NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

Quality in Sport. eISSN 2450-3118.

Journal Home Page https://apcz.umk.pl/QS/index

RUDNICKI, Jakub, SZCZUPAJ, Maciej, MICHALICHA, Iga, LEJA, Wiktoria, BŁASZCZAK, Maciej, LATALSKA, Katarzyna, PASTUSZAK, Andżelika, BORKOWSKI, Konrad, KOT, Jakub, and ZULFIQAR, Zeeshan. Sex Differences in Stress Fracture Incidence and Risk Factors in Athletes: A Narrative Review. Quality in Sport. 2026;54:70527. eISSN 2450-3118. https://doi.org/10.12775/QS.2026.54.70527

The journal has been awarded 20 points in the parametric evaluation by the Ministry of Higher Education and Science of Poland. This is according to the Annex to the announcement of the Minister of Higher Education and Science dated 05.01.2024, No. 32553. The journal has a Unique Identifier: 201398. Scientific disciplines assigned: Economics and Finance (Field of Social Sciences); Management and Quality Sciences (Field of Social Sciences).
Punkty Ministerialne z 2019 - aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).
The authors declare that there is no conflict of interest regarding the publication of this paper.
Received: 03.04.2026. Revised: 11.04.2026. Accepted: 21.04.2026. Published: 26.04.2026.

Sex Differences in Stress Fracture Incidence and Risk Factors in Athletes: A Narrative Review

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Abstract

Background. Stress fractures are a prevalent overuse injury in athletes, with female athletes consistently reporting higher incidence rates than males. This disparity is driven by an interplay of anatomical, hormonal, biomechanical, and training-related factors.

Aim. This narrative review aims to synthesise the current evidence on sex differences in stress fracture incidence and to identify the key risk factors underlying this disparity.

Methods. A narrative literature review was conducted using PubMed, Web of Science, and Scopus. Studies published between 2015 and 2026, with an emphasis on 2020–2026, were included. Peer-reviewed original research articles, systematic reviews, and meta-analyses addressing stress fractures in athletes with sex-stratified data were considered.

Results. Female athletes exhibit higher rates of tibial, metatarsal, and tarsal stress fractures compared to males. Contributing factors include smaller bone cross-sectional geometry, lower cortical bone density, and distinct trabecular microarchitecture. Hormonal disruptions associated with the Female Athlete Triad and Relative Energy Deficiency in Sport further impair bone metabolism in women. Sport-specific loading, early specialisation, low body mass index, and menstrual irregularities compound this risk.

Conclusions. The excess stress fracture risk in female athletes is multifactorial. Effective prevention requires sex-specific screening for energy deficiency, menstrual health monitoring, and individualised training load management.

Keywords: stress fracture, bone stress injury, female athlete, sex differences, Female Athlete Triad, Relative Energy Deficiency in Sport, biomechanics, bone geometry

1. Introduction

Stress fractures have become the most common overuse injuries found in athletic populations with a major clinical challenge associated with them because they can disrupt training continuity and competitive performance. While acute fracture is typically caused by an injury sustained from a traumatic event, the stress fracture occurs when there has been repetitive mechanical loading applied to the bone causing greater than the bones capacity for remodeling or repair. Tibia, metatarsals, and tarsal bones are commonly involved in high-impact weight-bearing disciplines [1].

A growing amount of data indicates that females are more likely than males to develop stress fractures as an athlete. This sex-based disparity has been documented across a range of sporting contexts, from collegiate athletics to military training environments, and appears to be particularly pronounced in running-based disciplines [2]. The reasons why females are more susceptible to stress fractures is not entirely known but will include a variety of factors including anatomically based differences, biomechanics, hormonal fluctuations, and nutritionally related factors.

The Female Athlete Triad — defined by low energy availability, menstrual dysfunction, and reduced bone mineral density - has historically represented a major predisposition to bone stress injury in females from a hormone based perspective [3]. More recently, this concept has been expanded into the broader Relative Energy Deficiency in Sport (RED-S) model, which recognizes very similar physiological responses to relative energy deficiency in males; although with generally less severe health risks [4].

Anatomically and biomechanically there are sex-related variations that increase one's susceptibility to injury. Women generally exhibit smaller bone cross-sectional geometry and lower cortical bone density, which may reduce the structural capacity of bone to withstand cyclic loading [1]. The lower extremities also vary anatomically due to sex; specifically the pelvis is wider and the Q angle is larger in females than in males. This changes how much force is absorbed by the body as well as the distribution of force on the lower limb when performing such activities as running or jumping [2].

Although there has been a long history of documented increased frequency of stress fractures among female athletes, little is known about how the interaction of various biologic, training and demographic risk factors differs by sex. It is critical to understand these sex-specific differences to develop appropriate prevention strategies as well as create individualized training programs that minimize the risk of injuries while allowing for optimal athlete development. The purpose of this narrative review is to summarize and integrate the available literature on sex-based differences in stress fracture occurrence and their associations with anatomically, hormonally, and demographically as well as sport based, or other risk modifiers.

2. Methodology

A comprehensive search using the electronic databases MEDLINE/PubMed, Web of Science and Scopus was undertaken. Since we wanted to consider all relevant evidence we did not limit our search to one database. All studies published over the last decade (2015-2026) were considered for inclusion, with particular focus being placed upon those studies that had been published since 2020 up until 2026. There was no linguistic limitation applied during this initial phase of searching but only those publications written in English were subsequently assessed.

A combined approach using both Medical Subject Headings (MeSH) and free-text keywords was employed for the literature search. Keywords that included "stress fracture," "bone stress injury," "fatigue fracture," "sex differences," "gender differences," "female athlete," "Female Athlete Triad," "Relative Energy Deficiency in Sport," "Bone Mineral Density," "Running Injury," "Military Training" and "Athletes" were utilised in multiple Boolean combinations (AND/OR), to achieve maximum sensitivity while minimising false positives.

Studies that met eligibility criteria included those that provided new or synthesized information regarding the incidence of stress fractures or bone stress injuries (BSI) among athletic or physically active individuals; also, studies had to provide sex-specific incidence rates for males and females, or directly compare the sexes. The various types of studies that could be included within this review include systematic reviews/meta-analysis, prospective and retrospective cohort studies, cross-sectional studies, and case series. Excluded from the review would be studies focused solely upon non-athlete, elderly or pediatric populations with no relevance to sport participation, as well as single-case reports/conference abstracts with no access to a full-text version.

The articles were selected through a two-stage process. In stage one, the reviewer evaluated all article titles and their corresponding abstracts for relevance. Following this evaluation, the full-text version of all potentially relevant studies were reviewed based on established inclusion/exclusion criteria. All reference lists from identified studies were also manually searched for additional relevant literature that may have been missed during the initial database searches. Since this is a narrative review, there was no need to formally appraise the quality of the included studies using an appraisal tool. Instead, peer-reviewed studies published in reputable indexed journals with clear descriptions of the population studied and how outcomes were defined were preferred. The synthesized data were organized into thematic categories (predefined) consistent with those outlined above.

3. Aim

The purpose of this narrative review is to provide an inclusive examination of all available research regarding sex differences in the occurrence rate and risk factors associated with stress fractures in athletes. Specifically, it will seek to: (1) identify and describe the sex based differences in stress fracture incidence rates among female and male athlete populations; (2) examine anatomically and biomechanically based reasons which explain the differences found between sexes; (3) investigate the effect of hormonal and endocrine factors such as those involved in the Female Athlete Triad and Relative Energy Deficiency in Sport (RED-S), on stress injury risk from bone stress injuries; (4) examine sport specific and training specific variables that can vary by sex; and (5) assess how age, BMI and other demographic factors can contribute to varying degrees of sex differences in stress fracture susceptibility.

4. Results

4.1. Incidence of Stress Fractures by Sex

The scientific literature has repeatedly demonstrated that females have a significantly greater risk of developing stress fractures than do male athletes in a wide variety of sports and training environments. The largest study to date assessing the incidence of stress fractures among collegiate athletes in the United States demonstrated that female athletes represented the majority of all reported stress fracture injuries; additionally, it was noted that the tibia, metatarsal bones, and navicular bone were the most commonly injured locations [5].

A systematic review with meta-analyses (examining sex-specific differences in running related injuries) demonstrated that female runners have an increased risk of developing stress fractures when compared to male runners [2]. The results of the meta-regressions also indicated that the degree of difference in risk (between males and females) would be influenced by such factors as; training volume/intensity, age, and history of previous injury. Therefore, these findings indicate that it's not likely a singular variable or cause that contributes to the higher incidence of stress fracture in female runners. Rather, the combination and interaction among multiple contributing variables are likely responsible.

Epidemiologic studies conducted within the military training environment are consistent with studies from the civilian sports setting. Military recruits who undergo intensive physical training programs show a marked difference in incidence of stress fractures; women develop them at an extremely high rate compared to their male counterparts, specifically within the lower extremity [6]. This environment offers a unique opportunity because the training load for both men and women is standardized and externalized.

The differences in natural history of bone stress injury have been demonstrated to be different based on sex as well. Studies investigating prospective data suggest that females are at greater frequency for developing stress injuries than male athletes; however, female athletes appear to recover more slowly from these injuries when they experience continued caloric deficits or hormonal disturbances [7]. A cohort study designed to investigate stress fracture formation among elite female distance runners reported several significant predictors of new stress fractures during a 6-month follow-up period demonstrating the importance of sex-specific surveillance and tracking for this population [8]

Fracture location is apparently influenced by sex as well. Females typically develop a larger percentage of tibia and metatarsal stress fractures while males appear to have a greater variety of fracture locations. The differences in anatomical preference probably reflect an interaction between bone shape, biomechanics, and hormone-influenced bone metabolism, all of which are discussed in subsequent sections.

4.2. Anatomical and Biomechanical Differences Affecting Injury Risk

Structural variations within the geometric dimensions of bones (i.e., sex) are one of the most important determinants of the different levels of risk for stress fractures among men and women. The ability of bone to withstand repeated loading without failing is based upon its cross-sectional area, cortical thickness, and the spatial distribution of mineralized tissue about the neutral axis. On average, women exhibit less than their male counterparts with respect to cross-sectional area of the tibia as well as lower cortical bone areas per unit of body size. Therefore, when subjected to the same level of mechanical load, there will be greater bone strains generated in women which increases the propensity for the accumulation of micro-damage resulting from fatigue [9].

Bruce et al. (2022), conducted a study of young active adult tibia and fibula geometries. Their research found that there was an association with both decreased bone cross-sectional area and lower bone mineral density volume, and increased estimated bone strain when subjected to loading [9]. The researchers also identified that sex differences in the above mentioned geometric factors contributed to the difference they noted in bone strain between males and females. They concluded that mechanical disadvantage due to sex-related variations in bone morphological characteristics is likely to be a contributing factor to the greater injury rate among women.

Military research on training has added additional data to show there is a correlation in males and females regarding Tibia Bone Geometry and Bone Stress Injuries. Research conducted by Koltun et. al., (2022), showed that when comparing recruits undergoing extreme military training those with a lower tibia Cross Sectional Area and Trabecular Density had a higher probability of developing Bone Stress Injuries, and this was seen as a trend among both male and female recruits.[6] However, the geometric disadvantages at baseline in the female recruits resulted in a greater percentage of female recruits having the skeletal features that placed them into high-risk categories which contributed to the overall increased rate of injuries among the female recruits.

The trabecular bone architectures of females and males at the microstructural level differ as indicated by High-Resolution Imaging. Hughes et al., (2023), showed that distal tibia microarchitecture changed significantly for both men and women during the eight-week U.S. Army Basic Combat Training program, but that a pattern of trabecular adaptation was observed among female recruits unlike male recruits [10]. The sex specific adaptations to mechanical loadings may be an indication of the difference in bone remodeling dynamics and can contribute to why women are likely to develop micro-damage quicker than men when subjected to repetitive loading conditions.

During gait or locomotion, there are several differences between men and women regarding how they load bones. The majority of studies have reported larger peak vertical ground reaction forces per unit of bone area for women than for men. Furthermore, while both male and female athletes experience tibia bending moment and lower limb joint angle variation during a run, the range of values is wider for women. A cross-sectional study conducted by Gaudette et al. (2025), indicated the biomechanically related determinants of bone stress fractures among athletes were gender-dependent by anatomical location; with proximal and distal tibiae experiencing distinctly different types of loading patterns, and that the pattern of this type of loading was gender-specific in nature [11] . Therefore, it is important to consider the site-specific biomechanics when evaluating the risk for injury.

Men and women also differ in their gait patterns during a run. When running, females typically exhibit more pronounced hip adduction (when the legs move inward) and contralateral (opposite side) pelvic drop when on one leg, which increases the bending forces that act on the tibia. The degree to which these patterns occur can likely be attributed in large measure by a number of sex related anatomical features such as pelvic width and the differing amounts of force generated by the hip abductors. Differences in how much each gender demonstrates these traits were shown in models to increase tibial stresses and have therefore been identified as potentially modifiable risk factors for developing stress fractures among female distance runners [12].

4.3. Hormonal and Endocrine Factors (Female Athlete Triad / RED-S)

Hormonal status is one of the biggest factors that determine the strength and health of an athlete's bones as well as the overall bone health in female athletes. Energy intake affects how hormones (and thus bone) work in women; when there are disruptions to the HPG axis it provides an important mechanism by which nutritional deficiencies affect bone. The female athlete triad is defined as three components: low energy availability, irregular menses and decreased BMD. This is still the commonly recognized way that all these relationships have been described [3]. The updated consensus statement from the coalition to expand upon the female athlete triad also added a new model of the adolescent female, along with current research on what happens physiologically when young females have chronic deficit of calories. Low energy availability, which means that you consume too little calories from your diet compared to how much energy you expend through physical activity, will result in a lower level of production of luteinizing hormone (LH) and estrogen [13]. A low level of LH and estrogen disrupts normal menses and results in an environment where there is less activation of osteoblasts (cells responsible for bone growth) and increased bone resorption. Therefore, a female athlete with low levels of LH and estrogen, due to inadequate energy consumption, will lose bone mineral density over time. Unfortunately, this loss of bone mineral density occurs when a female athlete is usually developing her bone mass and losing it in her youth or young adult years. As a result, if a female athlete does not develop sufficient bone mass during these years she is likely to have a higher number of stress fractures during her athletic career.

Although the RED-S framework of the IOC identifies an analogical skeletal response from relative energy deficit in male athletes as well, it is noted that there are differences in the biochemical pathways for these responses due to sex hormones; specifically, a decrease in IGF-1 and testosterone levels appears to mediate the response in males rather than a reduction in estrogen [14]. In addition to differences in the biochemical pathways for RED-S in males compared to females, it has been observed clinically that women have a higher risk of fractures when they develop RED-S. This is likely due to the fact that estrogen directly affects bone remodeling at much greater rates than does testosterone; also female athletes are more frequently subject to extreme levels of caloric restriction compared to their male counterparts.

here are many published studies that link both menstrual irregularity and oligo/amenorrhea to an increased risk for bone stress injuries. A scoping study by Macmillan et al. (2024), evaluating the association between menstrual cycle features and musculoskeletal injuries among female athletes found that menstrual irregularities resulted in higher injury rates for all types of injuries, including bone stress injuries [15]. It was noted from the study that while there is some variability as to when during the menstrual cycle these injuries occur, it suggests that varying levels of hormones throughout the cycle can play a major role in the amount of tissue that will be injured.

The association between hormonal contraceptives and stress fractures is still being researched. Cheng et al. (2021) assessed how menstrual irregularities, the use of hormonal contraception, and bone stress injuries related to each other in female collegiate athletes in the U.S. [16] They found that athletes experiencing menstrual irregularities but no hormonal contraception use had a greater chance of developing bone stress injuries than those athletes without either problem. Oral contraceptives seemed to offer some degree of skeletal protection as they maintained endogenously supplied oestrogen levels due to hypothalamic suppression. However, this protection wasn’t apparent for all athletes taking oral contraceptives; specifically, athletes using progestin-only contraceptives didn't seem to be protected to the same degree.

Vitamin D and calcium level is an additional area of endocrine nutritional influence on the risk of bone stress injuries and has some sex specific implications. There is evidence that inadequate levels of vitamin d can impair calcium absorption by the body and therefore lead to a decrease in bone mineralization and also potentially affect muscle strength. All these factors will contribute to a higher risk for stress fractures. Females who compete in sports that take place indoors as well as females who live at high latitude are at an increased risk for being deficient in vitamin D; this along with the negative impact of low energy availability and disturbances in menses have further exacerbated the risk for poor skeletal health.

4.4. Sport-Specific and Training-Related Risk Factors

The impact and frequency of a particular sports activity are primary determinants of stress fracture risk and each factor interacts with biological sex in its own way. Sports activities which involve high-impact, weight-bearing exercise and repetitive contact with the ground (i.e., long-distance running, basketball, gymnastics, etc.) produce the greatest cumulative cyclic loads on bones. These types of loads are most likely to cause fatigue related micro-damage in cortical bone [5], and research indicates that females tend to have a greater incidence rate of stress fractures than males when participating in these same sports. Therefore it would appear that there are certain biologic vulnerabilities of women that are exacerbated by the specific loading requirements of a particular sport.

Popp et al. (2023), examined female runners, that have experienced bone stress injuries in order to investigate the characteristics of impact loading when athletes were either under "fresh" or "fatigued" conditions [12]. The results showed that females who had suffered from repeated stress fractures displayed different impact loading characteristics than female runners who had either never been injured or suffered one injury. Females with a history of multiple stress fractures exhibited larger average and instantaneous loading magnitudes over the tibia as well. It appears these biomechanical loadings on female runners' bones are not only responsible for their first stress fracture(s); however, they continue to be a source of risk for future stress fractures -- especially when their bodies are experiencing fatigue due to muscle and nerve exhaustion.

The environment provided by military training environments provides an opportunity for researchers to examine the impact of abrupt changes in training load on stress fracture injuries due to bone loading; female military recruits have a significantly greater rate of lower extremity (lower-limb) stress fractures compared with their male counterparts regardless of receiving the exact same training schedule and therefore experiencing the same amount of external load [6]; although both genders may receive the same level of external load while undergoing similar training protocols, there is evidence to suggest that biological factors such as bone geometry, hormone levels and bone remodeling are the main contributors to the increased risk seen in female gender, as opposed to being based on the level of training load itself.

Training load progression rate has been identified as a modifiable risk factor for stress fractures in athletes of both sexes. However, it appears that the relationship between increasing training load and injury is more sensitive to women than men. Vannatta et al. (2020) conducted a systematic review and meta analysis on biomechanical factors contributing to running related injuries and report that sample characteristics including sex significantly moderated observed relationships between loading variables and injury outcomes [17]. Specific hazardous patterns included sudden increases in weekly training miles; reduced recovery time frames; and rapid transition from low impact activities to high-impact activities were most prevalent in female athlete populations

Sport specialization at a young age has been identified as another type of risk factor for injury that may have sex-specific consequences. The early commitment to a single high impact sport reduces opportunities for youth athletes to develop a wide range of motor skills and increases their exposure to repetitive loading in specific areas of their skeleton (i.e., less than ideal variation). The rate of early sport specialization is also higher within many sports where females are over-represented including, but not limited to, gymnastics and dance. This could help explain why the tibia and metatarsals have the highest incidence of stress fractures among adolescent girls when compared to adolescent boys [7].

4.5. Age, BMI, and Other Demographic Modulators of Sex Differences

Demographic factors that are commonly found to include body mass index (BMI), and age have an effect on the risk of developing a stress fracture. Furthermore demographic factors can either modify or amplify the size of the difference in injury rates that exists between males and females. Low body mass index has been identified as a risk factor for lower bone mineral density and stress fractures in female athletes; with it being established that there is a direct correlation between body composition, energy available, and skeletal health [18] . Conversely, the relationship between BMI and fracture risk is less clear in male athletes; with the relationship being influenced by different paths.

Rauh et al. (2020), conducted a study examining sport specialization and low bone mineral density in female high school distance runners. They found that high school female distance runners who were younger when they began specializing as well as had lower body mass index (BMI's) demonstrated significantly lower bone mineral density than their non-specialized peers [18]. The results from this study support the need for young female runners to maintain an appropriate caloric intake so as to avoid excessive leanness; since a low body mass can have a negative effect on both the loading of bones by reducing the mechanical load placed upon them as well as negatively affecting hormonal production (suppression of reproductive hormone).

A prospective cohort study on high level female distance runners was conducted by Ishida and Tohyama (2026). They found that there are several predictive risk factor for developing a stress fracture over a 6 month time frame [8]. Lowered body mass index (BMI), menstrual irregularity, as well as having had previous stress fractures were among the strongest indicators of developing an additional injury; thus, demonstrating how individuals can have increased levels of risk when they develop and present with other related risks. Because the study is prospective it adds further validity to their findings regarding the temporally prior relationship of these risk factors.

Age is a key factor that influences the connection between sex and the incidence of stress fractures. Adolescent girls who participate in high-impact sports are at an increased risk for developing stress fractures as they go through their most active phase of sports while also going through a time when their bones reach peak density. When adolescent females experience periods of low energy and/or irregular menses (which can occur as a result of many factors such as excessive caloric restriction), the negative effect on bone density may be long-lasting and continue well beyond adolescence [19].

In addition to data from the general population, additional studies conducted among military personnel and athletes have provided insight into the ways in which specific demographic factors may influence the relationship between sex and fractures. For example, Mroz et al. (2025) examined how body composition, bone density, and tibial microarchitectural features differed in college level female athletes who participated in different levels of sports that had varying degrees of impact load [20] . In comparison to their lower-impact counterparts, those female athletes competing at higher levels were found to have better bone microarchitecture and greater bone mineral density than female athletes competing at the same collegiate athletic division but engaged in less impact loaded sports; the results suggest an advantageous effect for habitual high-impact loading as it relates to osteogenesis. However, the study's findings also highlight the importance of having adequate caloric intake and endocrine function to realize the beneficial effects of regular high-impact exercise on the skeleton in women.

Ethnicity and Race are factors which influence bone micro-architecture with respect to training-induced changes. Hughes et al. (2023) demonstrated that while the same types of changes occurred in the distal tibia for both sexes during military Basic Training, there were significant racial differences; this emphasizes the necessity to include demographic diversity when considering race/sex based risks for fractures from repetitive mechanical loading [10]. Therefore, it is important to move past a binary gender approach to developing an inclusive, multi-factorial method for risk stratifying individuals.

5. Discussion

The evidence synthesized in the narrative review clearly indicates that female athletes have a significantly and consistently greater incidence rate for stress fractures when compared with male athletes. This increased incidence is due to an aggregation of several factors influencing both males and females across the realms of biology/hormones, mechanical/biomechanics, and training. There does not appear to be one factor alone which can account for the variation in injury rates by gender; however, it is clear that female athletes are at greater risk as a result of a combination of their biomechanically disadvantageous skeletal structure and hormonal vulnerability, and the type of physical loads to which they are subjected in sports.

The anatomically-related and biomechanically-related evidence summarized in this review provides a strong mechanistically-based rationale for why the incidence of stress fractures would be greater in females than males. A combination of smaller tibia cross-sectional size; less cortical bone area; as well as differences in trabecular structure, contribute to a reduced ability of the female skeleton to withstand loads and therefore result in an increased level of bone strain at a given applied force [9]. While these physical parameters cannot be modified over the short-term time frame, they could potentially be offset somewhat through certain types of exercise programs aimed at increasing osteogenic loading of bones and enhancing periosteal apposition during early adolescence. The biomechanical studies by Gaudette et al. (2025), demonstrated that while there was some variability in the injury rate among different parts of the body, the factors that influence the likelihood of a proximal vs. distal bone stress injury were distinctly different [11], which has important implications for developing prevention strategies specifically related to a particular sport or type of activity.

In terms of hormones as it relates to the clinical implications of fractures among female athletes, I would say the most impactful is likely related to low energy availability, menstrual irregularities, and nutritional deficiencies because these factors can all be modified. According to De Souza et al., (2026) and the revised Female Athlete Triad Consensus Statement, energy availability remains the key driver in the causal pathway from disturbed eating patterns to disrupted menstrual cycles and subsequently poor bone health [3]. Most importantly, De Souza et al. (2026), with their inclusion of an adolescent model into the consensus statement, recognize that the effects of the triad will be even greater if they occur during the time frame of peak bone mass development; during this phase, bone loss due to the triad cannot be reversed.

Nutrition is an important area of focus when addressing both the Female Athlete Triad and Reducing Excess Energy Availability Disorder (RED-S), as such disorders can affect how a coach/clinician works with their athlete population. According to Grabia et al. (2024), nutrition plays a key role in preventing bone loss from exercise-related injuries that may lead to stress fractures. They found that adequate calorie intake, along with sufficient amounts of calcium and vitamin D, in addition to other nutrients can help preserve bone density which will lower the likelihood of suffering a stress fracture [13]. Therefore, a clinician/coach must use nutrition assessment techniques during regular physical examinations to determine whether a female athlete is at high risk for stress fractures based on her activity level.

The relationship between menstrual cycle parameters and the impact of hormonal contraceptives on stress fractures creates additional factors for clinicians to consider. The findings of MacMillan et al. (2024), which noted that both phases of menstrual cycles and irregularity influence an athlete's musculoskeletal injury risk, suggest temporary alterations in muscle and connective tissue vulnerability due to varying hormone levels during different phases of their menstrual cycle [15]. Additionally, combined oral contraceptives were shown to protect against skeletal injuries by Cheng et al. (2021), therefore raising the question whether these agents should be prescribed to amenorrheic athletes to provide additional skeletal protection; however, there is currently no substantial data supporting this approach as an appropriate primary method of intervention [16].

Sport-specific as well as training related risk factors provide additional examples of how complex sex differences are in the occurrence of stress fractures. For example, although both male and female runners are subject to similar volumes of training and therefore, theoretically would be subjected to comparable stresses on their bones, females have been found to experience a significantly greater number of stress fractures than men; this difference is most likely due to biological risk factors versus training behavior [12]. Therefore, there are several modifiable aspects of training (e.g., progressive loading or early specialization) which could serve as targets for prevention strategies. When developing periodized training programs coaches and sports medicine professionals should use gender specific guidelines based upon the increased susceptibility of females to overuse bone injury.

Demographic evidence supporting this article supports the necessity for an athlete-specific approach to assessing the risk of developing a stress fracture in athletes. A pattern of low body mass index, abnormal menstruation patterns, previous stress fractures, adolescents and/or participating in high impact sports are common characteristics of athletes who have many factors increasing their risk of experiencing a future stress fracture [8]. Screening tools that evaluate the total or cumulative risk of multiple factors including the above will provide a useful tool for evaluating risk in athletes [14] and thus should become a standard screening tool used by clinicians working with athletes; especially females competing at the college level and professional/elite levels.

There are several limitations in this review that need to be recognized. It is a narrative review, therefore; as with all narrative reviews there are many forms of bias in the selection of the studies that were chosen for this review including selection bias due to an inability to use systematic search methods to find other relevant articles. Also, since many different study types (i.e. case-control, cohort etc.) and subjects (i.e. men vs. women) have been reported in the literature examined within this review, the ability to compare results directly is limited. In addition, using the two group classification system (i.e. male and female), which was used by most of the studies examined, will likely limit how well the overall results can represent the full range of athletes' hormone levels and bone densities. Therefore, additional research must include longitudinal study designs and gender stratification in order to better understand what factors contribute to the difference in stress fracture rates between genders.

6. Conclusions

The overall consensus of this review is that female athletes suffer from stress fractures more frequently than male athletes for a broad range of sports and training conditions. There are no singular contributing factors which explain why females have an elevated risk of stress fractures; however, it can be inferred by the combination of anatomical, biomechanical, hormonal, dietary, and training-related vulnerabilities in female subjects as they relate to each other in a complicated or synergetic fashion.

Anatomical differences between genders exist. Women have less dense bones (smaller bone area) compared to men, and they also exhibit anatomically different microstructural properties. As such, when subjected to loads similar to those experienced by males, the greater bone strains associated with female anatomy are more likely to result in fractures. Additionally, the Female Athlete Triad and RED-S models indicate that low energy availability, and consequently menstrual irregularity or cessation is responsible for lower bone mineral density and increased risk of fracture in female athletes. Adolescent athletes represent an especially vulnerable subset, where bone damage can occur early in their life and be permanent.

From a practical standpoint, preventing stress fractures in female athletes will require multidisciplinary approach that includes screening for nutritional status, monitoring of menstrual cycle health, biomechanical assessment and management of training load. Routine screenings for energy availability, menstrual function and bone density should be standardized for all high impact/wight-bearing sport disciplines by women. Guidelines for training in sex-specific models must be developed to account for difference between skeleton response of woman and progressive loading demands.

More prospective research with sex stratified approaches as well as standardized outcomes is required to determine the individual contributions of all risk factors and to assess the effectiveness of programs that target specific vulnerabilities of males and females. A more comprehensive knowledge base regarding the biological and environmental variables that influence stress fracture risk in female athletes will be necessary to maximize long term athletic performance through improved injury prevention strategies.

Disclosure

Author Contributions:

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All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgements: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process During preparing this work the authors have used ChatGPT for the purpose of improving language and readability. After using this tool, the authors have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication.

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