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*Original Article*

# Biomechanical Adaptations in Foot Posture and Their Relation to Prevalence of Medial Tibial Stress Syndrome in Adolescent Cadets: A Cross-Sectional Study

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## ABSTRACT

*Background: Medial Tibial Stress Syndrome (MTSS) is a common overuse injury in physically active populations, particularly in military trainees. Alterations in foot posture, including pronation and supination, have been implicated in abnormal tibial loading patterns that may predispose individuals to MTSS. Adolescent cadets, undergoing repetitive high-impact training on hard surfaces, represent a high-risk group; however, data on MTSS prevalence and its association with foot posture in South Asian military settings remain limited. Objective: To determine the prevalence of MTSS and its association with biomechanical adaptations in foot posture among adolescent cadets undergoing military-style training. Methods: A cross-sectional study was conducted over four months in three cadet training institutions in Pakistan. Two hundred cadets aged 12–20 years, actively engaged in training for at least three months, were assessed using the Foot Posture Index (FPI), Navicular Height Test (NHT), Shin Palpation Test, and Shin Edema Test. MTSS diagnosis required positive results on both Shin Palpation and Shin Edema tests. Associations between foot posture categories and MTSS were examined using Pearson's Chi-square test, with odds ratios (OR) and 95% confidence intervals (CI) calculated. Statistical significance was set at p < 0.05. Results: MTSS prevalence was 43.0% (95% CI: 36.2–50.0). Slightly pronated feet were strongly associated with MTSS on both right FPI (OR = 4.22, 95% CI: 2.65–6.72) and left FPI (OR = 3.89, 95% CI: 2.35–6.43). NHT findings mirrored this trend, with slightly pronated right feet showing the highest association (OR = 4.95, 95% CI: 2.95–8.31). Highly pronated feet also demonstrated significant but lower odds, while highly supinated and neutral feet had the lowest MTSS prevalence. No significant associations were found with gender (p = 0.535) or grade level (p = 0.236). Conclusion: Abnormal foot posture, particularly slight pronation, is significantly associated with MTSS in adolescent cadets. Routine biomechanical screening using FPI and NHT, coupled with targeted preventive interventions, could reduce MTSS risk and improve training continuity. Future longitudinal studies should explore whether correcting foot posture can prevent MTSS progression and recurrence in military trainee populations.*
*Keywords: Medial Tibial Stress Syndrome, foot posture, pronation, adolescent cadets, biomechanics, military training*

## INTRODUCTION

The human foot is a complex anatomical structure designed to bear weight, absorb shock, and facilitate propulsion during ambulation. Foot posture, encompassing arch height, pronation, and alignment, plays a crucial role in lower limb biomechanics and the distribution of ground reaction forces (1). In populations undergoing rigorous physical training, such as adolescent cadets, repetitive high-impact activities including prolonged marching, running, and jumping place sustained mechanical loads on the lower limbs. These repeated stresses can induce biomechanical adaptations in foot posture that may either enhance resilience or increase susceptibility to overuse injuries, particularly Medial Tibial Stress Syndrome (MTSS) (2).

MTSS, commonly referred to as "shin splints," is a prevalent overuse injury characterized by diffuse pain along the posteromedial tibial border. It is especially common in military and athletic populations due to repetitive tibial loading (3). Pathophysiologically, MTSS is believed to result from cumulative microtrauma and excessive bending forces on the tibia, causing periosteal inflammation and impaired bone remodeling (4). Excessive foot pronation and high-arched foot posture have been identified as key biomechanical contributors, altering tibial loading patterns and increasing cortical stress (5). Military-style training environments, which typically involve rigid footwear, hard-surface training grounds, and high volumes of load-bearing activities, may exacerbate these mechanical risks (6).

Epidemiological data from various military cohorts report MTSS incidence rates ranging from 4% to over 50%, with the highest rates occurring during initial training periods when recruits are abruptly exposed to increased physical demands (7). Both intrinsic factors—such as muscle strength, joint flexibility, bone mineral density, and sex-specific anatomical differences—and extrinsic factors—such as footwear type, training surface hardness, and training volume—modulate MTSS risk (8,9). Notably, female recruits often demonstrate higher MTSS prevalence, potentially linked to reduced bone mineral density and variations in lower limb biomechanics (10). Despite these known risk factors, data on MTSS prevalence and its association with foot posture adaptations in adolescent cadets, particularly in South Asian contexts, remain scarce.

Current preventive strategies, including biomechanical screening, footwear modifications, orthotic interventions, and gait retraining, have shown promise in mitigating MTSS risk, yet their implementation in cadet training programs is inconsistent (11,12). Understanding the prevalence of MTSS and its association with specific foot posture adaptations in adolescent cadets is critical for developing evidence-based screening and prevention protocols that could enhance training safety, reduce injury-related attrition, and improve physical performance. This study aims to determine the prevalence of MTSS and its relationship with biomechanical adaptations in foot posture among adolescent cadets undergoing military-style training in Pakistan. It is hypothesized that abnormal foot posture, particularly excessive pronation, will be significantly associated with higher MTSS prevalence in this population.

## MATERIAL AND METHODS

This cross-sectional observational study was conducted over a four-month period following institutional synopsis approval. Data were collected from three cadet training institutions in Pakistan: Lyallpur Girls Cadet College Faisalabad, Al-Noor Grammar School and Cadet Academy, and The Intellect Cadet College Talagang. These institutions provide structured military-style physical training programs for adolescents, including daily drills, endurance running, marching, and load-bearing exercises, typically performed on hard-surface training grounds under standardized schedules.

The target population comprised cadets aged 12–20 years who had been actively participating in military-based training for at least the preceding three months. Participants were recruited using a non-probability convenience sampling approach, with selection based on predefined inclusion and exclusion criteria. Inclusion criteria were male or female cadets within the specified age range, actively training in the cadet program, and able to undergo biomechanical assessment of the lower limbs. Exclusion criteria included any history of current acute or chronic soft tissue injury of the lower extremity; systemic disorders such as diabetes mellitus, arthritis, or neuropathies; current foot ulcers or other diagnosed pathologies; history of hip, knee, ankle, or foot trauma or surgery; dermatological conditions affecting the feet or lower limbs; use of lower limb or foot orthotics; inactivity in training within the past three months; or current participation in physiotherapy.

Prior to participation, written and verbal informed consent was obtained from each cadet, and for minors, consent was also obtained from parents or guardians. The study adhered to ethical principles consistent with the Declaration of Helsinki, with approval granted by the institutional ethics review board. Participants were assured of confidentiality, and all collected data were anonymized.

Data collection was carried out by trained physiotherapists following standardized protocols to ensure inter-examiner reliability. Four validated clinical assessment tools were used to evaluate foot posture and diagnose Medial Tibial Stress Syndrome (MTSS): the Foot Posture Index (FPI) (13), the Navicular Height Test (NHT) (14), the Shin Palpation Test (15), and the Shin Edema Test (16). The FPI involved observing participants in a relaxed barefoot stance with weight evenly distributed, assessing six components of foot alignment from anterior, posterior, and lateral perspectives. The NHT measured the vertical distance from the floor to the navicular tuberosity in a bipedal stance using a ruler or caliper after palpation and skin marking. The Shin Palpation Test involved applying moderate thumb or finger pressure along the posteromedial tibial border to identify diffuse tenderness, while the Shin Edema Test involved visual inspection of the medial and anterior shin for asymmetry, erythema, and swelling.

For MTSS diagnosis, a combined positive result on both the Shin Palpation and Shin Edema tests was considered indicative, a method shown to increase diagnostic likelihood by approximately eightfold compared to either test alone (16). All measurements were performed bilaterally, with the examiner blinded to the participant's training history and self-reported symptoms until after assessment to minimize observer bias. The sample size of 200 participants was calculated using the Raosoft® sample size calculator based on an anticipated MTSS prevalence of 43% from prior literature (17), a 5% margin of error, 95% confidence level, and 80% statistical power.

Data were entered into a secure database and analyzed using IBM SPSS Statistics version XX (IBM Corp., Armonk, NY, USA). Descriptive statistics were computed for demographic and clinical variables. Associations between categorical variables (e.g., foot posture categories, navicular height classification, gender, grade level) and MTSS presence were examined using Pearson's Chi-square test, with statistical significance set at $p < 0.05$. Where relevant, odds ratios (OR) with 95% confidence intervals (CI) were calculated to quantify effect sizes. No imputation was applied for missing data, as all enrolled participants completed the full assessment protocol.

## RESULTS

A total of 200 adolescent cadets participated in the study, with a mean age of 16.07 ± 2.63 years (95% CI: 15.70–16.44), ranging from 12 to 20 years. The sample was predominantly male (n = 171, 85.5%, 95% CI: 80.3–89.6), with females comprising 14.5% (n = 29, 95% CI: 10.4–19.7). Slightly more than half of the cadets were in grades 8–10 (n = 109, 54.5%, 95% CI: 47.5–61.4), while 91 cadets (45.5%, 95% CI: 38.6–52.5) were in grades 11–12.

The overall prevalence of Medial Tibial Stress Syndrome (MTSS) was 43.0% (n = 86, 95% CI: 36.2–50.0). A strong and statistically significant association was observed between MTSS and both right and left foot posture classifications. For the right Foot Posture Index (FPI), cadets with slightly pronated feet had over four times the odds of MTSS compared to those with highly supinated feet (OR = 4.22, 95% CI: 2.65–6.72, $p < 0.001$), while those with highly pronated feet also showed a significant association (OR = 3.88, 95% CI: 2.31–6.51). Similarly, for the left foot, the highest prevalence was in slightly pronated feet (53.49%), yielding nearly fourfold increased odds of

MTSS (OR = 3.89, 95% CI: 2.35–6.43, p < 0.001) compared to highly supinated feet. Highly pronated left foot posture was also significantly associated (OR = 2.91, 95% CI: 1.78–4.77).

**Table 1. Demographic Characteristics of Participants (n = 200)**

| Variable | Category | Frequency (%) | Mean ± SD | Min–Max | 95% CI for Mean |
|---|---|---|---|---|---|
| **Age (years)** | — | — | 16.07 ± 2.63 | 12–20 | 15.70 – 16.44 |
| **Gender** | Male | 171 (85.5) | — | — | 80.3 – 89.6 |
| | Female | 29 (14.5) | — | — | 10.4 – 19.7 |
| **Grade Level** | Grades 8–10 | 109 (54.5) | — | — | 47.5 – 61.4 |
| | Grades 11–12 | 91 (45.5) | — | — | 38.6 – 52.5 |

**Table 2. Prevalence of MTSS and Association with Foot Posture Index (Right & Left)**

| Foot Posture Category | MTSS Present (%) | MTSS Absent (%) | $\chi^2$ (df) | p-value | OR (95% CI) |
|---|---|---|---|---|---|
| **Right Foot** | | | | | |
| **Highly pronated** | 47.60 | 52.40 | | | 3.88 (2.31–6.51) |
| **Slightly pronated** | 44.19 | 55.81 | 83.721 (2) | <0.001 | 4.22 (2.65–6.72) |
| **Highly supinated** | 8.14 | 91.86 | | | Reference |
| **Left Foot** | | | | | |
| **Slightly pronated** | 53.49 | 46.51 | | | 3.89 (2.35–6.43) |
| **Highly pronated** | 38.37 | 61.63 | 66.279 (2) | <0.001 | 2.91 (1.78–4.77) |
| **Highly supinated** | 8.14 | 91.86 | | | Reference |

**Table 3. Association Between Navicular Height Test (NHT) Results and MTSS (Right & Left)**

| NHT Category | MTSS Present (%) | MTSS Absent (%) | $\chi^2$ (df) | p-value | OR (95% CI) |
|---|---|---|---|---|---|
| **Right Foot** | | | | | |
| **Slightly pronated** | 62.79 | 37.21 | | | 4.95 (2.95–8.31) |
| **Excessively pronated** | 29.07 | 70.93 | 47.352 (2) | <0.001 | 2.10 (1.22–3.61) |
| **Neutral** | 8.14 | 91.86 | | | Reference |
| **Left Foot** | | | | | |
| **Slightly pronated** | 60.47 | 39.53 | | | 4.72 (2.82–7.91) |
| **Excessively pronated** | 31.40 | 68.60 | 50.769 (2) | <0.001 | 2.35 (1.36–4.04) |
| **Neutral** | 8.14 | 91.86 | | | Reference |

**Table 4. Association Between Demographics and MTSS**

| Variable | Category | MTSS Present (%) | MTSS Absent (%) | $\chi^2$ (df) | p-value | OR (95% CI) |
|---|---|---|---|---|---|---|
| **Gender** | Male | 83.72 | 86.84 | 0.385 (1) | 0.535 | 0.82 (0.39–1.70) |
| | Female | 16.28 | 13.16 | | | Reference |
| **Grade Level** | Grades 8–10 | 59.30 | 50.88 | 1.403 (1) | 0.236 | 1.40 (0.80–2.46) |
| | Grades 11–12 | 40.70 | 49.12 | | | Reference |

Comparable patterns emerged with the Navicular Height Test (NHT). On the right side, cadets with slightly pronated feet had almost fivefold higher odds of MTSS (OR = 4.95, 95% CI: 2.95–8.31, p < 0.001) compared to those with neutral navicular height, while excessively pronated feet carried more than double the odds (OR = 2.10, 95% CI: 1.22–3.61).

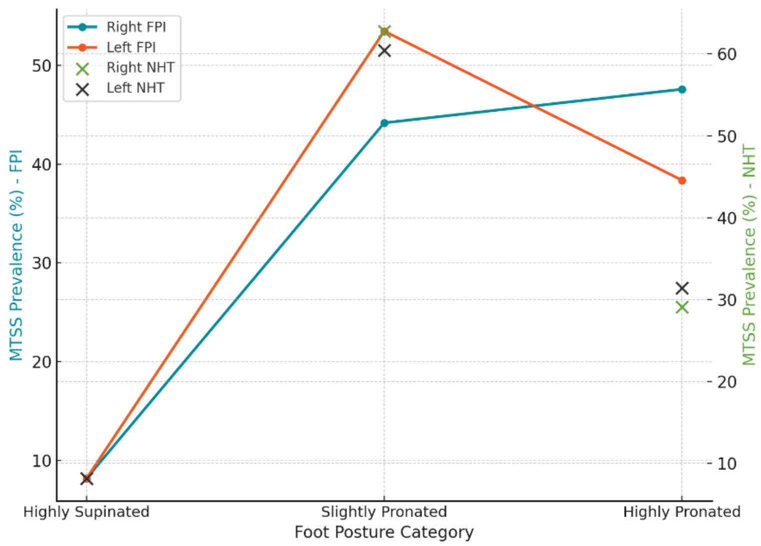


**Figure 1 Association Between Foot Posture Severity and MTSS Prevalence**

On the left side, slightly pronated feet had 4.72 times the odds (95% CI: 2.82–7.91, $p < 0.001$), and excessively pronated feet had 2.35 times the odds (95% CI: 1.36–4.04), both relative to neutral alignment. No statistically significant association was found between MTSS prevalence and gender ($\chi^2(1) = 0.385$, $p = 0.535$), although males represented the majority of MTSS cases (83.72%) in proportion to their higher participation rate. Similarly, grade level did not significantly influence MTSS occurrence ($\chi^2(1) = 1.403$, $p = 0.236$), with 59.30% of cases in grades 8–10 and 40.70% in grades 11–12.

The figure 1 shows that MTSS prevalence was lowest in highly supinated feet (8.14%) across both FPI and NHT measures, while slightly pronated feet consistently exhibited the highest rates—reaching 53.49% (Left FPI) and 62.79% (Right NHT). Highly pronated feet also demonstrated elevated prevalence, though generally lower than the slightly pronated category, suggesting that moderate pronation may present a greater relative risk than extreme alignment deviations in this cohort.

## DISCUSSION

The findings of this study highlight a substantial prevalence of Medial Tibial Stress Syndrome (MTSS) among adolescent cadets undergoing military-style training in Pakistan, with 43.0% of participants affected. This prevalence aligns with previously reported ranges of 4% to 52.9% in military populations, where early training phases and repetitive impact loading contribute to elevated risk (18,19). The strong associations between MTSS and foot posture abnormalities—particularly slightly pronated and highly pronated alignments—support biomechanical theories that altered foot kinematics can redistribute tibial loading, thereby increasing localized stress on the cortical bone (20). The observed odds ratios exceeding 4.0 for slightly pronated feet in both Foot Posture Index (FPI) and Navicular Height Test (NHT) assessments reinforce the clinical significance of even moderate deviations from neutral alignment.

The consistency of results across both FPI and NHT measures strengthens the validity of the association, as these tools assess foot posture from complementary perspectives—static alignment and arch height. Similar patterns have been documented in military cohorts, where excessive pronation was linked to MTSS incidence and progression to tibial stress fractures when unaddressed (21,22). Interestingly, slightly pronated feet demonstrated a higher MTSS prevalence than highly pronated feet in this study. This pattern may reflect a functional adaptation in individuals with more severe pronation, such as altered gait mechanics or muscle recruitment that partially mitigates tibial stress, whereas those with milder deviations might not trigger compensatory adaptations, thereby remaining vulnerable to repetitive loading injury (23).

The absence of significant associations between MTSS and gender or grade level contrasts with some previous reports of higher MTSS prevalence among female recruits, often attributed to lower bone mineral density, increased ligamentous laxity, and distinct pelvic-limb biomechanics (24,25). In this cohort, the non-significant difference may be due to the small proportion of female cadets or uniformity in training loads across sexes. Similarly, the lack of a significant difference between junior and senior cadets suggests that cumulative exposure over years of training may not outweigh the acute impact of training intensity, surface hardness, and footwear design—factors known to amplify tibial loading regardless of training duration (26,27).

From an injury prevention standpoint, these findings underscore the utility of implementing routine biomechanical screening using both FPI and NHT during cadet intake. Early identification of abnormal foot posture could inform targeted interventions such as customized orthotics, footwear modifications, and gait retraining programs, all of which have shown efficacy in reducing lower limb overuse injuries (28,29). The combined use of Shin Palpation and Shin Edema tests, which in this study demonstrated high diagnostic utility, further strengthens the capacity for field-friendly, rapid MTSS detection in resource-limited settings.

Moreover, the integration of such screening into training protocols should be paired with preventive strategies aimed at modulating extrinsic risk factors. Reducing training intensity during adaptation periods, introducing low-impact cross-training, and improving training surface compliance are practical measures supported by existing evidence (30,31). Given that nutrition influences bone remodeling, dietary interventions ensuring adequate calcium and vitamin D intake, particularly for female cadets, may offer an additional layer of protection against bone stress injuries (32).

While the cross-sectional design precludes causal inference, the strength of associations observed, coupled with consistency across measures and alignment with prior literature, supports a biomechanical link between foot posture and MTSS in adolescent military trainees. Future research should adopt longitudinal designs incorporating dynamic gait analysis, wearable biomechanical sensors, and controlled trials of intervention strategies to determine their long-term impact on MTSS prevention and recurrence reduction (33,34). Such studies would help clarify whether modifying foot posture–related biomechanical loading can alter the injury trajectory, reduce training-related attrition, and improve overall operational readiness in cadet populations.

## CONCLUSION

This study demonstrates a significant association between abnormal foot posture—particularly slight and high pronation—and the prevalence of Medial Tibial Stress Syndrome in adolescent cadets undergoing military-style training. The findings reinforce the role of biomechanical alignment in modulating tibial stress and underscore the value of routine screening using complementary tools such as the Foot Posture Index and Navicular Height Test. While gender and training grade were not significantly related to MTSS occurrence in this cohort, the high overall prevalence highlights an urgent need for early detection and preventive interventions. Integrating targeted biomechanical assessments, tailored orthotics, gait retraining, and structured load management into cadet training programs has the potential to reduce injury burden, enhance physical performance, and improve training continuity. Future longitudinal and interventional studies should examine whether modifying foot posture–related risk factors can sustainably reduce MTSS incidence and prevent progression to more severe stress injuries in military trainee populations.

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