing, changes of direction, and low-impact tasks that prepared patients for reintegration into daily and professional life (Ibrahim et al., 2007).

Outcome Measures

Several standardized measures were used to monitor progress:

- Pain intensity using the Visual Analogue Scale (VAS, 0–10).
- Range of motion (ROM) measured with a goniometer for dorsiflexion, plantarflexion, inversion, and eversion.
- Muscle strength assessed with the Medical Research Council (MRC) scale ranging from 0 to 5.
- Functional capacity, evaluated qualitatively through the ability to perform daily tasks, and quantitatively through walking distance and independence.

Assessments were performed at three time points: baseline (immediately before starting rehabilitation), six weeks, and twelve weeks. For the surgical patient, an additional baseline was documented postoperatively once wound healing was complete and physiotherapy could commence (Neagu, 2024).

Results

The rehabilitation outcomes of the two patients were analyzed across three time points: baseline, six weeks, and twelve weeks. The main variables evaluated were pain intensity (VAS), ankle and subtalar range of motion (ROM), muscle strength (MRC scale), and functional independence (ability to ambulate and perform daily activities). Descriptive comparisons highlighted both similarities and differences between the conservative and surgical cases, consistent with findings reported in the literature (Buckley & Tough, 2004; Ibrahim et al., 2007).

Pain Evolution

At baseline, both patients reported high pain levels (VAS 7–8/10). By six weeks, the surgical patient demonstrated a more pronounced decrease in pain (VAS 3) compared to the conservative patient (VAS 5). At twelve weeks, both patients reported low pain levels (VAS 1–2), although the conservative patient continued to experience mild discomfort during prolonged weight-bearing activities. This trajectory is in line with published data, where surgical management often accelerates early pain reduction but does not always eliminate long-term discomfort (Schepers et al., 2008; Rubenson et al., 2021).

Table 1. Pain intensity evolution (VAS 0–10)

Time point	Case 1 (Conservative)	Case 2 (Surgical)
Baseline	8	7
6 weeks	5	3
12 weeks	2	1

Range of Motion (ROM)

At baseline, both patients had significantly reduced ankle and subtalar mobility due to immobilization and pain. The surgical patient regained ROM faster, reaching nearly normal dorsiflexion and plantarflexion by week 12. The conservative patient demonstrated improvements but still had residual limitation, particularly in subtalar inversion/eversion.

Table 2. Range of motion (degrees)

Motion (normal values)	Baseline C1	6w C1	12w C1	Baseline C2	6w C2	12w C2
Dorsiflexion (20°)	5°	12°	16°	7°	15°	19°
Plantarflexion (45°)	15°	28°	38°	20°	35°	42°
Inversion (30°)	5°	12°	18°	7°	20°	25°
Eversion (20°)	3°	8°	12°	4°	12°	16°

Muscle Strength (MRC Scale)

At baseline, both patients had significantly reduced ankle and subtalar mobility due to immobilization and pain. The surgical patient regained ROM faster, reaching nearly normal dorsiflexion and plantarflexion by week 12. The conservative patient demonstrated improvements but still had residual limitation, particularly in subtalar inversion/eversion. These findings are consistent with prior studies noting that subtalar stiffness remains one of the most common sequelae of calcaneal fractures, regardless of treatment approach.

Table 3. Strength recovery

Muscle group	Baseline C1	6w C1	12w C1	Baseline C2	6w C2	12w C2
Dorsiflexors	3	4	5	3	4+	5
Plantarflexors	2	3	4+	2	4	5
Invertors/Evertors	3	4	4+	3	4+	5

Functional Independence

At baseline, both patients were dependent on crutches and unable to perform daily tasks involving prolonged standing or walking. By six weeks, the surgical patient had progressed to partial independent ambulation with reduced use of assistive devices, while the conservative patient remained dependent on one crutch. At twelve weeks, both patients achieved independent ambulation. The conservative patient still reported fatigue and discomfort after long-distance walking, while the surgical patient reported stiffness but was able to perform most daily activities.

Table 4. Exercice progression

Time point	Case 1 (Conservative)	Case 2 (Surgical)
Baseline	Non-weight bearing, two crutches	Non-weight bearing, two crutches
6 weeks	Partial weight-bearing, one crutch	Partial to full weight-bearing, cane only
12 weeks	Independent ambulation, fatigue at >1 km	Independent ambulation, minor stiffness

Summary of Results

Overall, the surgical case demonstrated a faster recovery trajectory, particularly regarding pain reduction, ROM, and muscular strength. However, both cases reached functional independence by the end of the twelve-week program. The conservative patient exhibited persistent limitations in subtalar mobility and endurance, whereas the surgical patient showed residual stiffness during sudden changes of direction. These findings suggest that although surgical management may accelerate early recovery, conservative management, when combined with structured rehabilitation, can achieve comparable long-term independence.

Data Analysis

Given the small sample size, no statistical analysis was performed. Instead, data were presented descriptively, highlighting trajectories of improvement across the measured variables. Tables and figures were used to illustrate the progression of pain reduction, ROM increase, muscle strength recovery, and improvements in functional independence. The qualitative comparison between the conservative and surgical case provided insights into how the rehabilitation program influenced outcomes depending on the initial treatment strategy.

Analysis of results

The initial testing results of the ninth-grade students indicate a similar level of motor skills between the two subject groups, as reflected by the average values obtained. Thus, the experimental group recorded an average of 12.83, while the control group had an average of 12.66, confirming the homogeneity of the motor skill level between the groups at the start of the experiment.

Although the initial tests showed a comparable degree of motor skills, the final tests revealed improvements in both groups, with a more pronounced progress in the experimental group. The latter demonstrated a superior capacity for performance development, the difference between the final averages being 16 for the experimental group and 13 for the control group.

The progress recorded by the experimental group was statistically significant, at a significance level of $p < 0.0005$. To illustrate these differences between the averages, Graph no. 1 was created:

Discussions

The present study investigated the role of a biomechanically guided rehabilitation program in two patients with calcaneal fractures managed through different medical approaches: conservative immobilization and surgical reduction with internal fixation. Although limited by the case-series design, the findings contribute valuable insights into how rehabilitation can be adapted to individual clinical contexts while adhering to biomechanical principles.

The results indicated that both patients achieved functional independence by the end of the twelve-week rehabilitation protocol, but the recovery trajectories differed. The surgically treated patient demonstrated faster pain reduction and earlier restoration of mobility. These outcomes are consistent with previous studies reporting that surgical intervention facilitates anatomical alignment, which improves plantar force distribution and allows earlier mobilization (Buckley & Tough, 2004; Ibrahim et al., 2007). However, residual subtalar stiffness and occasional discomfort persisted, echoing findings from the literature that even well-reduced fractures rarely return to full functional capacity (Rubenson et al., 2021; Schepers et al., 2008).

Conversely, the conservatively managed patient showed slower progress, with prolonged edema and delayed restoration of motion in the subtalar joint. Nevertheless, the patient ultimately achieved independence in daily activities, demonstrating that conservative treatment can be effective when combined with a carefully structured physiotherapy program. This observation aligns with reports highlighting that conservative treatment, although slower, can yield outcomes comparable to surgery when rehabilitation is rigorous and individualized (Ibrahim et al., 2007; Neagu, 2024).

From a biomechanical perspective, several principles underpinned the rehabilitation protocol applied in this study. First, gradual weight-bearing progression respected the load tolerance of the healing calcaneus and ensured correct redistribution of plantar pressures, a concept strongly emphasized in biomechanical analyses of the hindfoot (Angin & Demirbüken, 2022). Second, targeted mobilization of the subtalar joint was essential to re-establish inversion and eversion mechanics, which are crucial for adapting gait to uneven surfaces. Third, strengthening of plantarflexors, dorsiflexors, and peroneals addressed muscle groups most affected by immobilization, while proprioceptive training was used to restore neuromuscular control and prevent compensatory gait strategies, consistent with modern sports rehabilitation principles (Neagu, 2024).

The findings also reflect the broader consensus that rehabilitation after calcaneal fractures must be individualized and biomechanically informed rather than standardized (Schepers et al., 2008). Patients with surgical fixation may benefit from earlier mobilization, whereas those treated conservatively may require extended pain and edema management. Regardless of the pathway, both require structured physiotherapy that balances tissue protection with functional restoration.

Another key aspect highlighted by this study is the psychosocial dimension of recovery. Although not formally assessed, both patients reported frustration during periods of limited mobility and expressed relief as independence was regained. This is in line with research suggesting that long-term disability after calcaneal fractures is not only physical but also psychological, affecting quality of life and return to work (Rubenson et al., 2021). Patient education, especially when integrating biomechanical explanations, may enhance adherence and confidence during the rehabilitation process.

Limitations and Future Directions

The primary limitation of this study is the very small sample size, which precludes generalization. The absence of objective gait analysis or plantar pressure measurements limited the capacity to quantify biomechanical changes. Furthermore, follow-up ended at twelve weeks, and long-term outcomes such as return to work, participation in sports, and risk of post-traumatic arthritis were not assessed. Future research should involve larger cohorts, standardized outcome measures, and longer follow-up periods. Incorporating technologies such as 3D gait analysis or baropodometric platforms could provide deeper insights into how biomechanical restoration evolves over time.

Conclusions

Rehabilitation after calcaneal fractures is complex and must be tailored to the patient's clinical background. This study demonstrated that both conservative and surgical patients can achieve satisfactory outcomes when rehabilitation is structured around biomechanical principles. Physiotherapy focusing on pain control, progressive mobilization, muscle

strengthening, proprioceptive training, and gait re-education proved effective in restoring function. Surgical treatment may accelerate the recovery process, but conservative management remains a viable option if followed by rigorous rehabilitation. Ultimately, individualized, biomechanics-based rehabilitation programs are essential for minimizing disability and optimizing quality of life.

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