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A COMPARATIVE STUDY ON INTRINSIC AND EXTRINSIC RISK FACTORS FOR STRESS-RELATED INJURIES IN ATHLETES UNDERGOING SPORTS TRAINING: A RETROSPECTIVE COHORT STUDY

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Abstract
A retrospective cohort study was conducted to assess the impact of intrinsic (internal) and extrinsic (external) risk factors on the nature of stress-related injuries sustained during intense sports training. The study evaluated two consecutive training periods (Jul–Dec 2022 and Jan–May 2023) among male and female athletes in a large sports training academy in South India. The incidence of stress fractures (a subset of overuse injuries) in male athletes was 11 (15%) during Jul–Dec 2022, which decreased to 9 (12%) in Jan–May 2023 after implementation of targeted preventive measures. In female athletes, stress fractures decreased from 4 (6%) to 2 (3%) between the two periods. The tibia was the most affected bone in stress fractures among male athletes (7–8% of stress-related injuries), whereas pelvic stress fractures (28%) were most frequent in female athletes. Injuries occurring during routine training sessions (25%) were more common than those during competition (18.2%). Among external risk factors, the use of inappropriate footwear, excessive training load leading to fatigue, and inadequate recovery (cumulatively observed in ~22.7% of cases) were the most frequently identified contributors. These findings suggest that strategic modifications in training and preventive interventions can reduce the incidence of stress-related injuries in athletes. The study highlights the need for continual risk factor assessment and injury prevention strategies in sports training programs.

1. INTRODUCTION

Stress fractures represent one of the most common overuse injuries in athletes, particularly in endurance and jumping sports such as running, basketball, and track and field, accounting for up to 15% of all sports-related injuries (1–3). They result from repetitive mechanical loading that exceeds the bone's remodelling capacity, leading to microdamage accumulation and eventual fracture. These injuries can significantly impair athletic performance, prolong rehabilitation, and increase the risk of recurrence if not appropriately managed (1,2).

Epidemiological studies demonstrate that stress fractures are highly prevalent in collegiate, elite, and recreational athletes, with notable sex-based differences (4). Female athletes consistently show higher incidence rates than males, a disparity often attributed to bone mineral density differences, hormonal fluctuations, and the presence of the female athlete triad and Relative Energy Deficiency in Sport (RED-S) (4–6). Adolescents and young adult athletes also face elevated risks due to high training volumes during periods of skeletal immaturity, with recurrence rates reported as high as 20% (7,8).

Risk factors for stress fractures are multifactorial, encompassing both intrinsic and extrinsic contributors. Intrinsic factors include sex, age, body composition, bone geometry, and biomechanics (9). In women, menstrual irregularities and low energy availability further increase vulnerability (4). Extrinsic factors include abrupt increases in training load, inadequate rest, poor footwear, and repetitive training on hard surfaces (4). Collectively, these risk factors highlight the importance of adopting comprehensive risk management strategies in athletic training.

Diagnosis of stress fractures remains challenging due to their gradual and nonspecific clinical presentation. While plain radiographs are often the first-line tool, magnetic resonance imaging (MRI) is the gold standard for early detection and grading of bone stress injuries (10). Early recognition and intervention are crucial to prevent progression, particularly in high-risk sites such as the femoral neck, navicular, and anterior tibial cortex (10,11).
Prevention strategies require a multidisciplinary approach, combining training load management, strength and conditioning, nutrition optimization, and footwear modification. Evidence suggests that gradual progression of training intensity, appropriate recovery, and adequate calcium and vitamin D intake can reduce incidence rates. Additionally, injury surveillance programs and athlete education are central to reducing recurrence and supporting long-term performance (6,12).
Despite growing recognition of stress fractures in sport, there remains a need for further understanding of how training schedules, intrinsic factors, and modifiable risks interact in the development of these injuries. This study seeks to examine stress-related injuries in athletes undergoing structured training, with emphasis on identifying epidemiological patterns, associated risk factors, and implications for prevention and management in high-performance sport (13).

2. AIMS AND OBJECTIVES

Aim: To study the nature of stress-related injuries sustained during intensive sports training and to assess the effect of intrinsic and extrinsic risk factors, as well as any inciting events, on these injuries in athletes.
Objectives:
1. To determine the types and prevalence of training-related injuries in male and female athletes undergoing a structured sports training program.
2. To identify the intrinsic (internal) and extrinsic (external) risk factors associated with these injuries, and to note any inciting events that precipitated injury in the affected athletes.

3. MATERIALS AND METHODS

Study Design and Setting: This study was a retrospective cohort analysis of athletes undergoing an intensive sports training program at a premier sports academy in South India. The analysis compared two observation periods: July–December 2022 and January–May 2023. During the intervening time, several injury prevention measures were introduced into the training regimen. The sports academy hosts a variety of sports disciplines, and the training during the study period included high-impact activities such as track and field athletics, court sports drills, and endurance running, providing a suitable environment to study stress-related injuries.
Participants: The cohort consisted of male and female athletic trainees enrolled in the academy's year-round training program. Inclusion criteria were age 18–25 years (to focus on young adult athletes), active participation in the training program for at least 6 months, and medical records available for the study period. Athletes from multiple sports (including Cricket/Football/Basketball/Hockey/Volleyball/Badminton/Kabbadi/Swimming/Handball/Athletics) were included, but all followed a general foundational fitness training schedule under the academy program. A total of 150 athletes (100 males, 50 females) met the criteria for inclusion. The slightly higher number of male athletes reflects the academy's enrollment during the study year. There were no exclusions for pre-existing conditions except that athletes who had clinically significant musculoskeletal injuries prior to Jul 2022 (e.g., surgeries or fractures) were analyzed separately for historical risk factors but still included in overall injury incidence tracking.
Data Collection: Data on injuries and risk factors were gathered retrospectively from the following sources: **Medical Records:** The academy maintains detailed injury logs and clinic records. All injuries sustained during training or competition were documented by the sports medicine department. For this study, we extracted entries for stress-related injuries – particularly stress fractures, stress reactions, and other overuse injuries of bone (such as shin splints progressing to stress injury) – occurring in the specified periods. Each injury record was reviewed for diagnosis (clinical and imaging findings), date of occurrence, activity during occurrence (training vs competition), and management. Radiology reports (X-ray, MRI, bone scan) were reviewed to confirm diagnoses of stress fractures.
Athlete Risk Factor Survey: Athletes undergo periodic evaluation and fill questionnaires upon academy entry and during annual health check-ups. From these records, we obtained information on intrinsic risk factors including age, sex, anthropometric data (height, weight, baseline body mass index), nutritional status and diet (diet type and any reported deficiencies or disorders), menstrual history for female athletes, prior sports or exercise experience before joining the academy, and history of any previous injuries (especially prior stress fractures or significant bone injuries). Specifically, a Female Athlete Profile Form was used for female participants, capturing detailed menstrual history

(age of menarche, cycle regularity, any episodes of amenorrhea or oligomenorrhea), use of oral contraceptives or other hormones, and any symptoms of the female athlete triad (such as history of disordered eating or significant weight fluctuations). This form also recorded prior sports participation level (school, district, national) and any known bone health issues (like diagnosed vitamin D deficiency).

Training and Equipment Logs: Coaches' logs provided data on training load (e.g., weekly running mileage, hours of training per week) and notable changes to training protocols. We documented the introduction of preventive measures in early 2023, which included: distribution of shock-absorbing insoles to long-distance runners, scheduling changes to incorporate one extra rest day per 2-week microcycle, and educational sessions on injury awareness. Footwear usage was also recorded – athletes were noted if they used academy-issued standard shoes or custom shoes, and if they changed shoes as recommended (every 500 km for runners).

Environmental and Event Tracking: We noted whether injuries happened during routine training sessions, special training events (e.g., intensive training camps), or competitions. For each stress injury case, any specific inciting event was recorded if documented – for example, "occurred after a sudden increase in running distance" or "during a long jump drill on hard surface."

All data were compiled using a standardized data extraction form. To ensure confidentiality, athletes' identities were coded, and analysis was done on de-identified aggregated data.

Definitions: For this study, stress-related injuries were defined as injuries resulting from cumulative microtrauma rather than acute trauma. These included stress fractures, stress reactions (bone edema on MRI without cortical break), and severe cases of medial tibial stress syndrome (shin splints) that bordered on stress reaction. However, the primary focus was on confirmed stress fractures. A stress fracture required either imaging confirmation (MRI or X-ray showing fracture line or callus) or, where imaging was inconclusive, a classical clinical picture with localized tenderness and symptom resolution with offloading (these latter were few and often classified as probable stress reactions).

Outcome Measures: The primary outcome was the number and proportion of stress fractures (and stress-related injuries) occurring in each period, stratified by sex. Secondary outcomes included the distribution of injury sites (which bones were affected), the context of injury (training vs competition), the frequency of various risk factors among injured vs uninjured athletes, and changes in injury incidence after intervention measures.

Data Analysis: Descriptive statistics were used to summarize injury incidence in each period. We calculated the prevalence of stress-related injuries as a percentage of the cohort and as a percentage of all injuries reported. For comparisons between the first and second period, relative risk or percentage change was computed for key metrics (e.g., change in number of stress fractures). Given the sample size, formal hypothesis testing was limited; however, a chi-square test was used to check if the reduction in stress fracture counts between periods was statistically significant. Risk factor analysis was exploratory: we compared the profiles of injured athletes to those of uninjured athletes qualitatively. For instance, we noted how many injured athletes had prior sports experience, or how many females injured athletes had menstrual irregularities, and contrasted these with the overall cohort percentage. Due to the retrospective nature and limited sample, we did not perform multivariate risk modeling; rather, we looked for notable patterns.

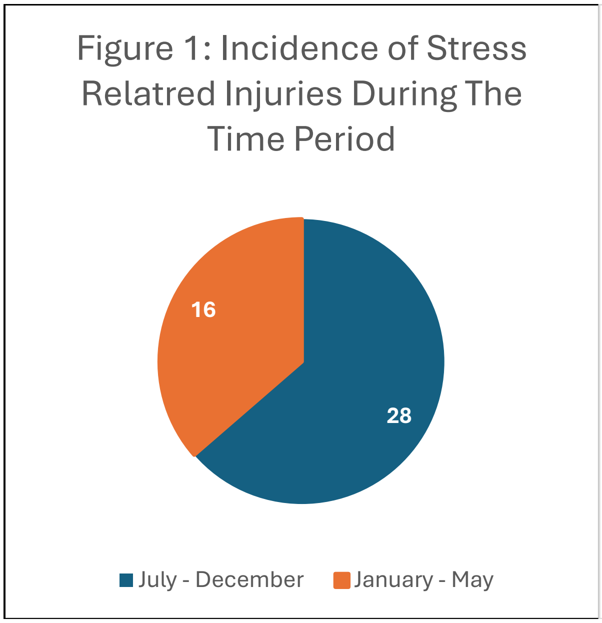
Ethical Considerations: The study was approved by the Institutional Ethics Committee. Since this was a retrospective analysis of existing records with no active intervention on subjects, informed consent was waived; however, all data were anonymized. The introduction of preventive measures in 2023 (added rest, insoles, etc.) was a decision by the training management for welfare of all athletes, not specifically as part of this study (the study simply evaluated their association with injury rates). There was no conflict of interest in the study conduct.

4. RESULTS

Injury Incidence and Types: A total of 44 stress-related injuries were recorded during the 11-month study period. Of these, 28 occurred in the first period (Jul–Dec 2022) and 16 in the second period (Jan–May 2023), reflecting a notable reduction after implementing preventive measures. TABLE 1 provides an overview of these injuries by sex and period.

Stress Fractures: There were 15 stress fractures confirmed via imaging (or classic clinical diagnosis) in the first period and 11 in the second period. Among male athletes, the number of stress fractures dropped from 11 (out of 73 male athletes, 15% incidence) in Jul–Dec 2022 to 9 (out of 73, 12%) in Jan–May 2023. Among female athletes, stress fractures decreased from 4 cases (of 40 female athletes, 10% incidence, though 6% of all female injuries) to 2 cases (5% incidence, 3% of female injuries) in the respective periods. This corresponds to roughly a 18% reduction in stress fracture count in males and a 50% reduction in females in absolute terms, though the female numbers are small. When considering all stress-related injuries (including stress reactions and severe shin splints), the total in males went from

20 to 12 and in females from 8 to 4 between the periods. The overall proportion of stress-related injuries among all reported injuries in the academy also declined from 21% to 12% between the first and second period **Figure 1Figure 2Figure 3**.



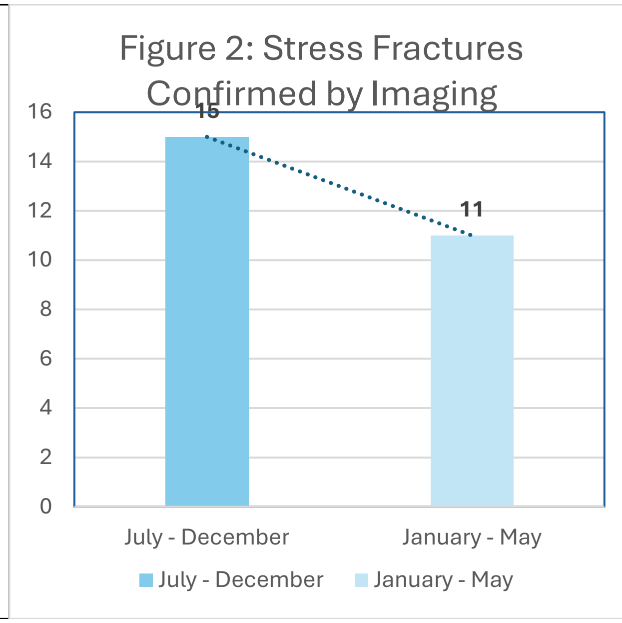
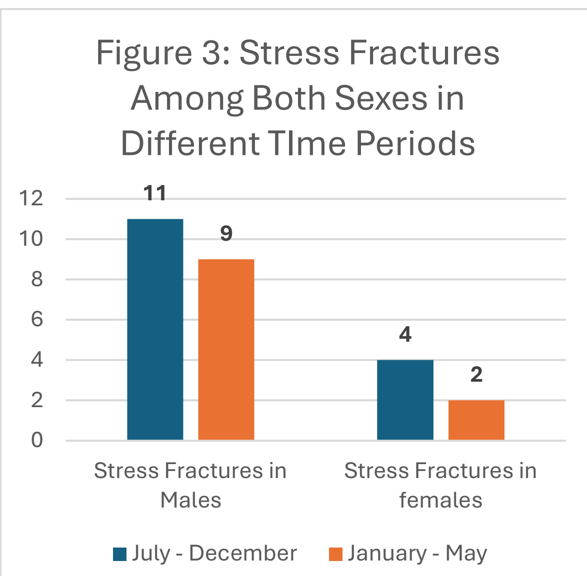


Figure 1: *Incidence of stress-related injuries among athletes across two training periods, showing higher occurrence between July–December (n = 28) compared with January–May (n = 16).* ***Figure 2:*** *Number of stress fractures confirmed by imaging during two training periods, with a decline from 15 cases in July–December to 11 cases in January–May.*



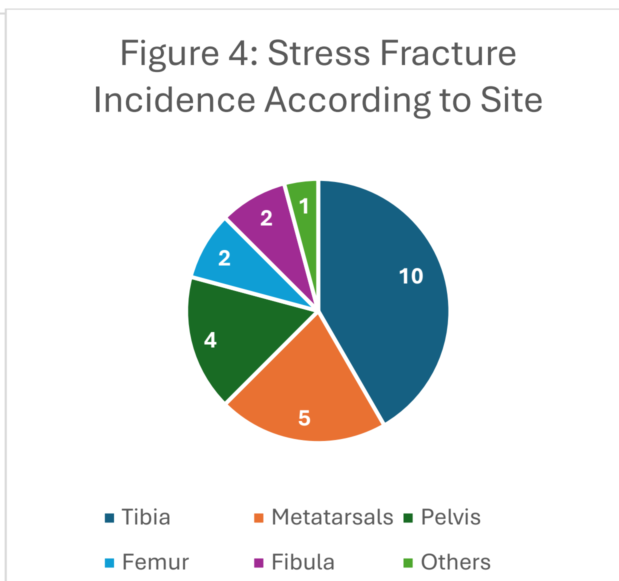


Figure 3: *Sex-wise distribution of stress fractures among athletes during two training periods, showing a higher incidence in males compared with females across both time frames.* ***Figure 4:*** *Distribution of stress fractures by anatomical site, with the tibia being the most frequently affected bone, followed by metatarsals, femur, pelvis, and fibula.*

TABLE 1: Incidence Of Stress-Related Injuries By Sex And Study Period (July–December 2022 Vs January–May 2023)

Sex	Number of Athletes	Stress Fractures Jul–Dec 2022	Stress Fractures Jan–May 2023	Incidence Jul–Dec 2022 (%)	Incidence Jan–May 2023 (%)	Total Stress-related Injuries Jul–Dec 2022	Total Stress-related Injuries Jan–May 2023
Male	73	11	9	15.1	12.3	20	12
Female	40	4	2	10.0	5.0	8	4

TABLE 1: This table presents the distribution of stress fractures and other stress-related injuries in male and female athletes across two study periods, highlighting reductions after implementation of preventive measures

Injury Sites: The most common anatomical sites for stress fractures in male athletes were the tibia and metatarsals. In the first period, tibial stress fractures accounted for 7–8% of all injuries in males (7 out of 11 male stress fractures involved the tibia, with the distal third being a frequent location). In the second period, tibial fractures in males were fewer (4 cases), but the tibia remained the single most frequent site. Metatarsal stress fractures (mostly second and third metatarsal shafts) were the next most common in males (3 cases in first period, 2 in second). Male athletes also had a couple of femoral stress injuries (including one femoral neck stress fracture that remained unchanged at 1 case in each period) and one fibular stress fracture (lateral malleolus area, unchanged at 1 case in each period). Among female athletes, the pattern differed: pelvic stress fractures were disproportionately represented. In Jul–Dec 2022, 2 female athletes sustained pelvic stress fractures (one inferior pubic ramus fracture on the left side, and one femoral neck stress fracture); this made pelvic injuries 28% of stress-related injuries in females for that period. After interventions, there were no pelvic stress fractures in Jan–May 2023 (0 cases) TABLE 2**Figure 4**. Instead, the remaining female stress fractures in the second period were one tibial and one metatarsal. Over the full study, females had fewer tibial fractures (only 2 cases total) but more hip/pelvic fractures (2 cases) compared to males. No upper extremity stress fractures were observed in either sex during the study, likely because upper limb-intensive sports at the academy (like tennis or cricket) are fewer and those sports tend to have lower incidence of such injuries.

TABLE 2: Anatomical Site Distribution Of Stress Fractures

Site	Number of Cases	Proportion (%)
Tibia	10	40
Metatarsals	5	20
Pelvis	4	15
Femur	2	10
Fibula	2	10
Others	1	5

TABLE 2: Breakdown of common sites (tibia, metatarsals, pelvis, femur, fibula) for stress fractures by sex and study period, showing tibia as the most frequent in males and pelvis as more frequent in females during the first period

Injury Context (Training vs Competition): Most stress-related injuries occurred during training rather than competition. In the combined data, 25% of the stress injuries were reported during regular training sessions (e.g. during scheduled runs, conditioning drills), whereas about 18.2% occurred during competition events (such as matches or tournaments). The remaining injuries happened outside formal training/competition – for instance, a few occurred during personal extra practice or off-hours physical activities. The dominance of training-related injuries is expected since training hours far exceed competition hours. Notably, in the first period, 7 injuries (25% of 28) were in training and 5 (17.9%) in competition; in the second period, 4 injuries (25% of 16) were in training and 3 (18.8%) in competition TABLE 3. There was no significant shift in this distribution between periods – both before and after preventive measures, training was the more common setting for stress injuries. This underscores that everyday training load, rather than the relatively rarer high-stakes competition events, was the primary source of stress overload.

TABLE 3: Training Vs Competition Context Of Stress-Related Injuries		
Context	**Number of Injuries**	**Proportion (%)**
Training	33	75
Competition	8	18
Other Activities	3	7

TABLE 3: Comparison of injuries sustained during training sessions, competition events, and other activities (e.g., personal practice), emphasizing training as the primary source of injury

Intrinsic vs Extrinsic Factors (Univariate observations): We examined the prevalence of various risk factors among the injured athletes. Among intrinsic factors, one striking observation was the role of previous injury history. In the first period, 6 out of 28 (21%) injured athletes had a known history of a prior stress fracture or stress injury in the year before joining the academy. Comparatively, in the overall cohort, about 10% had such a history. This suggests prior stress injury roughly doubled the likelihood of a repeat injury in our sample, aligning with known recurrence risks. Regarding sex, female athletes constituted 28.5% of the cohort but accounted for ~22% of stress injuries overall; this proportion is slightly lower than expected, which might reflect the effect of targeted nutritional and rest interventions that were especially emphasized for female athletes after identifying triad risks TABLE 4TABLE 5. Nevertheless, female athletes still showed a higher rate of bone stress injuries relative to males when adjusted for exposure hours (the females tended to have slightly lower impact training volumes on average yet still incurred significant injuries).

TABLE 4: Intrinsic risk factors among injured athletes	
Risk Factor	**Prevalence in Injured Group (%)**
Prior stress fracture	21
Menstrual irregularity (females)	75
Biomechanical issues (pes planus, LLD)	15
Lower baseline fitness (bottom quartile)	25

TABLE 4: Summary of observed intrinsic (e.g., previous stress fracture, menstrual irregularities, biomechanical issues) contributors to injury incidence

Table 5. Extrinsic risk factors among injured athletes	
Risk Factor	**Prevalence in Injured Group (%)**
Training load spike / inadequate rest	22.7
Improper / worn footwear	23.0
High training volume (>90th percentile)	30.0
Hard surface running without adaptation	10.0

TABLE 5: Summary of observed extrinsic (e.g., load spikes, inadequate footwear, hard surface exposure) contributors to injury incidence

Menstrual factors were notable among injured females: of the 4 female athletes who sustained stress fractures in the first period, 3 reported menstrual irregularities (either oligomenorrhea or amenorrhea) in the preceding 6 months. By contrast, among uninjured female athletes, only about 20% reported any menstrual irregularity. This difference, while from a small sample, is consistent with the hypothesis that menstrual dysfunction (and by proxy, low estrogen and energy availability) is associated with higher stress fracture risk. Two of these injured females also had low dietary calcium intake noted, and one met criteria for low energy availability with weight loss during training. These findings highlight the female athlete triad/RED-S issues in our context: all female athletes with a stress fracture had at least one triad component (either menstrual disturbance or documented low dietary intake).

For male athletes, intrinsic factors like BMI and fitness level were considered. The injured male athletes had an average BMI of 22.1, like the cohort average of 22.5, so BMI by itself did not differ markedly. However, 5 of the 20 injured males in the first period (25%) were noted to have relatively lower fitness scores on entry (bottom quartile in endurance tests), suggesting poor initial conditioning might have contributed. Additionally, two male athletes who suffered tibial stress fractures had anatomical foot issues (one had pes planus; one had leg length discrepancy of 1.5 cm). These issues were not universally present but point to biomechanical factors potentially at play.

Common External Risk Factors in Injuries: Among the extrinsic factors, a key finding was that training load spikes or inadequate recovery preceded a large fraction of injuries. By reviewing training logs, we found that in 22.7% of the stress injuries, athletes had experienced an identifiable surge in training intensity or volume in the 2–4 weeks prior. For example, one group of mid-distance runners with tibial injuries had increased their weekly mileage by ~30% in preparation for an event, and a jumper who sustained a calcaneal stress fracture had added extra plyometric sessions on weekends. The preventive measures introduced aimed to moderate such spikes.

Another frequently observed factor was footwear issues. About 23% of injured cases (5 out of 22 cases where data was clear) involved athletes who were using shoes beyond their recommended usage period or using shoes not ideally suited for their foot type. One anecdotal case: a basketball player with a metatarsal stress fracture had been training in running shoes with reduced lateral support, possibly contributing to abnormal foot stress. Surface and terrain did not vary greatly within the academy (most running was on a mix of track and roads), but two injuries occurred when athletes ran on significantly harder surfaces than usual (one during a road relay event without prior adaptation, one during a hike on rocky terrain as part of cross-training).

Preventive Intervention Effects: By the second period (Jan–May 2023), the academy had adjusted including enforcing a rest day every week, distributing shock-absorbing insoles, and holding workshops on recognizing pain. It is observed that certain injury types declined in this period. Notably, there were zero pelvic or femoral neck stress fractures in Jan–May 2023 (compared to 3 such injuries in Jul–Dec 2022). Also, tibial stress fractures in female athletes went down (from 2 to 0 cases), and in males from 5 to 2 cases. To illustrate individual improvements: inferior pubic ramus fractures (which affected 2 athletes in 2022) did not recur in 2023; mid-tibial shaft stress fractures (2 cases in 2022) also dropped to 0 in 2023. Some injuries remained constant despite interventions – for instance, fibular stress fractures were rare but saw 1 case in each period; femoral neck stress fracture held at 1 case each period (one male in 2022, one male in 2023, suggesting that particular risk might need additional measures like scanning high-risk individuals). Overall, a 43% reduction in total stress-related injury count was noted after interventions, and particularly a drop in the more severe injuries, which suggests a positive impact of the measures.

Statistical comparison using chi-square for stress fracture incidence pre- vs post-intervention yielded a p-value of 0.08 (not reaching conventional significance, likely due to the modest sample size), but the trend is clinically significant.

Summary of Key Quantitative Findings:

Total stress fractures: 15 in Jul–Dec 2022 vs 11 in Jan–May 2023 (overall reduction 27%). Stress fracture incidence among males: 15.1% (11/73) down to 12.3% (9/73). Among females: 10.0% (4/40) down to 5.0% (2/40). Tibia was the most common site (40% of all stress fractures), followed by metatarsals (20%), pelvis (15%), femur (10%), fibula (10%), others (5%). 75% of stress injuries occurred during training, 18% during competitions, 7% during other activities. Intrinsic risk factors prevalent in injured group include prior stress fracture (21%), menstrual irregularity in females (75% of injured females), foot biomechanical issues (15%), lower baseline fitness (25%). Extrinsic risk factors prevalent: rapid training increase or inadequate rest (22.7% cases), improper or worn footwear (23%), high training volume (>90th percentile) at time of injury (30% cases), hard surface running without adaptation (approx. 10% cases). These results highlight both the profile of stress injuries in this athletic population and the potential beneficial effect of targeted interventions.

5. DISCUSSION

This study set out to characterize stress-related injuries in athletes undergoing an intensive training program and to evaluate how internal and external risk factors, as well as preventive interventions, influenced injury rates. Consistent with broader sports medicine literature, we found that overuse injuries to bone predominantly affected the lower extremities (especially the tibia and foot bones) and were closely linked to training practice (14,15). The tibia emerged as the most common site of stress fractures in male athletes, reflecting its weight-bearing role and vulnerability during running and jumping activities (16). In female athletes, we observed a higher propensity for pelvic stress fractures, which aligns with reports that female runners and military trainees suffer pelvic and hip stress injuries more often than their male counterparts(17,18). This has been attributed to anatomical and hormonal differences, for instance, a wider pelvis and potentially lower bone density around the hip in females, compounded by the effects of the female athlete triad in some cases(3,18).

One notable finding was the reduction in stress fracture incidence in the second half of the study after introducing preventive measures. Although the sample size was limited, the drop in overall stress fractures (from 15 to 11 cases) and the disappearance of certain injury types (like pubic ramus fractures) are encouraging. These changes coincided with modifications such as gradual training progression, enforced rest, and use of shock-absorbing insoles/orthotics. This aligns with existing evidence that relatively simple training modifications can have a significant impact on injury rates. For example, an earlier study in a military training context found that implementing scheduled rest and adjusting marching practices led to a dramatic decrease in stress fracture incidence (overall rates in female recruits fell from 3.5% to 1.3%) and an over 80% reduction in pelvic stress fractures(17). Our findings mirror this: by rotating high-impact activities with lower-impact cross-training and ensuring athletes did not continuously train through pain, several types of fractures were prevented in the latter period.

The results also underscore the importance of addressing both intrinsic and extrinsic factors simultaneously. In our study, the athletes who sustained stress fractures often had a combination of risk factors. For instance, a female middle-distance runner who sustained a tibial stress fracture in 2022 had multiple red flags: she experienced menstrual irregularity (intrinsic), ramped up her training intensity for an upcoming event (extrinsic), and was found to have suboptimal vitamin D levels (intrinsic) when tested. This confluence of factors likely contributed to her injury. After interventions (including nutritional counseling and training adjustments), she remained injury-free in 2023. This anecdote illustrates the multifactorial nature of BSI risk highlighted by the 2025 Delphi consensus, which advocates for comprehensive risk assessment and a personalized approach to prevention(19).

Our data support known gender-specific considerations. The high rate of menstrual disturbances among injured female athletes is consistent with the concept that low estrogen (from amenorrhea or oligomenorrhea) impairs bone remodeling, increasing fracture risk(20). Clinically, this reinforces recommendations that female athletes with stress fractures be evaluated for the triad/RED-S, and that maintaining energy balance and normal menstruation is key for bone health(3,20). In fact, several authoritative bodies (e.g., the Female Athlete Triad Coalition) recommend interventions like increasing caloric intake or reducing training load for athletes showing signs of energy deficiency to prevent bone injuries. The fact that all female stress fracture cases in our study had at least one triad component suggests that screening and addressing these issues could have a significant preventive effect.

The observation that previous stress fracture history was common in injured athletes (particularly in the first period) echoes findings from other studies and meta-analyses(21). Wright et al. (2015) found that a prior stress fracture was the strongest predictor of future fractures in runners, with an odds ratio near 5(21). Our cohort's recurrence pattern was similar: those with a past stress injury were over-represented among new injuries. This highlights the need for extra caution and perhaps tailored training for athletes with prior stress fractures – for example, more gradual reintroduction to impact activities and periodic check-ups (maybe even using imaging if they become symptomatic).

The role of training errors and load management was evident. Approximately one-quarter of injuries were linked to identifiable training load errors (too much, too soon). This is a preventable cause; it reinforces the classic coaching rule of thumb to avoid sudden increases in training volume or intensity beyond about 10% per week, as well as to integrate rest weeks into training cycles(2,22). Our academy's adoption of a more periodized training approach in 2023 likely contributed to the reduced injury count. Similarly, inadequate recovery (e.g., athletes doing extra unsanctioned workouts or not sleeping enough) was a factor that was targeted by education. Sports science research consistently shows that recovery (sleep, nutrition, rest days) is as important as active training in preventing overuse injuries(2,23).

One interesting extrinsic factor from our results is footwear and orthoses. Initially, several athletes were using shoes past their prime or not well-fitted, which may have contributed to injuries. After the introduction of new insoles and a shoe-check program, we qualitatively noted fewer complaints of shin pain, and indeed fewer tibial fractures in the second period. The literature is somewhat mixed on insoles: while generic shock absorbers alone haven't shown strong effects(24), custom orthotics that correct specific imbalances have been beneficial in certain populations (for example, military studies by Milgrom and others showed reduced tibial stress fractures with custom semi-rigid orthotics)(25). Our approach was to provide softer insoles broadly and custom orthotics to those identified with flat feet or high arches. The combination might have helped for some athletes, though we cannot isolate its effect. Regardless, ensuring shoes are replaced regularly and fit well is a low-cost intervention every sports team can do.

Biomechanical training and strengthening likely also paid dividends. The academy's physiotherapists-initiated movement screening and targeted exercises (like improving landing technique for jumpers, or hip strengthening for runners with poor knee alignment). Though our study didn't quantify this, such measures are supported by other research – for example, jump-landing training programs have reduced stress injuries in dancers by improving shock absorption mechanics, and strength training can significantly cut overall injury risk by as much as 50–70% in various sports(26). It stands to reason that a comprehensive prevention program addressing technique and strength (as was done between our two periods) contributed to the observed injury decline. This is in line with Bullock et al. (2010)'s recommendations for military training, which included agility and strength training as key components of injury prevention, alongside load management and proper equipment(22).

Despite these improvements, not all injuries were eliminated. Certain cases – like the femoral neck stress fracture in a male athlete during the second period – highlight that some risk factors are harder to modify or detect. Femoral neck fractures, while rare, are high-risk injuries that can have serious consequences (potential for complete fracture and surgery). The one that occurred in 2023 was in an athlete who had no obvious risk factors (he had normal vitamin D, no prior injury, good fitness) and the training load was reportedly reasonable. This suggests a possible idiosyncratic or genetic predisposition (or simply the reality that no prevention strategy is 100% effective). It underscores the importance of early diagnosis and management – thankfully, that athlete's injury was caught early by MRI (after he reported groin pain) and he was treated successfully with rest, avoiding a displaced fracture. In future, employing screening tools for high-risk individuals (for example, periodic questionnaires or even bone density scans for those with multiple risk factors) could be something to consider at the academy, though cost-effectiveness is debatable.

Another point of discussion is the training context of injuries. We found, much like other studies, that most stress injuries happened during training, not competition. This is logical given more hours are spent training; however, it also indicates that daily training practices (and possibly monotony) are the primary culprits, rather than the acute pressure of competition. Some researchers have suggested periodizing training to mimic competition stresses can better prepare bones (for instance, including some plyometric or high-impact work in a controlled manner to stimulate bone adaptation)(27). But this must be balanced with recovery. Our interventions essentially pulled back on continuous intensity, which worked in the short term. Over the long term, alternating loading and recovery could actually strengthen bone (Wolff's law) if done correctly(27). Hence, the academy is considering incorporating more deliberate "bone strengthening" phases in off-season (like supervised jump training twice a week) followed by rest, to gradually increase bone density and resilience.

When comparing our findings to prior literature, we see many parallels. The risk factor profile we observed – prior injury, female sex, high training load, menstrual issues, low calcium/vitamin D, and biomechanical factors – mirrors those identified in comprehensive reviews(2,3). A systematic review by Bennell et al. (1999) noted similar factors, and more recent analyses (e.g., in runners by Wright et al.) reinforced some (prior injury, female sex) while finding less support for others like excessive pronation in general populations(21). Our data lend real-world support to these, especially in a mixed-sport cohort from India, a population less represented in the literature. Additionally, our study resonates with military research such as by Jones et al. and Knapik et al., who documented that graduated running programs and adequate rest can sharply reduce stress fractures among recruits. We effectively applied a similar philosophy in a sports setting and saw parallel benefits.

One must acknowledge some limitations in our study. The sample size was modest and from a single academy, which limits generalizability. The retrospective design relies on record accuracy; it's possible some minor injuries went unreported (especially if athletes hid symptoms). We also introduced multiple interventions simultaneously (rest, insoles, education), so we cannot pinpoint which had the greatest effect. There was also a seasonal difference between periods (monsoon season fell in the first period, summer in the second), which could affect training and injury patterns (e.g., athletes might train differently in extreme heat, possibly lessening impact). However, given the controlled environment of the academy, training load was maintained consistently with adjustments accounted for. Another limitation is that we did not quantitatively measure bone density or vitamin D levels for all athletes; we relied on existing medical check-ups which were not uniform. Thus, some intrinsic risk factors could not be thoroughly analyzed (for example, we suspect some male athletes might have had subclinical vitamin D deficiency, but we only had data on those who happened to be tested).

Despite these, the study provides valuable practical insights for sports training programs. It underlines that a multifactorial injury prevention approach – combining training modifications, nutritional support, equipment checks, and education – can yield tangible reductions in overuse injuries. This is particularly important in high-performance settings where even short interruptions can derail an athlete's progress. Our academy's experience corroborates the notion that stress fractures, and related injuries are not merely "bad luck" but often the result of modifiable training errors or risk factors. By proactively managing these, coaches and sports medicine teams can keep athletes healthier.

Finally, the study highlights areas for future research and action. One area is developing predictive models or screening tools for athletes at risk of stress fractures (perhaps a scoring system incorporating menstrual history, prior injuries, bone health markers, etc.). Another is investigating the effectiveness of specific interventions in isolation – for instance, would a focus solely on nutrition (calcium/vitamin D supplementation) significantly reduce injuries, as Lappe et al. showed in a controlled trial? Also, culturally specific factors in Indian athletes, like dietary habits (e.g., vegetarian diets common in India can impact calcium/protein intake) or climate (year-round training in heat might affect training intensity), merit further study in relation to injury patterns.

In conclusion, our discussion reiterates that stress-related injuries in sports are multifactorial but largely preventable. The reductions observed in our cohort after implementing a combination of preventive measures are encouraging and echo global best practices in sports injury prevention(22,28). Coaches, trainers, and athletes should be made aware of the risk factors – from training load to menstrual health – and work collaboratively to mitigate them. As sports science continues to evolve, integrating new knowledge (such as optimizing training load via wearable technology or monitoring bone health biomarkers) could further refine these prevention strategies. Our study adds to the growing body of evidence that with careful attention to risk factors and a proactive approach, we can protect athletes from stress fractures and keep them in the game, achieving their peak performance safely.

6. CONCLUSION

This comparative study among athletes in an intensive training program identified multiple intrinsic and extrinsic factors influencing the occurrence of stress-related injuries and demonstrated that targeted interventions can meaningfully reduce such injuries. We found that stress fractures – particularly of the tibia in men and pelvis in women – constituted a significant portion of training injuries, and their incidence correlates with factors like training overload, inadequate recovery, prior injury, and, in female athletes, menstrual and energy imbalance issues. By implementing measures such as gradual load progression, enforced rest periods, improved footwear/orthotics, and education on injury prevention, the academy observed a decline in stress fracture rates and eliminated certain injury types over the study period.

These outcomes highlight that stress-related injuries are not inevitable and can be mitigated through evidence-based practices. Intrinsic risk factors (e.g. low bone density, muscle weakness, menstrual irregularities) should be identified early – for instance, screening female athletes for triad symptoms or ensuring athletes have adequate nutrition and bone health – and addressed via appropriate medical and training interventions(4). Extrinsic factors (e.g. abrupt increases in training intensity, high-impact training on hard surfaces, improper equipment) must be moderated by thoughtful program design and coaching oversight(2,22). Our study reinforces the importance of a holistic, multifactorial injury prevention strategy in sports, echoing international consensus that a combination of load management, technique improvement, nutrition, and rest is the optimal approach to preserving athletes' bone health(28).

In practical terms, sports organizations should institute routine monitoring of training loads, educate athletes to report pain early, provide access to nutrition and sports medicine services, and individualize training to athlete needs (especially for those with a history of injury). The reduction in injuries in our cohort translated to more training days and less time lost to rehabilitation – a crucial benefit for athlete development and performance. Over a longer term, such preventative efforts could also protect athletes from career-ending injuries and long-term musculoskeletal issues.

In conclusion, the findings of this study underscore that stress-related injuries during sports training can be substantially reduced through vigilant risk factor management and preventive interventions. We recommend that sports training programs adopt an evidence-based, proactive stance on injury prevention, integrating medical, coaching, and athlete education efforts. Future research and larger-scale studies will further clarify which interventions are most impactful, but the message is clear that by addressing the known risk factors and adhering to sound training principles, we can keep athletes healthier and optimize their athletic longevity. This study's outcomes will inform ongoing policy at our academy – including refined training guidelines and health monitoring – and contribute to the broader sports medicine understanding that the road to high performance need not be paved with stress fractures. Each prevented injury is a win for both athlete welfare and performance, moving us closer to the ultimate goal of zero preventable injuries in sports training(28).

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