Proceedings of ICBioMed 2025 Symposium: AI for Healthcare: Advanced Medical Data Analytics and Smart Rehabilitation
DOI: 10.54254/2753-8818/2025.AU26770

Rehabilitation Effects on Ankle Kinematics after Recurrent Sprains

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Abstract. Repeated ankle sprains are a common concern for sports enthusiasts. This type of injury is predisposed to chronic ankle instability and disturbing joint kinematics. Biomechanical changes such as limited dorsiflexion range of motion (ROM), abnormal inversion–eversion patterns, and compensatory movement strategies also contribute to an increased risk of reinjury. The aim of this paper is to determine the effect of targeted rehabilitation interventions on ankle kinematics in individuals with a history of recurrent sprain. These programs are usually structured and composed of balance training, proprioceptive exercises and strengthening exercises for peroneal and calf musculature with significant achievements regarding dorsiflexion range movement, restoration of more symmetrical inversion–eversion mechanics outcome, and functional instability mitigation. In addition, neuromuscular (incorporating agility drills) training improves dynamic stability, encourages symmetrical loading patterns during gait and landing, and ensures a safe return to sport-specific activities. While the results of this study confirm that a comprehensive rehabilitation program emphasizing kinematics restores mechanical and neuromuscular function, they also highlight the importance of doing so to prevent future recurrence and maintain an anatomically intact ankle joint.

Keywords: Ankle kinematics, rehabilitation, instability.

1. Introduction

Ankle sprains are among the most common musculoskeletal injuries, accounting for a large fraction of sports-related and, therefore, regular everyday injuries globally. They are most common in physically active populations such as athletes, military personnel and people who exercise recreationally. Lateral ankle sprains are thought to make up approximately 85% of all ankle sprains, with inversion trauma being the leading mechanism [1]. Although the majority of patients do well with nonoperative management, others develop recurrent sprains or chronic ankle instability (CAI), and this can occur in up to 40% [2]. This recurrence is frequently due to persistent joint derangement, proprioception deficits, neuromuscular control failure and poor muscle strength. Recurrent ankle sprains may lead to substantial changes in normal ankle kinematics. It can present as a limited range of motion in dorsiflexion, overpronation during normal walking and altered subtalar joint mechanics leading to compensatory changes at the knee and hip [3]. These biomechanical adaptations may affect functional ability and increase the risk of additional injury, as

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DOI: 10.54254/2753-8818/2025.AU26770

well as degenerative changes, including development of ankle arthritis at an early age. Moreover, impaired sensorimotor function after such an injury is likely to disrupt the feedforward and feedback mechanisms relevant for postural control. This can place the ankle at increased risk for instability during dynamic activities.

Rehabilitation is a cornerstone for the management of these deficits and to normalize kinematic patterns. The aims of traditional programming: Restoring the range of motion (ROM) in dorsiflexion and plantarflexion. A structured strength program of peroneal, gastrosoleus soleus and deeper intrinsic foot muscles for joint stability. Proprioceptive and balance training to improve sensorimotor integration, postural control [4]. Additionally, more advanced programs against a program that involves plyometrics, agility drills and sport-specific training may reduce the risk of re-injury while prepping an individual to return to play.

There is evidence to suggest that targeted rehabilitation interventions can lead to measurable improvements in ankle kinematics. For instance, balance training has been shown to normalize inversion–eversion patterns during gait, and proprioceptive exercises have been found to enhance joint position sense and dynamic stability [5]. Manual therapy, particularly joint mobilization, has been shown to be effective in improving dorsiflexion range of motion (ROM), which is essential for normal walking, running and squatting mechanics [6]. Furthermore, combining neuromuscular training with traditional strengthening programs has been associated with enhanced movement symmetry and reduced re-injury rates [7].

Despite the proven benefits of rehabilitation, a deeper understanding of its specific effects on ankle kinematics in individuals with recurrent sprains is still needed. While many existing studies focus on functional outcomes such as balance and strength, fewer investigate how these interventions influence joint motion patterns during dynamic tasks. Gaining this understanding is crucial for refining rehabilitation protocols, developing objective assessment tools and enhancing long-term outcomes. Therefore, this study aims to examine the effects of rehabilitation on ankle kinematics following recurrent sprains. This information will be valuable to not only clinicians and sports medicine professionals, but also coaches, athletes and individuals engaged in high-risk activities.

2. Rehabilitation treatment for recurrent lateral ankle sprains

2.1. Pathological mechanisms and kinematic changes of recurrent lateral ankle sprains

Repeat lateral ligament for ankle sprains, which also can cause a series of kinematic changes, are predominantly expressed as reduced walking range of motion, reverse inversion supination disorder and relaxing moment and treat instability. This lack of flexibility and sensory impairment may contribute to inappropriate motor patterns in the hip and knee, leading to chronic joint stiffening or an abnormal gait. That means the left and right ankles create force in an asymmetric way, a phenomenon that can impair functional mobility so that one not only doesn't do something well as they should, but their capacity to move is limited because of activity limitations — these lead to injury. They may even cause an increased risk of more severe injuries. Rehabilitation effectively starts with normalizing ankle abduction and inversion/eversion control, and progresses to dynamic stability as balance and proprioceptive training are reintroduced. Stretching your gastrocnemius and lower leg muscles helps keep them in shape. Neuromuscular and agility training, those as perceptual-motor coordination; unarmed therapy and taping, along with joint mobility and dynamic function. The ultimate aim of addressing the last site of injurious rehabilitation and self-stabilization is to normalize gait mechanics, reduce compensatory strategies around the ankle joint and prevent

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another incident in the future. Dorsiflexion has been found to be significantly increased and loading kinetics improved with joint mobilization in the acute [1]. This suggests a mechanically advantageous change post-mobilization, as evident from a 3° decrease in the plantar and flexion angle at initial contact identified by a controlled study done on individuals with chronic ankle instability (CAI) [1]. Another study found that a 4-week mobilization intervention could similarly induce significant increases in the step speed and maximum dorsiflexion angle and first peak vertical ground reaction force (vGRF) during gait [2]. This will aid in recovering some of the dorsiflexion ability and increase weight-bearing stability in those with chronic instability [3]. Ankle dorsiflexion is important for proper gait, balance and many athletic movements. Recurrent lateral ankle sprain results in decreased dorsiflexion secondary to capsule tightness, scar tissue, along with altered joint motion. Restrictions become limitations that reduce mobility and exacerbate compensatory loading in the knee or hip joint. Manual therapy technique of joint mobilization refers to broad-based, slow single or repetitive passive accessory motion applied at varying amplitudes aimed to restore normal arthrokinematics, aimed toward increasing dorsiflexion range of motion.

2.2. The role and mechanism of joint mobilization surgery in rehabilitation

Research has consistently demonstrated the value of joint mobilization in improving ankle mobility. A key study found that participants with chronic ankle instability (CAI) who underwent anterior-to-posterior talocrural joint mobilization experienced a statistically significant reduction in plantarflexion angle at initial contact during the landing task, indicating improved dorsiflexion control [4]. In addition, posture control is enhanced and neuromuscular coordination is better when landing with one leg, which supports the view that mobilization surgery can reduce mechanical dysfunction and improve joint proprioception. From a biomechanical perspective, joint mobilization can facilitate soft tissue adaptation and neurophysiological responses. Mobilization stimulates the joint capsule's mechanoreceptors and those in the surrounding tissues [5]. This can lead to the inhibition of muscle guarding through a reflex response and enhanced proprioceptive input to the central nervous system. This process increases passive range of motion and improves dynamic joint control, which is essential for preventing future sprains. Furthermore, manual therapy can reduce joint stiffness and improve synovial fluid circulation, promoting tissue healing and restoring mobility [5].

Further research has confirmed the effectiveness of joint mobilization surgery in treating functional disorders after sprains. Hand-operated joint mobilization surgery, especially when combined with weight-bearing training, can significantly improve the dorsiflexion function and functional outcomes of patients with chronic ankle instability [6]. The research results indicate that these improvements are not only statistically significant but also clinically significant and are often associated with improved scores on the Foot and Ankle Ability Scale (FAAM), as well as improved performance on functional tasks such as squatting, stair climbing, and balance tests. In clinical practice, joint mobilization surgery should be included in the rehabilitation process as early as possible, especially for patients with a reduced range of motion or pain at the end of dorsiflexion. Therapists may use Grade III or IV mobilization techniques to address capsular restrictions, followed by active exercises to reinforce the new range of motion. In some cases, mobilization with movement (MWM), a technique combining manual therapy and patient participation, has demonstrated enhanced effects by incorporating neuromuscular activation during joint manipulation [7].

Furthermore, one recent randomized controlled trial investigated the effect of a 4-week joint mobilization intervention on functional gait variables in individuals with functional ankle instability

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(FAI). Patients who underwent mobilization surgery experienced significant improvements in stride length, walking velocity and knee ankle foot orthosis (KAFO) ground reaction force compared to those who received traditional treatment [7]. It is pertinent to mention in this context that the change pattern observed also resulted in more symmetrical and economic distribution of vertical ground reaction forces as well among intervention groups [8].

2.3. Collaborative intervention of balance, proprioception and muscle strength training

Dynamic stability, as measured by the DVJ test, improved significantly in exercises promoting balance [wobble board ($p = 0.023$), perturbation drills and single leg stance] for proprioception tasks. The SEBT, CAIT and FAAM all reflect either objective or subjective changes in outcomes [9]. A previous systematic meta-analysis found that long-term, multidimensional exercise treatment significantly improved SEBT reach distances and FAAM outcomes as well. Each of these studies identified different forms of therapy as being beneficial to correcting individual directional deficits: joint mobilization, strength training and proprioceptive training, respectively [2]. When the training is done in isolation, it helps to prevent the recurrence of the sprain as well. A meta-analysis of over 3700 participants demonstrated that with proprioceptive programming, the ankle sprain risk decreased in all subjects ($RR = 0.64$ for previous sprains) [10]. Stable through the proper activation and strengthening of the peroneal and calf muscles. Both of the latter are responsible for joint position sense and functional stability, so exercises that target these muscle groups may be beneficial. A prospective controlled study suggests that joint repositioning in patients with CAI improves following strengthening interventions [3]. This strategy helps to further develop sensorimotor integration while reducing compensatory mechanics, such as by coupling strength. The same applies to agility drills and plyometric training, but with a focus on the dynamic neuromuscular control of the ankle joint. They allow timely activation of stabilising muscles and facilitate anticipatory contraction patterns that are protective of inversion injuries. While fewer randomized trials of these types of interventions are available, they are routinely recommended in RTS protocols and clinical practice guidelines as part of restoring lumbo-pelvico-femoral movement mechanics and confidence with weight-bearing [11]. Combined rehabilitation programs integrating manual therapy, proprioception, strength and dynamic exercises have also been shown to result in improvements in kinematics, including increased dorsiflexion during gait5, and 6, decreased inversion at initial contact7, more symmetrical movement patterns (63%)8 and reduced need for compensatory hip movements with subsequent decrease in knee strategies3. For example, the future trial of joint mobilization reported improvements in normalized step speed and plantarflexion control [2]. These interventions are said to lower the probability of forming chronic ankle instability and re-rupture. This will go on to result in improved outcomes such as long-term athletic performance, foot and ankle functionality (FAAM), confidence in dynamic movement and reduced likelihood of re-injury [2]. Allowing joint movement in abduction range, for example, should help limit plantarflexion during landing (improving shock absorption) and increase dorsal extension during gait. Balance intervention may lead to baseline normalization of the contact distance at SEBT and improved measures in posture control. Improved postural control will enhance recovery and stabilize movement in dynamic tasks. Exercises that are targeted at the condition can help in bettering joint position perception as well as muscle responsiveness, which involves strength and sensorimotor integration. Good integration with mobility, control, and flexibility training will cover the need for over-compensation at your knees and hip joints by directly addressing the target injury site from working independently. Furthermore, the proprioceptive training of the entire system can greatly decrease the risk for re-sprains [10]. Given these results, clinicians should apply

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individualized rehabilitation programs to patients who have recurrent ankle sprains. These protocols should be initiated by joint mobilization for increasing dorsiflexion range of motion, followed by progressive balance and proprioception to be included within all strengthening neuromuscular exercise programs. Tools such as SEBT, FAAM and CAIT can assist clinicians in identifying patients with specific deficits for targeted interventions [10].

Recent studies of sensory motor training (SMART) interventions similarly underscore that the provision of standardized, integrated programs for restoring perceptual function and motor mechanics outperforms standard care [12]. Such strategies may be different at varying phases of rehabilitation, and are likely necessary in combination to achieve kinematic normalization long-term, with chronic ankle instability less likely to develop. Future research should explore the ideal dose and timing of a mixed strategy to reach these goals. More research is necessary regarding gait biomechanics in order to quantitatively measure remaining increased EMG coactivity or compensatory strategies post-treatment and determine any subsequent risk factors. The rehabilitation of recurrent ankle sprains needs such a clinical approach to rectify abnormal biomechanics and neuromuscular control. The evidence in review suggests the effectiveness of joint mobilization, proprioceptive training, strength and dynamic movement retraining. To restore kinematic function, a within-systems perspective of movement patterns and sensorimotor control throughout the lower kinetic chain is needed, not only joint-directed intervention. One of the fundamental clinical implications based on this idea is to start with an early restoration of dorsiflexion by means of joint mobilization. Limited dorsiflexion range of motion has consistently been associated with aberrant walking mechanics, lower capacity for shock attenuation, and greater compensatory loading at proximal joints. As such, clinicians should examine dorsiflexion during both open and closed chain activities, along with focusing on mobilization strategies (e.g., talocrural glides or mobilizations with movement) to the terminal-end ranges of motion. Immediate gains in dorsiflexion following manual therapy should be trained through functional weight-bearing exercises like deep squats, step-downs and lunge progressions to provide the motor system a stimulus to retain the new range. Proprioceptive and balance training can be initiated soon after the initial phase of rehabilitation and should be included in all phases of rehab. Outcomes and therapeutic exercises can be combined using tools such as the Star Excursion Balance Test(SEBT) and Y-Balance test [9]. Perturbation training, which is characterized by unexpected balance disturbances to challenge postural control, promotes real-time sensorimotor adaptation and prepares athletes for the unpredictability of dynamic environments. Muscular asymmetries and neuromuscular deficits of the peroneal and intrinsic foot muscle groups should also be a clinical priority. For those athletes, strengthening programs should include isometric holds, isotonic resistance and high-speed eccentric loading as sport-specific movements require [3]. Clinicians can use an EMG-based biofeedback or pressure-sensing insoles to assess muscle firing patterns during gait and prescribe individualised correction strategies for patients who maintain a compensatory pattern. Sport-specific agility drills, reaction-time training, and fatigue-resistance conditioning should be incorporated into return-to-sport protocols for athletes [11]. Functional testing can be made performance-ready in the form of a single-leg hop for distance, lateral bound and timed up-and-go tests that may reveal residual asymmetries. Yet static function may improve in injured athletes while more subtle dynamic deficits remain, which place them at risk for re-injury. Future studies should aim to elucidate the ideal treatment combinations and dosages for different patient populations (e.g., adolescents, athletes, patients with generalized ligamentous laxity). Longitudinal studies that track changes in kinematics six to twelve months after rehabilitation will delineate which interventions lead to long-term benefits with regard to the prevention of chronic ankle instability (CAI) [12]. Also, integration with wearable technology like

DOI: 10.54254/2753-8818/2025.AU26770

inertial motion sensors and mobile gait trackers is providing opportunities for objective and real-time measurement abilities during clinic-based or naturalistic movement evaluation. Improved terminology and diagnostic criteria for ankle instability are also needed. Given, for instance, that the clinical presentations of FAI and MAI often overlap despite potentially distinct implications for treatment pathways. Consensus definitions and targeted intervention algorithms could increase the specificity of rehabilitation and the ability to generalize research [12]. And do not forget the importance of patient education and compliance. For example, explaining to patients why they are doing them and setting goals with their provider can also serve as mediators, as well as providing tools for use at home, like resistance bands or balance pods. Individuals returning to high-impact or cutting sports with an elevated risk for subsequent injury should be advised of a home program that incorporates balance drills and ankle-specific strengthening exercises, post-discharge [10].

3. Conclusion

No study has evaluated the effects of targeted rehabilitation on ankle kinematics in individuals with recurrent lateral ankle sprains. These results indicate that rehabilitation programmes consisting of joint mobilisation, proprioception training, strength and dynamic movement retraining can improve measures associated with each theory of CAI. Especially anterior-to-posterior talocrural joint mobilisation reduced the plantarflexion angle at initial contact and increased weight-bearing dorsiflexion, which were accompanied by significant improvements in landing kinematics. Balance and proprioception training can significantly improve postural control (SEBT + FAAM). The use of isolated proprioceptive programmes resulted in a >35% lower rate of recurrent sprains. Strength training of the peroneal and calf muscles will enhance joint position sense and dynamic stabilization. Together, these findings indicate that integration of exercise specifically targeted for the mechanical aspects of ankle stability, combined with agility drills, promotes anticipatory neuromuscular activation patterns that protect against inversion injuries. Implementing integrated, sport-specific protocols produced greater improvements in movement symmetry and lower knee and hip compensatory loading as well as significantly higher performance levels on functional tests (single leg hops and single leg lateral bounds). These results highlight the critical need for concurrent attention to mechanical and neuromuscular deficits in rehabilitation programs if normal ankle kinematics are to be restored and re-injury is to be prevented. This study has clinical implications that could reduce the development of chronic ankle instability by providing clinicians, sports medicine practitioners, and coaches with data to include in their treatment protocols for long-term joint health in active populations.

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