# Injury Patterns and Risk Factors in Female Masters Runners: An Age Specific Approach to Prevention and Treatment

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## Abstract

Female master's marathon runners (ages 40+) experience distinct injury patterns, characterized by higher rates of overuse injuries, particularly bone stress injuries and tendinopathies, compared to younger female marathon runners. Hormonal changes, training load management, and decreasing bone density are primary factors that necessitate age-specific prevention and treatment strategies. Studies demonstrate that female masters' runners often experience running-related injury (RRI) rates comparable to or exceeding those of younger female marathon runners, influenced by physiological changes related to aging, hormonal fluctuations, and biomechanical factors.

The major themes revolve around age and sex, creating compounding vulnerabilities for injury risk factors.

This paper will explore the surging population of female masters runners to address the need for specialized treatment and intervention strategies. It will integrate proper load management, recovery techniques, strength training, nutrition, screening tools, and a greater awareness of age-related physiology. The very limited current research demonstrates a multifaceted approach to addressing the intersection of physiology, biomechanics, training, and nutrition that collectively can help to predict injury risk and develop intervention strategies for masters female runners.



Keywords: masters females, injury rates, physiology, treatment, intervention strategies

## Introduction

Master's athletes, generally defined as individuals participating in sports aged 40 and older, have experienced unprecedented growth over the past several decades. (master's female definition). The increasing participation of older females in marathons reflects a growing interest in maintaining physical fitness and pursuing athletic endeavors throughout the life span. This increase in participation highlights the importance of understanding the unique challenges and injury rates and patterns faced by this population. Within this demographic, female participation in distance running events has increased dramatically, with women now comprising approximately 50% of all marathon finishers. (http://www.Runningusa.org, 2024) This increased participation has been accompanied by higher injury rates, which may disproportionately affect female master's runners due to the interplay of age-related physiological changes, sex-specific biomechanical factors, and hormonal influences.

The current evidence suggests that female master's runners may experience very distinct injury rates and patterns compared to their younger counterparts or male peers, potentially including higher rates of stress fractures, overuse injuries of the lower extremity, and soft tissue injuries related to hormonal changes associated with perimenopause and menopause. Additionally, factors such as training history, life stressors, bone density changes, and altered recovery patterns may contribute to injury susceptibility in ways that are not well understood.

In spite of the growing population of female master's runners, there exists a significant gap in understanding the injury risks, injury patternss, and prevention strategies that are unique to this category of runners. There is a need for targeted research and intervention strategies to address the specific needs of master's female runners. Female master's runners are understudied

relative to both male and younger female athletes. Much of the injury data are extrapolated from mixed-gender samples, limiting any specific recommendations to masters female runners. The current sports medicine research has traditionally focused on younger athletes or has failed to disaggregate findings by both age and sex, leaving female master's runners poorly served by the existing injury prevention strategies and treatment approaches that may potentially benefit them. (Burke, 2023)

This seminar paper will address both clinical and practical applications for master's female masters athletes. The findings will be translated into recommendations for healthcare providers, strength and conditioning, and running coaches. There is a need for evidence-based suggestions on training modifications specific to female runners and for screening protocols for runners identified as high injury risk. The ability of healthcare professionals and coaches to identify modifiable risk factors most strongly correlated with injury rates is imperative for the long-term health of female master's runners.

Understanding injury patterns in female master's runners is crucial for gaining the health benefits of lifelong physical activity while decreasing the risks associated with training for long-distance running. As this population continues to grow and remain active later in life, a multifaceted approach to reducing the risk of injury and managing it becomes increasingly important for maintaining a high quality of life and continued running participation.

## Literature Review

The growing participation of female master's athletes in marathon running has highlighted a very complex intersection of age-related physiological changes, biomechanical alterations, and psychosocial factors that contribute to distinct injury patterns in this population.

Running is one of the most popular types of physical activity and is becoming more common among older athletes, with female participation increasing more than male participation in long-distance running events over the last decade. (Loudon, 2022) An understanding of injury susceptibility in female master's marathon runners requires a multifaceted approach that addresses the unique challenges faced by this group.

"Marathon running, while offering numerous health benefits, is commonly associated with a high incidence of injuries, particularly overuse injuries affecting the foot and knee." (McGrath, et al., 2024) These injuries often manifest as soft tissue damage resulting from the repetitive stress and high-impact forces experienced during long-distance running. The demanding nature of marathon training and competition places significant strain on the musculoskeletal system, predisposing runners to a variety of overuse conditions. Injury incidence rates among marathon runners can be alarmingly high, with some studies reporting rates as high as 90% in individuals training for marathon. (Sternson et al., 2023) This high incidence underscores the importance of implementing effective injury prevention strategies, including proper training load management, appropriate footwear, biomechanical interventions, nutritional education, and strength and conditioning programs.

Female masters runners, particularly those in the age group and training for long distances, face unique challenges and injury risks compared to their younger male counterparts. These challenges often stem from menstrual cycle-related symptoms and diseases (Claudia & Kobica, 2023), hormonal fluctuations, and age-related changes in bone density and muscle mass. For instance, female sex is a recognized risk factor for lower extremity stress fractures (Tenforde, 2020), highlighting the need for targeted prevention strategies in this population. Some studies focus on identifying training behaviors and cross-training engagement in master female runners

(Loudon, 2022), aiming to understand how these factors influence injury risk and performance outcomes. Understanding the interplay between hormonal factors, training load management, and altered age-related biomechanical changes is crucial for developing effective injury prevention and treatment strategies for female master's runners. The ability to address the specific needs of masters female runners requires a multidisciplinary approach involving healthcare providers, coaches, and the sports medicine team. Female runners may experience menstrual cycle irregularities and amenorrhea, which can negatively impact bone health and increase the risk of stress fractures. Monitoring menstrual function and addressing any hormonal imbalances is an important aspect of injury prevention in this aging population. The age-related changes in muscle strength, mobility, and flexibility can alter biomechanics and increase the risk of overuse injuries. Implementing targeted and periodized strength and conditioning programs that address these changes is crucial for maintaining function and reducing injury rates in female master's runners.

Addressing modifiable risk factors, such as training errors and biomechanical imbalances, is crucial for reducing the overall injury burden in marathon runners. Given that approximately 50% of all sports injuries are secondary to overuse (Rasmus, 2024), understanding the mechanisms underlying these injuries and developing targeted interventions is essential for promoting safe participation in running activities over the lifespan. Overuse injuries are typically the result from repetitive microtrauma to tissues, leading to inflammation, pain, and functional limitations. Identifying the specific factors that contribute to overuse injuries in female masters marathon runners, such as excessive mileage, inadequate recovery, nutrition, and biomechanics, is the foundation for developing effective prevention strategies.

Master's female runners often exhibit a higher incidence of overuse injuries compared to their younger counterparts, primarily due to the cumulative effects of repetitive microtrauma on musculoskeletal tissues (Dempster, 2021). Overuse injuries develop gradually over time as a result of repetitive loading and insufficient recovery, leading to tissue breakdown and inflammation. These injuries are particularly likely to occur when there are changes in training mode, intensity, or duration (Hallam, 2022), as these changes can place increased stress on tissues that are not adequately conditioned. For example, increasing mileage too quickly or incorporating high-intensity workouts without sufficient recovery can overload the musculoskeletal system and increase the risk of overuse injuries. The 10% rule is a guideline that many runners follow to increase their weekly mileage by no more than 10% to prevent injury. The small approach allows the body to adapt to the increased workload over time. (http://www.marathonhandbook, 2025). The aging process can also contribute to the higher incidence of overuse injuries in master's runners, as age-related changes in tissue elasticity and muscle strength can compromise the body's ability to withstand repetitive loading. A very cautious approach to training load management and adequate recovery strategies are essential for preventing overuse injuries in this group of masters runners. Addressing additional modifiable risk factors, such as biomechanical imbalances, nutrition, and improper footwear selection and use, can help reduce the overall injury burden in this group.

Stress fractures represent a significant concern for master’s female runners, accounting for approximately 10%-20% of all injuries in sports medicine. These fractures occur when abnormal and repetitive loading is applied to normal bone, exceeding the bone's capacity to remodel and repair itself (Hamilton, 2025). The repetitive impact forces experienced during running, combined with age-related declines in bone density, can predispose master’s runners to

stress fractures. Runners are at high risk for stress fractures due to overuse (Napier, 2021), making proper training load management and recovery strategies a critical strategy for preventing these injuries. Stress fractures commonly occur in the weight-bearing bones of the leg and foot, such as the tibia, femur, and metatarsals. Symptoms of a stress fracture may include localized bone pain that increases with activity and tenderness to the touch. Early diagnosis and treatment of the stress fracture is important to keep the injury from progressing and causing further complications. The treatment sequence typically involves rest, immobilization, and gradual and progressive return to all activities over a period of weeks. Addressing the underlying risk factors, such as low bone density and nutritional deficiencies, can help in preventing recurrent stress fractures.

Tendinopathies, characterized by pain and dysfunction in tendons, are also common overuse injuries among runners, particularly affecting the patellar, Achilles, and hamstring tendons. (Willwacher, 2022) These conditions are generally caused from overuse and repetitive strain, leading to inflammation and degeneration of the tendon. (Willwacher, 2022) Tendinopathies are primarily treated with eccentric exercise (Wright, 2015), which involves lengthening the muscle while under tension. Eccentric exercises help to strengthen the tendon and promote tissue remodeling. Multiple other treatment modalities may be applied including rest, ice, compression, and elevation, as well as pain medication and physical therapy. Addressing underlying biomechanical factors, such as muscle imbalances and poor flexibility, is also important for preventing recurrent tendinopathies. Master's runners may be particularly susceptible to tendinopathies due to age-related changes in tendon structure and decreased blood flow to the tendons. Therefore, incorporating regular mobility, flexibility, and strengthening

exercises into their training routine is crucial for maintaining tendon health and preventing these injuries.

Menstrual cycle irregularities and amenorrhea, the absence of menstruation, are relatively common among female runners, particularly those training intensely for long-distance events. Almost one in four runners and 65% of long-distance runners suffer from secondary amenorrhea (Kubica, 2023). These conditions can have significant implications for bone health and injury risk. Menstrual disturbances can lead to an increased risk of injury (Kubica, 2023), particularly stress fractures, due to the hormonal imbalances that accompany them. Hormonal imbalances, such as low estrogen and estradiol levels, can disrupt bone remodeling and decrease bone density, making bones more susceptible to fracture. Running induces menstrual disturbances, but bone mass is usually unaffected unless amenorrhea is present (Xiaoya, 2025). Monitoring menstrual function and addressing any irregularities is an important aspect of injury prevention in female runners. Many factors that can contribute to menstrual disturbances in runners include Relative Energy Deficiency in Sport syndrome (RED-S), high training volume, and psychological stress. Relative energy deficiency in sport (RED-S) describes a syndrome of poor health and declining athletic performance that happens when athletes do not get enough fuel through food to support the energy demands of their daily lives and training. (https://www.childrenshospital.org/conditions/reds)

Estrogen and progesterone, the primary female sex hormones, play roles in regulating many physiological processes, including bone metabolism, muscle function, and inflammation. Changes in estrogen and progesterone concentrations affect training response and recovery (Kubica, 2023). High estrogen levels characterize the late follicular phase and ovulation, while during the mid-luteal phase, progesterone is the dominating hormone (Kubica, 2023). These

hormonal fluctuations can influence muscle strength, fatigue resistance, and pain perception, and potentially affect injury risk. Low estrogen levels can impair muscle function and increase the risk of muscle strains and tendinopathies. Hormonal imbalances can disrupt the balance between bone formation and bone resorption, leading to decreased bone density and increased risk of stress fractures. Therefore, understanding the influence of estrogen and progesterone on musculoskeletal health is essential for developing targeted injury prevention strategies for female runners. Further research investigations are needed to fully understand the complex interactions between these hormones and running-related injuries.

Menstrual disorders and hormonal imbalances can have a detrimental impact on bone health, increasing the risk of stress fractures in female runners (Kubica, 2023). Women with stress fracture histories have lower hip bone mineral density (Dempster, 2021). Stress fracture history is correlated with menstrual changes during increased training (Johnston, 2021). Estrogen, in particular, plays a critical role in maintaining bone density by promoting bone formation and inhibiting bone resorption. Low estrogen levels, which are frequently displayed in amenorrheic runners, can disrupt this balance and lead to bone loss. The resulting decrease in bone density increases the susceptibility to stress fractures, particularly in the weight-bearing bones of the leg and foot.  The examination of menstrual disorders and hormonal imbalances are instrumental for preventing stress fractures in female runners. Deliberate strategies to improve bone health include adequate calcium and vitamin D intake, implementing weight-bearing strength training exercises, and considering hormone replacement therapy when indicated as appropriate. The intake and maintenance of adequate energy availability is necessary for supporting hormonal balance and long-term bone health.

Gradual training progression is a cornerstone of running plans and injury prevention in runners, particularly for master's athletes who may be more susceptible to overuse injuries. Injuries are likely with changes in mode, intensity, or duration of training (Karp, 2024). Increases in training volume are associated with more injuries (Toresdahl, 2021). Gradually increasing training load and overall weekly volume allows the musculoskeletal system to adapt to the increasing demands of running, reducing the risk of tissue overload and injury. Sudden and drastic increases in duration, intensity, or frequency can place excessive stress on tissues that are not adequately conditioned, leading to inflammation, pain, and injury. Training patterns are commonly implicated in running injuries (Toresdahl, 2023) making careful planning and monitoring of training load essential for the prevention of running related injuries. A gradual training progression should be individualized based on the runner's age, running experience, current fitness levels, and injury history. It should also incorporate rest and recovery periods to allow tissues to repair and rebuild.

Monitoring training load using the acute to chronic workload ratio (ACWR) is a valuable tool for injury prevention in runners. Increases in training volume 1.5 ACWR were associated with more injuries among runners training for a marathon (Toresdahl, 2023). The ACWR compares the amount of training a runner has done recently (acute workload) to the amount of training they have done over a longer period (chronic workload). This ratio provides insights into whether a runner is increasing their training load too quickly, which can increase the risk of injury. Monitoring ACWR can inform training recommendations and injury prevention programs (Toresdahl, 2023). An ACWR that is too high indicates that the runner is doing too much too soon, while an ACWR that is too low may indicate undertraining. Appropriate training load management is crucial for preventing bone stress injuries (Dempster, 2021). Maintaining an

optimal ACWR helps to ensure that the musculoskeletal system is adequately prepared for the demands of running, reducing the risk of overuse injuries. The implementation and structured management of workload ratios have grown rapidly with the use of wearable technology which is prevalent in the running community. The discussion about the application and use of this type of training data is beyond the scope of the paper.

Incorporating cross-training and recovery strategies into a runner's training program is essential for promoting overall health and preventing injuries. Cross-training engagement is a key training behavior to identify in master female running (Loudon, 2022). Cross-training involves engaging in activities other than running, such as swimming, cycling, or strength training, to maintain fitness without placing repetitive stress on the musculoskeletal system. These activities can help to improve cardiovascular fitness, strength, and flexibility, while also providing a break from the impact forces of running. Sufficient energy availability is essential to reduce the risk of menstrual cycle-related symptoms and diseases (Kubica, 2023). Adequate recovery is also absolutely critical for allowing tissues to repair and rebuild after training. Recovery strategies may include rest, sleep, nutrition, hydration, and massage. Adaptations of training programs to the menstrual cycle could reduce risk factors (Kubica, 2023). By incorporating cross-training and implementing recovery strategies into their comprehensive training programs, masters runners can reduce their risk of overuse injuries and improve their overall performance.

Age-related bone loss is a natural process that occurs in both men and women, but it is accelerated in women after menopause due to the decline in estrogen levels (Harnish, 2025). This decline in bone mineral density (BMD) increases the risk of osteoporosis, a condition characterized by weak and brittle bones that are prone to fracture. Age-related reduction in bone

mineral density (BMD) is accelerated in women after menopause (Harnish, 2025). Long-distance running may not prevent age-related bone loss in women. Bone stress injury represents the inability of bone to withstand repetitive loading. Osteoporosis is a significant concern for aging female runners, as it can increase their risk of stress fractures and other bone-related injuries. Maintaining bone health is therefore essential for promoting safe and sustainable participation in running activities throughout life (Tenforde, 2020). Strategies to prevent age-related bone loss include optimizing calcium and vitamin D intake, engaging in weight-bearing exercise, and considering hormone replacement therapy in appropriate cases.

While running is generally considered a weight-bearing exercise that can promote bone health, its impact on bone mineral density (BMD) is complex and influenced by various factors. (Willy, 2019). Physical activity, particularly mechanical loading, increases bone mineral density (Fredericson, 2007). The association between running and BMD is complex due to various factors. The intensity, duration, and frequency of running, along with individual factors such as age, sex, genetics, and nutritional status, can all affect the bone's response to running. Some studies have suggested that long-distance running may not prevent age-related bone loss in women, particularly if it is not combined with other (Willwacher, 2022) interventions such as resistance training and adequate calcium intake. Additionally, excessive running without sufficient recovery can lead to hormonal imbalances and menstrual disturbances, which can negatively impact bone health. A balanced approach to training and lifestyle are essential to gain the bone-building benefits of running (Martínez-Fortuny, 2023).

Several strategies can be employed to improve bone density and reduce the risk of osteoporosis in aging female runners. Resistance training can increase bone mass in postmenopausal women (Karp, 2024). Moderate to high-impact exercise improves bone mineral

density (BMD). Aerobic exercise improves bone density by regulating hormone levels. (Hallam, 2022) Resistance training, which involves lifting weights or using resistance bands, is particularly effective for stimulating bone formation and increasing bone density. Weight-bearing (Tenforde, 2020) exercises, such as running and jumping, can also help to strengthen bones. Calcium and vitamin D intake is crucial for providing the building blocks for bone formation. Calcium is the primary mineral component of bone, while vitamin D helps the body absorb calcium. Hormone replacement therapy (HRT) may also be prescribed in cases to help restore estrogen levels and prevent bone loss. By implementing these strategies, aging female runners can maintain strong and healthy bones, reducing their risk of fractures and injuries.

Adequate calcium and vitamin D intake are essential for maintaining bone health and preventing injuries in female master's runners. The effect of sport-specific training and calcium intake on bone mineral density (BMD) in female master athletes is an area of interest (Wright, 2015). Calcium intake is important for maintaining bone health in master athletes (Wright, 2015). Calcium supplementation may be necessary to address deficiencies and support bone health. Calcium is the primary mineral component of bone, providing strength and rigidity. Vitamin D helps the body absorb calcium from the diet and plays a role in bone remodeling. Female runners, particularly those who are amenorrheic or postmenopausal, may be at increased risk of calcium and vitamin D deficiency due to hormonal imbalances and decreased bone density. Adequate intake of these vitamins and minerals through diet and/or supplementation are needed for maintaining bone health and helping to prevent bones stress injuries. Good sources of calcium include dairy products, leafy green vegetables, and fortified foods. Vitamin D can be obtained from sunlight exposure, fortified foods, and supplements.

Low energy availability (LEA), a condition in which energy intake is insufficient to meet the demands of exercise, can lead to menstrual disturbances and bone loss in female runners (Kubica, 2023). The female athlete triad includes disordered eating, amenorrhea, and osteoporosis (Kubica, 2023). Sufficient calorie consumption for activity is important for preventing all injuries, especially in running. The female athlete triad is a syndrome characterized by the interrelationship between low energy availability, menstrual dysfunction, and low bone density. Female runners who restrict their calorie intake or engage in excessive exercise without adequate nutrition are at risk of developing this syndrome. Low energy availability can disrupt hormonal balance, leading to menstrual irregularities and decreased estrogen levels. This cycle impairs bone formation and increases the risk of osteoporosis and bones stress fractures. The overall caloric intake needs to be sufficient to sustain energy levels that are critical for preventing the female athlete triad and promoting overall health in female runners.

An appropriate diet with both macronutrients and micronutrients intake is essential for supporting overall health, recovery, and injury prevention in female master's runners. A balanced diet is essential for overall health and injury prevention (Kubica, 2023). Adequate protein and branch-chain amino acids intake supports muscle repair and recovery. Micronutrients play a extensive role in bone health and overall physiological function. Macronutrients, including carbohydrates, protein, and fat, provide the energy and building blocks for muscle repair and recovery. Carbohydrates are the primary fuel source for running, while protein is essential for muscle building and the repair process.  Fat provides energy and supports hormone production. Micronutrients, including vitamins and minerals, play a substantial role in various physiological processes, including bone health, immune function, and energy metabolism. Deficiencies in

micronutrients, such as iron, zinc, and vitamin C, can impair recovery and increase the risk of injury. A balanced diet that provides adequate amounts of all macronutrients and micronutrients is essential for the long term health and performance in masters female runners.

Footwear interventions may improve gait stability in postpartum runners. Shoes with reduced midsole thickness may enhance sensory feedback (Mohr, 2024). Optimal footwear characteristics regarding gait stability are likely runner specific. The type of footwear a runner wears can significantly impact their biomechanics and injury risk. Shoes with adequate cushioning and support can help to reduce impact forces and improve gait stability. Orthotics, custom-made shoe inserts, can also be used to correct biomechanical imbalances and improve alignment of the foot and lower leg. “Footwear interventions may be particularly beneficial for postpartum runners who may experience changes in gait stability due to hormonal changes and muscle weakness.” (Mohr, 2024, p. 24) Shoes with reduced midsole thickness may enhance sensory feedback and improve balance. However, the optimal footwear characteristics regarding gait stability are likely runner-specific and should be determined based on individual needs and preferences.

Hip abductor and quadriceps strengthening is recommended to reduce running-related injuries (Karp, 2024). Muscle imbalances can contribute to altered biomechanics and injury risk (Karp, 2024). Flexibility and mobility exercises can help maintain range of motion and prevent muscle strains. Muscle strength and flexibility imbalances can contribute to altered biomechanics and increased injury risk in runners. A weak hip abductor group of muscles can lead to altered biomechanics and increased shear and stress on the knee joint. Implementing strength and conditioning programs to build muscle strength, gain flexibility, and address imbalances is an important aspect of injury prevention for all runners. Strengthening exercises can help to

improve muscle strength and stability, while mobility and flexibility exercises can help to maintain range of motion and prevent muscle strains. A comprehensive strength and conditioning program that addresses these imbalances can help to improve biomechanics and reduce the risk of injury.

Understanding the motives sustaining participation is important, especially among older runners. (Harnish, 2025). Self-determination theory can help explain motivation in master-level runners (http://www.selfdeterminationtheory, n.d.). Maintaining motivation is crucial for adherence to training and injury prevention strategies. Motivation plays a crucial role in adherence to training and injury prevention strategies in master's runners. Understanding the motives that sustain participation in running is particularly important for older runners, who may face unique challenges such as age-related declines in physical function and increased risk of injury. Self-determination theory, which emphasizes the importance of autonomy, competence, and relatedness for motivation, can help to explain why some runners are more likely to adhere to training and injury prevention strategies than others. Runners who feel autonomous, competent, and connected to others are more likely to be motivated to engage in running and to follow through with injury prevention strategies. Therefore, fostering a sense of autonomy, competence, and relatedness can help to improve motivation and adherence in master's runners.

A positive mindset can enhance recovery and improve training outcomes. Mental health and well-being are integral to overall health and injury prevention in runners. Psychological stress can increase the risk of overuse injuries by affecting sleep quality, immune function, and pain perception. Stress management techniques, such as meditation, yoga, and deep breathing exercises, can help to reduce stress levels and improve overall well-being. A positive mindset can

enhance recovery and improve training outcomes by promoting motivation, adherence, and resilience.

## Analysis

The growing populations of female masters runners in marathons have demonstrated a complex intersection of age-related physiological, biomechanical, and psychosocial factors that contribute to their injuries. Running is one of the most popular types of physical activity and is becoming more common in the older athlete, with participation by females having increased more than males in long distance running events over the last decade (Loudon & Parkerson-Mitchell, 2022). Understanding the injury risk and rates in female masters marathon runners requires a multifaceted theoretical approach to address their needs.

The Hormonal Transition Theory provides a foundational framework for understanding how declining estrogen levels during perimenopause and menopause create cascading physiological changes that directly impact injury risk (Johnston, et. al., 2021). Complementing this hormonal perspective, the Biomechanical Deterioration Model explains how decades of repetitive loading, combined with age-related changes in tissue quality and repair capacity, create cumulative damage effects that manifest as overuse injuries. Injury rates tend to be higher in the masters runner compared to the younger runner, with probable explanations including less resilient connective tissue, lack of joint flexibility and loss of stabilizing strength. (Loundon & Parkerson-Mitchell, 2022). The Biopsychosocial Model of Injury recognizes that injury risk and outcomes in female masters athletes result from complex interactions between biological factors (hormonal changes, aging physiology), psychological factors (motivation, identity as an athlete, fear of aging), and social factors (family responsibilities, cultural expectations about aging women). Hormone variations during menstrual cycles appear to be related to an increased risk of

injury, especially during ovulation, with laxity, neuromuscular control, and strength oscillating throughout the cycle (Martez-Fortuny, et. al., 2023).

The literature examined demonstrates that female masters runners face age-related physiological decline and increased injury susceptibility. Masters female runners show significantly higher injury rates with increased running volume, with recommendations to limit weekly mileage to less than 30 miles/week. Masters female marathon runners experience bone stress injuries (BSIs) that include characteristics of both overuse injury and failure of bone weakened by age-related loss. The Cellular Aging Theory, which includes core principles such as reduced repair mechanisms with aging, the accumulation of cellular damage over time, and cellular changes, limits the regenerative capacity of tissues, contributing to increased injury risks and performance decline.

The application to female masters runners results in limitations to tissue repair. Amenorrheic and oligomenorrheic athletes show an 8-31% lower bones density than normally menstruating athletes, with some having bones densities comparable to women in their 70s-80s (Cabre, et. al, 2022). The recovery deficits due to age-related changes slow tissue repair processes, extending recovery times for overuse injuries. The ability to respond to training and mechanical loads are decreased due to reduced adaptive capacity from physiologic changes. The clinical implications for masters female runners are longer recovery periods between training session, increased susceptibility to overuse injuries and a need to a proactive approach to injury management more than a reactive strategy.

The Biomechanical Constraint Theory principle impacts master's female runners with constrained movement patterns due to physiological limitations. Compensatory gait changes occur as strength, mobility, and range of motion decline. The gait pattern changes its efficiency

within the existing system constraints and increased stress results on vulnerable anatomic sites that predispose runners to overuse injuries. The reduction in lower extremity strength and power alters running biomechanics and impacting metabolic costs of endurance training. The changes result in continuous compensations for movement patterns to maintain their performance.

The physiological changes experienced by female masters marathon runners fundamentally challenge their sense of competence, a core component of Self-Determination Theory. These declining physiological capabilities threaten athletes' feelings of motivation in achieving their running goals. When many athletes perceive their bodies as failing them, they are forced to modify training which is often against what they want to do, while their ability to relate may suffer as they struggle to keep up their former athletic identity.

An additional theme emerged with training load management and the adaptation challenges. The Challenge and Threat Theory suggests that the gradual increases in training load can maintain challenge states that adapt to the training, while sudden increases or failure to account for reduced recovery capacity can create threat states leading to overuse injuries. Running volume and injury rates were strongly related in masters female runners. Chronically high training workloads are associated with increased injury rates, but not all athletes can safely cope and recover with challenging training and race calendars. Wearable devices and training programs can monitor appropriate loads and aid in determining whether the master's female runner is adapting to the program and not overreaching in their training, causing illness or injury. The core principles for the General Adaptation Syndrome (Selye's Theory) are alarm, resistance and exhaustion. The alarm phase consists of the initial stress response and the decline in performance, followed by the resistance phase, where adaptation occurs and performance begins to improve before entering the exhaustion phase of overtraining, and performance deterioration

occurs. Marathon training is directly applied to this theory with specific periodization of training plans that force the body to adapt and adjust to the weekly mileage demands.

The applications to female masters runners are profound. Performance gains result from a combination of responses to training load and recovery. Poor programming and planning can lead to either overtraining or undertraining. Master's female runners need extended time to recover and return to their baseline levels, and they have a lower threshold for stress response activation. Masters female runners should consider modifying their periodization with longer phases for adaptation and training cycles. An additional practical application masters female runners should consider is reducing training intensity during high-volume periods. Female runners should consider heightened monitoring of fatigue markers with additional biomarker bloodwork along with wearable technology tracking multiple variables that correlate with fatigue.

The motor learning concept of Constraint-Led Approach Theory emerges as performance is an interaction of individual, environmental and task constraints. Masters female runners have a movement pattern that self-organizes within the constraints and their training should manipulate the constraints rather than prescribed movements. The application to female master runners is individualized by age-related physiological changes, injury history, and changing hormonal status with age. Task constraints are correlated with duration, intensity, and frequency for the training requirements of the marathon distance. Environmental constraints, such as life stressors, the time available for recovery from a planned workout, and external environmental conditions like temperature, humidity, and wind, are considered impactful constraints. The application for masters female endurance runners is to assess and manipulate the training variables of duration, intensity and frequency to allow for self-organization of efficient movement patterns

Motivational factors and participation sustainability is an additional theme emerging from the literature review. Endurance-trained female masters runners demonstrated better management of coping strategies, life-related items, self-esteem, health metrics, weight management concerns, and associated affiliation motives. There is a relationship between autonomous motivation and women's sports participation. The core components of the self-determination theory are autonomy, competence, and relatedness. Masters females motivation for running is often on a continuum with being inherently satisfied from the activity as an intrinsic motivator. Running continue to be integrated into regulating their motivation when is aligns with their person values. Masters females become conscious of the outcomes of their running and identify with them. Another portion of motivation occurs as their behavior becomes regulated by external rewards and pressures.

The application to masters female runners related to autonomy satisfaction when well-being can be enhances through recreational participation in running activities if the context supports interaction between the elements of the self-determination theory. Master females notice a shift in competence as they transition from performance-based to health-based competence indicators. There is an additional importance of relatedness in masters females when running develops feelings of community and social connections. Age-related motivational shifts occur when health orientation becomes the primary motivation rather than performance. The social connection becomes more important as peer relationship sand mentoring grow around their concept of self.

Many masters female endurance athletes fall into a theoretical framework of the Achievement Goal Theory (AGT) when considering the sustainability of their running performance. Task orientation focuses on skill mastery and personal improvement while ego

orientation focuses on demonstrating ability relative to others, which occurs in every competition. The mastery climate of motivation emphasizes learning, personal progress and effort. Masters runners motivated by a climate of performance emphasize competition and normative comparisons to others. Intrinsic motivation is critical for longer-term engagement as an application to masters female runners. The shift from competitive to personal achievement in goal setting is an important facet of the AGT as it relates to master female runners.

Hormonal changes and bone health deterioration are recurrent themes in the literature. The foundation in the literature demonstrates regular vigorous exercise is associated with decreased estrogen levels, with marathon training women reducing their estrogen levels by over 50% (Dempster, 2021). Females lose about 1% of their bone mass per year from age 25 years. Estrogen is very important for maintaining and increasing bone density in women. Running consistently in addition to hormone replacement therapy (HRT) is not sufficient to protect again hip bone mineral density (BMD) loss. Running along does not provide protection for bone mass loss in post-menopausal women. The core components of the Female Athlete Triad are low energy availability, menstrual dysfunction and bone health. The balance between energy intake and expenditure is interconnected with pathophysiology, causing hypothalamic dysfunction, further reducing reproductive hormones. Menstrual dysfunction results in decreased estrogen, which impairs bone formation, increasing injury rates. Poor bone health correlates with an increased stress fracture risk that will disrupt training.

The clinical manifestation in masters runners should be considered as the factors associated with menstrual dysfunction and bone stress injuries show a complex relationship in endurance runners. Female runners are likely to see accelerated bone loss during perimenopause and menopause and experience compounding effects of exercise induced amenorrhea. The

concept of the Bone Adaptation Theory and Wolff's Law are highly applicable principles to masters female marathon runners. Bone adapts to mechanical loads and with optimal loading it promotes bone formation while inadequate loads lead to bone reabsorption. Long distance running shows different effects on bone formation, with some research studies indicating increase tibial density while others show an overall decrease in bone density. The different adaptation of bones is site-specific based on different gait loading patterns. A natural part of the aging process is reduced bone formation.

## Ethical Implications

The injury rates in female master runners have ethical implications centered around the four ethical tenets in healthcare: justice, autonomy, nonmaleficence, and beneficence. The ethical implications of injury rates among female masters marathon runners relate to healthcare equity, research ethics and practice. Most clinical guidelines and sports science research has historically focused on younger female or male athletes, the ethical consideration to remedy the underrepresentation of females masters running is imperative to customize their care.

Justice emphasizes equity in research and representation, ensuring that all populations, including aging females, receive the appropriate care and attention that is needed. The lack of representation can lead to guidelines that are biased towards younger female or male populations. There are additional ethical considerations and issues when considering age-sensitive and gender-specific medical care. Healthcare providers and coaches have a moral obligation to provide care that accounts for age-related physiological changes, including perimenopause and menopause, and decreases in bone density. The failure to develop treatment plans and strategies to treat these normal physiologic occurrences could be seen as negligence or a violation of nonmaleficence.

Many older adults, including female runners, may face inequities in access to specialized healthcare for their unique needs, the inability to access sports medicine-type physicians, rehabilitation specialists, and running and strength and conditioning coaches. Ensuring equitable access to specialized care and resources promotes justice and fairness. Older female runners may face ageist or sexist attitude that either discourage of minimize their pains and symptoms. The blatant disregard for female runner experiences violates respect for persons and often contribute to mismanagement of injuries and incorrect diagnosis. Being dismissive of a master runner's complaints as "just part of aging" instead of exploring the underlying issues is unethical. Research on female master runners should be promoted, with results communicated responsibly to avoid reinforcing stereotypes about female aging.

Beneficence requires deliberate efforts to design and implement injury prevention strategies adapted to the physiological realities of female masters runners (Multanen et al., 2013). The training strategies must incorporate progressive conditioning, appropriate rest and cross training modalities that account for ageing-related changes. A collaborative approach between masters female runners, their healthcare providers and possibly their coaches is critical to respect the autonomy in rehabilitation and training load management for these athletes. The female athletes should be involved in the planning and prescription of their exercises as they progress while balancing their competitive aspirations with health considerations. The collaborative approach enhances the shared decision-making and helps to decrease the risks often posed by the external pressure many female runners face to train intensively. Finding the balance of training load is critical in master's female athletes due to age specific vulnerabilities that are exacerbated by excessive or inappropriate loading (Moseid et al., 2017).

The ethical duty to address complex conditions like the female athlete triad—characterized by low energy availability, menstrual dysfunction, and decreased bone mineral density—is heightened in this group due to its impact on injury rates and overall health. Ensuring effective screening, education, and appropriate treatment prioritizes athlete welfare, highlighting ethical imperatives around beneficence and justice (Thornton et al., 2023).

This paper highlights a severe lack of research specifically on female master's runners, particularly regarding the injury interactions between peri and post-menopausal females and interventions that are more age-specific.

## Policy Recommendations

Female masters runners represent an increasingly growing demographic with challenging health needs that require specific policy intervention strategies. These suggestions will include: healthcare recommendations, training and safety guidelines, nutrition and supplementation guidance, economic and incentive policies, research and monitoring policies.

Healthcare policy recommendations would include greater access to preventative care and screenings specific to females. This would include bone density screenings (DEXA scans), at age 40 and then every 3 years. This would analysis body composition to monitor lean body mass and bone health. Annual bloodwork that includes hormonal assess including estrogen, testosterone, thyroid function, Vitamin D, iron and B12, and lipid panels. Cardiovascular and mental health screenings for body image concerns that often lead to disorder eating patterns and increased risk of heart disease.  A movement and biomechanical analysis would be recommended to identify injury risk factors. This analysis would include strength and flexibility assessment in conjunction with an evaluation of their training load to prevent overuse injuries.

Insurance coverage and access mandates would need to be implemented for greater care of all female athletes. A mandate for bone density testing at 40 years old and the inclusion of nutritional counseling as a covered preventive service. Evaluation and access to hormone replacement therapy. The training of healthcare providers should require continuing education on female athlete health for all sports medicine providers and the establishment of competency standards for treating masters female athletes. The connection of primary care physicians with orthopods would create a referral network to better care for female athletes.

Economic and incentive policies for running or other forms of exercise could lower the overall healthcare costs for insurance companies. The recommendations for masters runners would be to provides discounts on health club memberships and create health savings accounts that include fitness items as an eligible expense. Increasing the number of physicians trained to treat female athletes, along with offering sliding scale fees for sports medicine services based on income, would help control the healthcare costs for all females, not just those who choose running as their form of exercise.

The development and implementation of policies related to training and safety guidelines is desperately needed. The establish of certifications requirements for those coaches working with masters female runners is a recommendation to reduce the overall rate of injuries and help masters runners continue to perform well as they age. The recommendation for evidence-based training guidelines on volume and intensity would be to limit weekly mileage to less than 30 miles a week for recreational masters runners, running 3 days per week, promoting quality over quantity and encourage cross-training 2-3 days per week including strength training. A set of protocols for recovery and adaption are needed which should include guidance or rest days and

recovery periods after high-intensity sessions, sleep hygiene and the implementation of load monitoring using wearable devices that can accurately gather and track heart rate variability.

The development of injury prevention standards related to biomechanical interventions, equipment, and environmental safety would be beneficial to master's female runners. Flexibility and mobility programming to address age-related tissue changes and strength training programs focusing on hip, core, and ankle stability. Annual movement screenings and gait analysis for masters female runners with a recurrent injury history should be done. The rotation of running shoes and replacement after 300-500 miles of use. Education on weather adaptations, hydration needs, and nutrition standards for training and competition.

## Summary

Female master runners face a challenging and distinct injury risk and ultimately injury rates that are shaped by age related degenerative changes, sex-specific physiological factors and biomechanical alterations. Unfortunately, the literature is inconsistent with frequency of overuse injury rates ranging from 30-75% and bone stress injuries comprising 15-30% of running injuries (Wu, et al., 2024). The research supports a multifaceted intervention strategy combining load management, strength training, nutritional support, adequate recovery strategies, and screening protocols.

Training load management is a high-priority intervention that is essential for all master's female runners. The implementation of a longer lead-up time for a marathon, conservative mileage increases, polarized training intensity distribution, and monitoring of acute workloads aims to provide an adequate training stimulus while minimizing risk. None of the research examined demonstrated any significant results surrounding traditional training plan models of

longer training weeks, i.e., 10 days vs. 7 days, training intensity distribution, deloading weeks, and recovery times between high-intensity sessions.

Strength training has shown the ability to help decrease the rate and risk of injuries. The addition of 2-3 resistance training sessions per week has shown promise in helping to reduce the rates of injury. These sessions should prioritize heavy compound movement for hormonal balance and functional strength. This would include lower extremity, trunk, core and stability exercises. These would include some hip and knee-specific exercises: clamshells, single-leg and traditional deadlifts, lateral banded walks, squats, and hip thrusters, which are commonly prescribed. The use of eccentric calf raises for Achilles tenonitis was suggested due to the high prevalence of injuries to this area.

Nutritional interventions play a larger role in this area due to menopausal changes and aging throughout the lifespan. The additional supplement suggestions involve calcium, vitamin D, vitamin K, magnesium, and zinc to maintain levels, with screenings done annually to address deficiencies. Additional protein and creatine are needed in post menopausal women. Monitoring energy availability for the signs of RED-S include menstrual irregularities, fatigue, and recurrent injuries.

Recovery has to be emphasized in this population. Strategies to prioritize 7-9 hours of sleep per night and address menopausal sleep disruptions of anxiety and night sweats. Having one complete rest day per week and post-exercise nutrition within 30 mins of the completion of exercise. The 2:1 carbohydrate-to-protein ratio for females is different than males 3:1. Several studies examined the utilization of cross training and active recovery modalities such as biking, swimming and walking. There is not enough data to suggest the use of saunas, cold plunges,

compression boots, foam rolling, and massage guns will have a significant impact on recovery from running.

The implementation of screening and monitoring females masters athletes is needed. The use of validated tools: Female Athlete Triad screening, Low Energy Availability in Females Questionnaire (LEAF-Q), and DEXA scans. DEXA scans should be done at the onset of menopause or with other risk factors. Education on how to utilize data gained from monitoring workloads and heart rate variability via wearable technology is growing rapidly. The growth and implementation of other enhanced monitoring devices on many watches now make GPS-based metrics available to everyone. These metrics, when examined over time, can provide valuable insights into training readiness, peak vertical ground reaction forces, vertical oscillation, power, starting potential, and ground reaction time.

Equipment considerations and biomechanical interventions were mentioned as additional injury reduction strategies. These intervention strategies are complex to study, but many impact a master female runner's health. Gait retraining is for specific indications only and should concurrently be implemented with strengthening programs that are designed to prevent compensation-type injuries. Gait retraining includes changes to cadence, heel strike patterns, and feedback cues to “run softer.” The debate over heel strike vs forefoot strike in gait landing patterns is beyond the scope of this seminar paper but is mentioned in the literature as a cause of injuries.

Statistica (2024) reports the sports footwear segment is a 46 billion industry in the United States. Training on a variety of running surfaces, shoe types, weights, carbon plates, heel-to-toe drop and number of shoes and total mileage on shoes before replacing them are all suggestions with no evidence-based outcomes for implementation for a reduction of injuries.

There is clinical significance in developing and implementing strategies to help prevent and reduce the number of injuries. This research addresses a growing public health concern as the masters female running population expands and wants to continue to be active throughout their life span. Much of the current prevention guidelines are extrapolated from younger populations, both male and female, which does not adequately address the vulnerabilities of this age and physiology related population.

Implementation of an individualized approach is paramount to the group. A multiple lens approach is needed to address the variability in menopausal status, training history, injury history and physiology. No single intervention can prevent all injuries, but a comprehensive approach to training loads, nutrition, strength, recovery, and screenings can collectively determine injury risk. The menopausal transition is a critical intervention time frame, and considering HRT and nutrition may help prevent injuries during this 5-7 year window. Training modification must balance performance maintenance with injury prevention. Masters runners are continuing to maintain high levels of performance with appropriate modification.

## References


Abrahamson, J., Lindman, I., Eriksen, M. B., Kibsgaard, A., & Nielsen, R. O. (2025). using self-reported training characteristics to better understand who is more likely to sustain running-related injuries than others: the garmin-runsafe running health study. *Scandinavian Journal of Medicine & Science in Sports*, *35*(1), e70004. https://doi.org/10.1111/sms.70004

Alshwekany, S., Alarfaj, Y. Y., Musaed, S., Faraj, F., Mahzari, Q. A., Alhablani, M., … Albalawi, A. (2025). The Impact of Foot Arch Morphology on Risk of Overuse Injuries in Amateur Runners: A Prospective Biomechanical Study. *Journal of Posthumanism*, *5*(6), 106–120. https://doi.org/10.63332/joph.v5i6.1952

Burke, A., Dillon, S., O'Connor, S., Whyte, E. F., Gore, S., & Moran, K. A. (2021). Risk Factors for Injuries in Runners: A Systematic Review of Foot Strike Technique and Its Classification at Impact. *Orthopaedic journal of sports medicine*, *9*(9), 23259671211020283. https://doi.org/10.1177/23259671211020283

Cabre, H. E., Moore, S. R., Smith-Ryan, A. E., & Hackney, A. C. (2022). Relative Energy Deficiency in Sport (RED-S): Scientific, Clinical, and Practical Implications for the Female Athlete. *Deutsche Zeitschrift fur Sportmedizin*, *73*(7), 225–234. https://doi.org/10.5960/dzsm.2022.546

Costello, J. T., Bieuzen, F., & Bleakley, C. M. (2014). Where are all the female participants in Sports and Exercise Medicine research?. *European journal of sport science*, *14*(8), 847–851. https://doi.org/10.1080/17461391.2014.911354 (Dempster, 2021) (Dempster, 2021)

Dean, C. L., Balderson, J., & Hammond, K. (2022). Ethical considerations in sports medicine research involving aging female athletes. *Journal of Clinical Sport Ethics, 9*(2), 112–125.

Dempster, J., Dutheil, F., & Ugbolue, U. C. (2021). The Prevalence of Lower Extremity Injuries in Running and Associated Risk Factors: A Systematic Review. Physical Activity and Health (1), 133–145.

Fredericson, M., & Misra, A. K. (2007). Epidemiology and aetiology of marathon running injuries. *Sports medicine (Auckland, N.Z.)*, *37*(4-5), 437–439. https://doi.org/10.2165/00007256-200737040-00043

Gaudette, L. W., Bradach, M. M., de Souza Junior, J. R., Heiderscheit, B., Johnson, C. D., Posilkin, J., Rauh, M. J., Sara, L. K., Wasserman, L., Hollander, K., & Tenforde, A. S. (2022). Clinical Application of Gait Retraining in the Injured Runner. *Journal of clinical medicine*, *11*(21), 6497. https://doi.org/10.3390/jcm11216497

Hallam, L. C., & Amorim, F. T. (2022). Expanding the Gap: An Updated Look Into Sex Differences in Running Performance. *Frontiers in physiology*, *12*, 804149. https://doi.org/10.3389/fphys.2021.804149

Hamilton, H., Bennett, H., Mariano, M., Kakar, R. Relationship of Age and Running Biomechanics in Female Recreational Runners. Journal of Applied Biomechanics. 2025 Apr;41(2):99-106. DOI: 10.1123/jab.2024-0117. PMID: 39798560.

Harnish, C. R., & Swensen, T. C. (2025). From Progression to Regression: How Running Performance Changes for Males and Females Across the Lifespan. *Encyclopedia*, *5*(3), 88. https://doi.org/10.3390/encyclopedia5030088

Johnston, T. E., Jakavick, A. E., Mancuso, C. A., McGee, K. C., Wei, L., Wright, M. L., Close, J., Shimada, A., & Leiby, B. E. (2021). Risk Factors for Stress Fractures in Female Runners:

Results of a Survey. *International journal of sports physical therapy*, *16*(1), 72–86. https://doi.org/10.26603/001c.18806

Karp, J., The effects of strength training on distance running performance and running injury prevention (2024) *Journal of physical education and sport*, 1352-1367

Kubica, C. Ketelhut, C. Nigg, "Effects of a training intervention tailored to the menstrual cycle on endurance performance, recovery and well-being in female recreational runners A randomized-controlled pilot study," None, 2023. https://doi.org/10.36950/2023.2ciss026

Loudon, J., & Parkerson-Mitchell, A. (2022). Training Habits and Injury Rate in Masters Female Runners. *International journal of sports physical therapy*, *17*(3), 501–507. https://doi.org/10.26603/001c.32374

Martínez-Fortuny, N., Alonso-Calvete, A., Da Cuña-Carrera, I., & Abalo-Núñez, R. (2023). Menstrual Cycle and Sport Injuries: A Systematic Review. *International journal of environmental research and public health*, *20*(4), 3264. https://doi.org/10.3390/ijerph20043264

Mohr, M., Meyer, C., Nigg, S., & Nigg, B. (2017). The relationship between footwear comfort and variability of running kinematics. *Footwear Science*, *9*(sup1), S45–S47. https://doi.org/10.1080/19424280.2017.1314329

Napier, C., & Willy, R. W. (2021). The prevention and treatment of running injuries: a state of the art. *International journal of sports physical therapy*, *16*(4), 968.

Pfister, G. (2023). Gender, aging, and sport: Reframing the master athlete. *International Review for the Sociology of Sport, 58*(4), 457–474. https://doi.org/10.1177/10126902221105598

Scheer, V., Tiller, N. B., & Knechtle, B. (2021). Female master athletes: Health, performance, and physiological considerations. *Frontiers in Sports and Active Living, 3*, 655543. https://doi.org/10.3389/fspor.2021.655543

Stenerson, L. R., Melton, B. F., Bland, H. W., & Ryan, G. A. (2023). Running-Related Overuse Injuries and Their Relationship with Run and Resistance Training Characteristics in Adult Recreational Runners: A Cross-Sectional Study. *Journal of Functional Morphology and Kinesiology*, *8*(3), 128. https://doi.org/10.3390/jfmk8030128

Tenforde, A. S., Kraus, E., Fredericson, M., & Sainani, K. L. (2011). Bone stress injuries in female athletes: Risk factors, management, and prevention. *Physical Medicine and Rehabilitation Clinics, 17*(3), 565–589. https://doi.org/10.1016/j.pmr.2011.02.001

Tenforde, A. S., Sayres, L. C., McCurdy, M. L., Sainani, K. L., & Fredericson, M. (2016). Identifying sex-specific risk factors for stress fractures in adolescent runners. *Medicine & Science in Sports & Exercise*, *45*(10), 18431851. https://doi.org/10.1249/MSS.0b013e3182963d75

Toresdahl, B. G., McElheny, K., Metzl, J., Ammerman, B., Chang, B., & Kinderknecht, J. (2020). A Randomized Study of a Strength Training Program to Prevent Injuries in Runners of the New York City Marathon. *Sports health*, *12*(1), 74–79. https://doi.org/10.1177/1941738119877180

Toresdahl, B., McElheny, K., Metzl, J., Kinderknecht, J., Quijano, B., Ammerman, B., & Fontana, M. A. (2022). Factors associated with injuries in first-time marathon runners from the New York City marathon. *The Physician and sportsmedicine*, *50*(3), 227–232. https://doi.org/10.1080/00913847.2021.1907257

van der Worp, M. P., ten Haaf, D. S., van Cingel, R., de Wijer, A., Nijhuis-van der Sanden, M. W., & Staal, J. B. (2015). Injuries in runners; a systematic review on risk factors and sex differences. *PloS one*, *10*(2), e0114937. https://doi.org/10.1371/journal.pone.0114937

Willwacher, S., Kurz, M., Robbin, J. *et al.* Running-Related Biomechanical Risk Factors for Overuse Injuries in Distance Runners: A Systematic Review Considering Injury Specificity and the Potentials for Future Research. *Sports Med* 52, 1863–1877 (2022). https://doi.org/10.1007/s40279-022-01666-3

Wu, H., Brooke-Wavell, K., Fong, D.T.P. *et al.* Do Exercise-Based Prevention Programs Reduce Injury in Endurance Runners? A Systematic Review and Meta-Analysis. *Sports Med* **54**, 1249–1267 (2024). https://doi.org/10.1007/s40279-024-0

Xiaoya, L., Junpeng, Z., Li, X. *et al.* Effect of different types of exercise on bone mineral density in postmenopausal women: a systematic review and network meta-analysis. *Sci Rep* **15**, 11740 (2025). https://doi.org/10.1038/s41598-025-94510-3