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Research Article

Influence of an Incisura Fibularis Guided Rehabilitation Protocol on Balance and Stability in Patients with Chronic Ankle Instability

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Abstract

Background: Chronic ankle instability (CAI) frequently follows lateral ankle sprains, resulting in recurrent giving way, reduced confidence, and impaired postural control. While conventional rehabilitation emphasizes strength, balance, and proprioception, it rarely accounts for anatomical variation in the incisura fibularis. To date, no randomized trial has directly tested whether tailoring rehabilitation to tibial notch morphology provides additional benefit, creating a gap this study aimed to address.

Methods: Sixty adults (18–40 years) with chronic ankle instability and radiographically confirmed R-shaped incisura fibularis were randomly allocated to Group A (tailored rehabilitation, n = 30) or Group B (conservative management, n = 30). Both groups completed a 12-week program (five sessions per week, 45–60 minutes each). Primary outcomes were the Cumberland Ankle Instability Tool (CAIT) and Y Balance Test (YBT) composite score, assessed at baseline and 12 weeks by blinded physiotherapists.

Results: After 12 weeks, both groups improved significantly ($p < 0.01$), but Group A achieved greater gains. CAIT scores increased by 8.4 points (15.4 ± 3.1 → 23.8 ± 2.8) versus 4.3 points in Group B (15.6 ± 3.0 → 19.9 ± 3.2), yielding a mean difference of 3.9 points (95% CI: 2.1–5.7; Cohen's d = 0.82; $p < 0.001$). Y Balance Test composite scores improved by 9.9% in Group A (66.8 ± 4.2 → 76.7 ± 4.5) versus 4.2% in Group B (66.7 ± 4.1 → 70.9 ± 4.8), with a mean difference of 5.8% (95% CI: 3.0–8.6; Cohen's d = 0.78; $p < 0.001$).

Conclusion: The tailored rehabilitation program was associated with greater 12-week improvements in ankle stability and dynamic balance compared to conservative management in this selected subgroup with R-shaped incisura fibularis. These findings highlight the value of exercise specificity and progression, but morphology itself was not tested as a causal factor. Larger trials including varied notch morphologies, extended follow-up, and mechanistic measures are needed to validate and generalize these results.

Keywords: Ankle Injuries; Joint Instability; Rehabilitation; Proprioception; Postural Balance

Introduction

Ankle sprains are among the most prevalent musculoskeletal injuries, often leading to pain, restricted activity, recurrent episodes of giving way, and long term functional limitations [1]. The majority involve the lateral ligament complex, particularly the anterior talofibular ligament, whereas syndesmotic or "high ankle" sprains of the distal tibiofibular syndesmosis are less frequent but typically require prolonged rehabilitation [2]. Chronic ankle instability (CAI) develops in a substantial proportion of cases, characterized by recurrent instability, impaired proprioception, and reduced postural control [3].

While ligament injury is central to CAI, anatomical variation may also influence joint stability. The incisura fibularis the tibial notch that accommodates the distal fibula contributes to tibiofibular alignment and ankle mortise stability [4]. Morphological differences, such as the R shaped notch, may alter osseous containment and increase reliance on ligamentous and neuromuscular restraint. This biomechanical relationship provides a rationale for investigating whether incisura fibularis morphology influences rehabilitation outcomes.

Conventional rehabilitation for CAI emphasizes sensorimotor training, strengthening, and balance exercises, often supplemented by manual therapy, taping, or bracing [5]. However, most protocols are not adapted to anatomical variation in the ankle mortise. Recognition of incisura fibularis morphology may therefore justify individualized rehabilitation strategies. Evidence directly comparing standard rehabilitation with morphology guided protocols remains limited, highlighting the need for controlled trials to determine whether tailored exercise selection provides additional clinical benefit.

Aim of the Study

The present randomized controlled trial aimed to evaluate the comparative effectiveness of a 12-week incisura fibularis guided rehabilitation protocol versus conventional conservative management in adults with chronic ankle instability (CAI) and R shaped incisura fibularis. Specifically, the study sought to determine whether tailoring rehabilitation to anatomical variation in the tibial notch would yield superior improvements in Self reported ankle stability, measured using the Cumberland Ankle Instability Tool (CAIT). Dynamic balance performance, assessed through the Y Balance Test (YBT) composite score. The overarching objective was to establish whether morphology guided rehabilitation provides greater clinical benefit than standard care in this population.

Materials and Methods

Study design and setting

This study was a randomized controlled trial comparing an *incisura fibularis* guided rehabilitation protocol (Group A) with conventional conservative management (Group B) in adults with chronic ankle instability (CAI) and R shaped *incisura fibularis*. This study was conducted in the Outpatient Department of Nandha College of Physiotherapy, Nandha Medical College and Hospital, Erode.

Randomization and allocation concealment

Participants were randomly assigned to Group A (incisura fibularis–guided rehabilitation) or Group B (conservative management) using a computer-generated random sequence. Allocation was concealed through sealed opaque envelopes prepared by an independent researcher not involved in recruitment or assessment. Outcome assessments (CAIT and YBT) were conducted by physiotherapists blinded to group allocation. Intervention therapists were not blinded due to the nature of the rehabilitation programs. A priori sample size estimation was performed using G*Power 3.1, based on detecting a medium effect size (Cohen's d = 0.6) with 80% power and $\alpha = 0.05$. The required sample was 52 participants; to account for potential attrition, 60 participants were recruited.

Participant flow and withdrawals

Of 84 screened individuals, 60 met eligibility criteria and were randomized (30 per group). All participants completed the 12-week intervention, with no withdrawals or exclusions. No missing data were recorded. Treatment adherence was high, with participants attending >90% of scheduled sessions. Attendance logs were maintained by supervising therapists. No adverse events were reported during the intervention period.

Eligibility criteria

Participants were adults aged 18–40 years presenting with recurrent ankle sprains and symptoms consistent with chronic ankle instability (CAI). CAI was defined according to established clinical criteria: persistence of instability for ≥6 months following the initial sprain, recurrent episodes of "giving way," and positive findings on anterior drawer or talar tilt tests. In addition, the Cumberland Ankle Instability Tool (CAIT) was administered at baseline, with scores below the validated cutoff of 27.5 indicating ankle instability. Individuals were excluded if they had a history of ankle surgery or fracture, neurological disorders likely to impair balance, inflammatory rheumatological disease or degenerative arthritis of the lower limb, or if they had sustained an ankle sprain within the preceding six weeks.

Morphology assessment

Radiographic imaging of the distal tibiofibular joint was performed to classify incisura fibularis morphology. Standard anteroposterior and mortise views were obtained in the Imaging Department. The R-shaped incisura was identified based on radiographic criteria describing a shallow notch with reduced osseous containment. All participants in this trial demonstrated R-shaped morphology, confirmed by two independent assessors (a musculoskeletal radiologist and an experienced orthopedic physiotherapist). Inter-rater agreement was calculated, yielding a kappa coefficient of 0.82, indicating substantial reliability. Morphology classification was performed by a board-certified radiologist with >10 years of musculoskeletal imaging experience, and independently verified by a senior physiotherapist trained in ankle biomechanics. Outcome assessments (CAIT and YBT) were conducted by physiotherapists blinded to group allocation.

Outcome measures

Ethical approval was obtained from the Institutional Ethics Committee of Nandha College of Physiotherapy prior to commencement of the study. Written informed consent was obtained from all the participants before enrolment. Pre and post intervention assessments were conducted using two complementary outcome measures were employed to evaluate the effects of the interventions.

- **Cumberland Ankle Instability Tool (CAIT):** The CAIT is a validated 9-item questionnaire assessing perceived ankle stability during daily and sport activities. Scores range from 0–30, with values below 27.5 indicating chronic ankle instability. Participants completed the CAIT at baseline and after 12 weeks under blinded assessor supervision.
- **Y Balance Test (YBT):** The YBT was administered using a standardized protocol. Participants performed anterior, posteromedial, and posterolateral reach tasks while standing on the test limb, with reach distances normalized to limb length. Three trials per direction were recorded, and the composite score was calculated as the sum of maximal reach distances divided by three times limb length × 100. Assessors were blinded to group allocation. Outcome assessments were performed by physiotherapists who were not involved in delivering the interventions and were blinded to group assignment. Intervention therapists were aware of group allocation but did not participate in outcome measurement.

Intervention protocol

The trial was conducted over eight months, with each participant completing a structured twelve week intervention program. Sessions were delivered five times per week, lasting 45–60 minutes each. Group A followed a morphology specific rehabilitation protocol emphasizing progressive strengthening of the fibularis muscles and other evertors, controlled movement near vulnerable ranges combined with proximal stabilization, and balance tasks incorporating external perturbations. Group B received conventional conservative management, consisting of sensorimotor training, progressive strengthening, joint mobilization, and adjunctive taping or bracing when clinically indicated. This design allowed for a direct comparison between a morphology guided rehabilitation approach and standard care, thereby evaluating whether tailoring exercise selection to incisura fibularis geometry enhances recovery in chronic ankle instability.

Intervention progression criteria

Progression through rehabilitation phases was based on symptom tolerance, movement quality, and task completion. Participants advanced only when pain-free performance and stable alignment were observed. Criteria included controlled eccentric loading without instability, successful completion of balance tasks, and safe execution of functional drills. Interventions were delivered by licensed physiotherapists with at least 5 years of musculoskeletal rehabilitation experience. All therapists underwent protocol-specific training sessions before trial commencement to ensure consistency. Fidelity was monitored through weekly supervision and adherence checklists. Attendance logs confirmed that participants completed >90% of scheduled sessions. Missed sessions were rescheduled within the same week to maintain treatment dose equivalence across groups. Adjunctive treatments such as taping or bracing were permitted only when clinically indicated and were documented. No pharmacological or surgical co-interventions were reported during the study period.

The intervention details are summarized in tabular format, with the Group A incisura fibularis guided rehabilitation protocol presented in Table 1, and the Group B conservative management protocol outlined in Table 2.

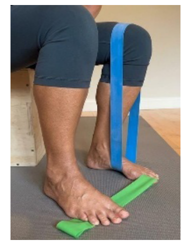
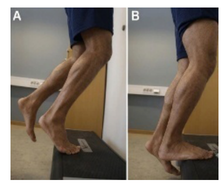
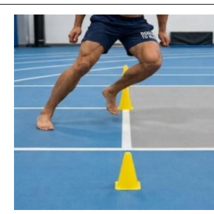
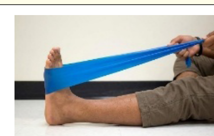
Phase and Duration	Clinical Rationale and Targeted Interventions	Photos
Phase 1: Foundation and Motor Activation (Weeks 1-4)	Interventions: Resisted eversion with concentric/eccentric control Hip abductor and trunk stabilization with foot posture control Adjunctive mobilization/taping only if clinically indicated Progression: Advance when pain-free eversion is performed with stable alignment and ≥90% adherence. Physiotherapist monitored technique quality; weekly fidelity checks	 Isolated peroneal resistance band setup.
Phase 2: Dynamic Control (Weeks 5-8)	Interventions: Controlled eccentric loading toward plantarflexion/inversion Reactive balance with planned/unanticipated perturbations Closed-chain squats, lunges, step tasks with alignment monitoring Progression: Progress when participant completes 3 consecutive sessions without instability or compensatory movement. Therapist ensured safe perturbation intensity and documented adherence.	 Controlled end-range eccentric loading drills.
Phase 3: Functional Progression (Weeks 9-12)	Interventions: Agility drills (acceleration, deceleration, cutting) Landing tasks progressing from bilateral to single-leg Sport/occupation-specific task exposure Progression: Advance when participant demonstrates controlled landings and safe multidirectional agility. Therapist supervised progression, matched tasks to individual sport/activity demands.	 High-speed multi-directional cutting maneuver.

Table 1: Group A: Incisura Fibularis Guided Protocol.

Phase and Duration	Standard Clinical Interventions	Photo
Phase 1: Initial Rehabilitation (Weeks 1-4)	Interventions: Supported/unsupported single-leg stance Four-direction ankle resistance exercises Bilateral heel raises Talocrural mobilization/ROM exercises Progression: Progress when participant maintains 30s single-leg stance without loss of balance. Therapist verified correct resistance-band technique and adherence logs.	 Four-way ankle resistance band exercises.

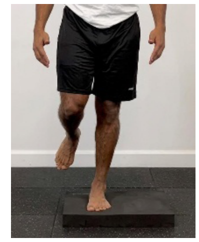
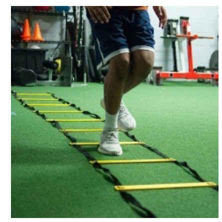
Phase 2: Progressive Rehabilitation (Weeks 5-8)	Interventions: Balance on foam pads/wobble boards Advanced resistance-band exercises Single-leg heel raises Body-weight squats Progression: Advance when participant performs 3 sets of heel raises with proper technique and tolerates unstable surfaces. Therapist monitored progression intensity and corrected compensations.	 Single-leg balance drill on a foam pad
Phase 3: Return to Function (Weeks 9-12)	Interventions: Straight-line jogging Basic ladder drills Bilateral jumping tasks. Progression: Progress when participant completes jogging and ladder drills without instability or pain. Therapist supervised graded return-to-activity sequence and documented adherence.	 Linear agility ladder drill.

Table 2: Group B: Conservative Management.

The incisura fibularis–guided rehabilitation program (Group A) was designed to address the specific biomechanical vulnerabilities associated with R-shaped tibial notch morphology. It emphasized targeted peroneal and evertor strengthening, controlled eccentric loading near instability ranges, perturbation training, and proximal hip and trunk stabilization. In contrast, the conservative management program (Group B) followed a standard progression of balance, strength, and mobility exercises without morphology-specific tailoring. Both protocols were delivered with equivalent treatment dose (frequency, duration, and session length), therapist oversight, and adherence monitoring, ensuring that observed differences in outcomes reflected the content and specificity of the rehabilitation strategies rather than treatment volume.

Data analysis

Descriptive statistics were reported as means and standard deviations. Paired *t* tests were used for within group pre post comparisons, while unpaired *t* tests were applied for between group post intervention comparisons. Owing to the unusually low variability in recorded change scores, the raw data should be verified against original case records prior to submission.

Table 3 presents the demographic and clinical characteristics of the study participants, including age distribution, sex, and ankle injury incidence. The study population consisted of relatively young adults with a mean age of 27.4 years, reflecting an active demographic commonly affected by recurrent ankle sprains. Both sexes were represented, with a slightly higher proportion of males (56.7%) compared to females (43.3%). All participants demonstrated chronic ankle instability with an average duration of 14.2 months since the initial sprain and approximately three recurrent episodes per individual. Radiographic assessment confirmed R shaped incisura fibularis morphology in every case, ensuring a homogeneous sample for evaluating the comparative effectiveness of the rehabilitation protocols.

The comparative outcomes of Group A (*incisura fibularis* guided rehabilitation) and Group B (conservative management) are presented in Tables 4.

Result

At baseline, both groups demonstrated comparable deficits in subjective stability and dynamic balance. After 12 weeks, both

Variable	Group A (n = 30)	Group B (n = 30)	Total (N = 60)
Age (years, mean ± SD)	27.6 ± 5.4	27.2 ± 5.8	27.4 ± 5.6
Sex (Male/Female)	17 / 13	17 / 13	34 / 26
Duration since initial sprain (months, mean ± SD)	14.5 ± 3.6	13.9 ± 4.0	14.2 ± 3.8
Recurrent episodes (mean ± SD)	3.2 ± 1.1	3.0 ± 1.3	3.1 ± 1.2
Incisura fibularis morphology	R shaped (100%)	R shaped (100%)	

Table 3: Demographic and Clinical Characteristics of Participants.

Parameters	Group A (n = 30) (Mean ± SD)	Group B (n = 30) (Mean ± SD)	Paired *t* Value	Unpaired *t* Value	P value	Mean Difference (95% CI)	Cohen's d
CAIT	23.80 ± 2.80	19.90 ± 3.20	A: 11.02 B: 11.23	5.02	< 0.001	3.90 (2.10 – 5.70)	0.82
YBT	76.70 ± 4.50	70.90 ± 4.80	A: 5.45 B: 4.61	4.83	< 0.001	5.80 (3.00 – 8.60)	0.78

Table 4

groups showed significant within-group improvements ($p < 0.01$). Group A achieved superior outcomes: CAIT improved by 8.4 points (from 15.4 ± 3.1 to 23.8 ± 2.8), compared with 4.3 points in Group B (from 15.6 ± 3.0 to 19.9 ± 3.2). Similarly, the Y Balance Test composite score increased by 9.9% in Group A (from 66.8 ± 4.2 to 76.7 ± 4.5) versus 4.2% in Group B (from 66.7 ± 4.1 to 70.9 ± 4.8). Between-group analysis confirmed highly significant differences favoring Group A (CAIT mean difference = 3.9 points, 95% CI: 2.1–5.7, Cohen's d = 0.82, $p < 0.001$; YBT mean difference = 5.8%, 95% CI: 3.0–8.6, Cohen's d = 0.78, $p < 0.001$).

Overall, these findings indicate that the morphology guided rehabilitation protocol produced greater gains in both self reported ankle stability and dynamic balance performance compared to conventional conservative management. The results support the clinical relevance of tailoring rehabilitation strategies to anatomical variation in the incisura fibularis.

Discussion

This randomized controlled trial compared a 12-week incisura fibularis–guided rehabilitation protocol with conventional conservative management in adults presenting with chronic ankle instability (CAI) and R-shaped incisura fibularis. Both groups demonstrated significant improvements in perceived ankle stability and dynamic balance; however, Group A achieved superior gains. Specifically, post-intervention CAIT scores improved to 23.8 ± 2.8 in Group A compared with 19.9 ± 3.2 in Group B, while YBT composite scores reached 76.7 ± 4.5 versus 70.9 ± 4.8, respectively. Between-group differences were statistically significant, with large effect sizes (CAIT Cohen's d = 0.82; YBT Cohen's d = 0.78), confirming clinically meaningful benefits of the tailored program.

These findings contribute to the limited literature examining the role of incisura fibularis morphology in ankle stability. Liu., *et al*. (2017) reported that fibular notch shape was associated with recurrent lateral ankle sprain, with flat configurations carrying the highest risk and gamma-shaped notches being least common [6]. The present study focused on the R-shaped notch, which Liu's cohort did not identify as most hazardous, raising questions about whether reduced osseous containment relative to a deep concave notch explains the observed instability, or whether radiographic classification differs from computed tomography-based categories. Wittouck., *et al*. (2025) reinforced this uncertainty in their systematic review, noting that the incisura fibularis functions as an intrinsic bony stabiliser yet remains under-investigated, with imaging and classification methods varying widely across studies [7]. To date, no comparable rehabilitation trial has been published, limiting benchmarking of effect sizes.

The tailored program incorporated several components beyond morphology-specific considerations, including targeted peroneal and evertor strengthening, controlled eccentric loading near vulnerable ranges, perturbation training, and proximal hip/trunk stabilization. These elements plausibly enhance reactive lateral control, though mechanistic proof is lacking. Fibular translation, ligament strain, peroneal activation timing, and ankle arthrokinematics were not measured, leaving the physiological basis of improvement speculative. Importantly, treatment dose was identical across groups in terms of frequency, duration, and session length, suggesting that specificity, progression, and challenge of exercises rather than volume accounted for the superior outcomes. Because all participants shared the same R-shaped morphology, the trial does not establish morphology itself as a causal factor in rehabilitation response.

Clinical interpretation must distinguish statistical from practical significance. Hiller., *et al.* (2006) validated the CAIT and identified a discriminating threshold near 27.5, with sensitivity of 82.9% and specificity of 74.7% [8]. In the present study, Group A achieved a mean post-intervention score of 23.8, and Group B 19.9, both below the threshold, indicating that participants would still be classified as unstable at 12 weeks. Nevertheless, the between-group difference of 3.9 points exceeded published estimates of the minimal clinically important difference (MCID), and both groups surpassed the MCID internally, confirming that conservative management also delivered meaningful benefit.

Clinical interpretation must distinguish statistical from practical significance. Hiller., *et al.* (2006) validated the CAIT and identified a discriminating threshold near 27.5, with sensitivity of 82.9% and specificity of 74.7% [8]. In the present study, Group A achieved a mean post intervention score of 23.60 and Group B 19.37, both below the threshold, indicating that participants would still be classified as unstable at 12 weeks. Nevertheless, the between group difference of 4.23 points exceeded published estimates of the minimal clinically important difference (MCID), and both groups surpassed the MCID internally, confirming that conservative management also delivered meaningful benefit.

Several limitations constrain interpretation. The change scores exhibited unusually low variability, producing large paired test statistics; reconciliation against original case records is essential before treating these estimates as reliable. Random sequence generation, allocation concealment, and assessor blinding were not fully documented, leaving outcomes vulnerable to bias. Planned four-week follow-up data were not reported, limiting insight into retention of benefit. Direction-specific reach values in the YBT were not analysed, which may have obscured asymmetries relevant to functional performance.

In summary, the superior improvements observed in Group A reflect the broader benefits of a comprehensive and progressive rehabilitation program delivered to participants with R-shaped incisura morphology, rather than morphology-dependent effects alone. Future studies including participants with varied notch morphologies, larger sample sizes, and mechanistic measures are required to clarify the interaction between bony anatomy and rehabilitation response.

Conclusion

The tailored rehabilitation program was associated with greater 12-week improvements in perceived ankle stability and dynamic balance compared to conservative management in this selected subgroup of patients with R-shaped incisura fibularis. These findings suggest that exercise specificity and progression enhance recovery in chronic ankle instability, but they do not confirm that morphology alone determines treatment effectiveness. Future research should include participants with varied notch morphologies, employ larger sample sizes, and incorporate mechanistic measures to clarify the interaction between bony anatomy and rehabilitation outcomes.

The concept of tailoring rehabilitation content to individual bony anatomy is promising, but current evidence does not justify routine radiographic screening in CAI. Future research should evaluate the reliability of notch classification, cost effectiveness, radiation exposure, and impact on treatment decisions before recommending morphology based rehabilitation as standard practice.

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Conflict of Interest

The authors declare no conflict of interest.

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