REVIEW ARTICLE

Common Running Overuse Injuries and Prevention

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ABSTRACT Runners are particularly prone to developing overuse injuries. The most common running-related injuries include medial tibial stress syndrome, Achilles tendinopathy, plantar fasciitis, patellar tendinopathy, iliotibial band syndrome, tibial stress fractures, and patellofemoral pain syndrome. Two of the most significant risk factors appear to be injury history and weekly distance. Several trials have successfully identified biomechanical risk factors for specific injuries, with increased ground reaction forces, excessive foot pronation, hip internal rotation and hip adduction during stance phase being mentioned most often. However, evidence on interventions for lowering injury risk is limited, especially regarding exercise-based interventions. Biofeedback training for lowering ground reaction forces is one of the few methods proven to be effective. It seems that the best way to approach running injury prevention is through individualized treatment. Each athlete should be assessed separately and scanned for risk factors, which should be then addressed with specific exercises. This review provides an overview of most common running-related injuries, with a particular focus on risk factors, and emphasizes the problems encountered in preventing running-related injuries.

KEY WORDS Runners, Exercise, Pain, Risk factors, Injury mechanism, Preventive methods.

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Introduction

Running is among most popular physical activities, which may be attributed to its accessibility, inexpensiveness and numerous positive effects. It has been shown, for example, to lower diabetes, hypertension and hypercholesterolemia risk (Williams & Thompson, 2013).

Although being a non-contact, submaximal, and continuous activity, running nonetheless elicits a considerable amount of injuries. Runners are particularly prone to sustaining overuse injuries, which occur due to frequent submaximal strain and/or inadequate recovery of the tissues involved (DiFiori et al., 2014). Several risk factors for developing running-related injuries have been investigated, and can be roughly divided into intrinsic (e.g. individual's abilities, anthropometric characteristics, and cognitive properties) and extrinsic (e.g. ground surface, footwear and training load) (Johnston, Taunton, Lloyd-Smith, & McKenzie, 2003).

Various strategies for running injury prevention are applied by coaches and runners themselves (e.g. stretching, warm-up, technique training). In this review, we will discuss the most common running injuries, underlying mechanisms, risk factors, and preventative strategies.

Biomechanics of Running

In this chapter, we will briefly review some biomechanical properties of running, focusing on aspects and parameters relevant to injury development and prevention.

Running cycle and joint kinematics

The running cycle consists of two fundamental phases: the stance phase and the swing phase. In kinematic

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analysis, the first contact with the ground (foot-strike) marks the beginning of the cycle for the leg (Anderson, 1996). From this point on, the muscles contract eccentrically to absorb landing forces. The moment of transition into concentric contraction and force generation is called "mid-stance" (also mid-support). Concluding the stance phase is the point of take-off, the last instant of foot touching the surface. Joint positions, velocity, and other kinematic variables are usually measured at these three crucial moments (Novacheck, 1998).

Most of the joint motion during the running cycle occurs in the sagittal plane. The pelvic range of motion is minimal (approximately 10°), which provides stability and efficiency (Novacheck, 1998). Hip range of motion rarely exceeds 40° (Pink, Perry, Houglum, & Devine, 1994). Peak extension (around 10°) occurs at the take-off. Typical peak hip flexion is around 30° (Nicola & Jewison, 2012). The knee is flexed to 20-25° at the foot strike, reaches 45° flexion in mid-stance and then extends to approximately 25° of flexion at take-off (Novacheck, 1998). In the case of striking heel-first (which most long-distance runners do), there is up to 10° ankle dorsiflexion at foot strike, and some plantar flexion must happen initially. Afterwards, the ankle moves into 20° of dorsiflexion during amortization and then into 20° plantar flexion during propulsion (Dugan & Bhat, 2005).

Abnormal kinematic parameters in the frontal plane (especially excessive ranges of motion) are most often linked to injury development. In the amortization phase, the pelvis drops to the side of the swing leg (generally not over 10°) and then returns to a neutral position throughout the propulsion phase (Nicola & Jewison, 2012). To compensate for this, the trunk is flexed laterally, to the side of the stance leg. Hip abduction and adduction both reach up to 10°. Peak adduction is achieved at the mid-stance, while peak abduction is the highest at the middle of the swing phase (Novacheck, 1998). The ankle is inversed (6 to 8°) at foot-strike, then it moves to 8° of eversion through the amortization phase (Nicola & El Shami, 2012). The eversion range of motion during stance phase is the main determinant of the foot pronation. Anything over 9° of eversion is considered moderate pronation, while 13° or more is labelled high pronation (Morley et al., 2010).

Horizontal movements are, like those in the frontal plane, smaller than sagittal movements (Novacheck, 1998). Internal hip rotation and consequential knee valgus are most often discussed in terms of injury development (Powers, 2003). Horizontal knee and ankle motion are minimal in normal running kinematics (Nicola & Jewison, 2012).

Muscle Work

The muscle activation pattern changes with running velocity and ground slope, yet the main force generators remain the same. Hip extensors are active in the second part of the swing phase and throughout the stance phase. Knee extensors, ankle plantar flexors, and hip abductors are active throughout the stance phase. Hip flexors propagate the leg forwards after the take-off. The glutes and the hamstrings pull the body forwards, while quadriceps and ankle plantar flexors generate more of an upward force. As noted before, there is an eccentric contraction occurring in the amortization phase. Muscles and tendons lengthen, absorbing the forces of the landing. Due to elastic properties, tendons return up to 95% of the energy stored in the amortization phase (Novacheck, 1998). Quadriceps seem to be the largest power contributor in amortization, while the most work in propulsion phase is generated by plantar flexors (Hamner, Seth, & Delp, 2010).

Foot-strike problems

Ground reaction forces are a major concern in running. Several trials have been conducted to investigate different interventions for minimizing these forces. Striking heel-first is particularly problematic, as the first part of the impact cannot be absorbed by the dorsiflexors and is, therefore, transmitted to passive tissues and muscles higher in the kinetic chain (Verdini, Marcucci, Benedetti, & Leo, 2006). Looking at force curve (Figure 1), there are two peaks in the case of heel strike. The height of the first peak should be as low as

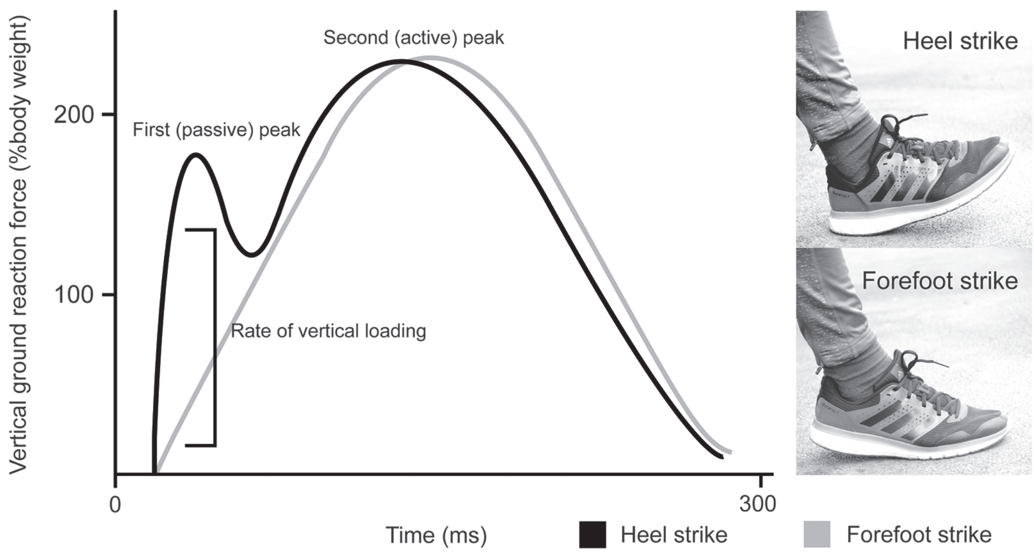

FIGURE 1 Comparison of ground reaction forces between heel strike and forefoot strike technique

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possible or even absent (which it is, in good running technique). Additionally, the average and the maximum slope of the curve (rate of vertical loading) before the first peak should also be noted. The reduction of all these three parameters is the primary goal when discussing lowering ground reaction forces (Zadpoor & Nikooyan, 2011). Striking heel-first not only increases the mechanical stress; it also causes the loss of energy. In the case of the proper technique, plantar flexors start to contract eccentrically immediately after the first touching the ground, and the energy absorbed is returned later in full amount. The heel strike impedes this, since some degree of plantar flexion must happen first so that the front of the foot also reaches the ground, and some energy is lost (Novacheck, 1998).

Most common running injuries

Sport-related injuries are classified as acute (also traumatic) or chronic (also overuse). Acute injuries occur due to sudden trauma (e.g. leg bone fracture caused by opponents' foul in soccer or sudden hamstring tear during sprinting). Chronic injuries develop gradually as a result of accumulating microtrauma, which is caused by repeated submaximal strain (Roos & Marshall, 2014). Depending on the appearance of pain, chronic injuries are further classified into four stages (McCarty, Walsh, Hald, Peter, & Mellion, 2010):

- Stage 1: Pain, present only after activity;
- Stage 2: Pain, present during activity, not impairing performance;
- Stage 3: Pain, present during activity, impairing performance;
- Stage 4: Ceaseless pain, not receding even with rest

A recent meta-analysis showed an incidence of 2.5 injuries per 1000 hours of exposure in long-distance track and field athletes. However, novice runners are at much higher risk, with an incidence of 33 injuries per 1000 hours of exposure (Videbaek, Bueno, Nielsen, & Rasmussen, 2015). Another review investigated the incidence of individual injuries. The highest incidence was reported for medial tibial stress syndrome (MTSS; 13.6-20.0%), Achilles tendinopathy (9.1-10.9%), patellar tendinopathy (5.5-22.7%), plantar fasciitis (4.5-10.0%), ankle sprain (10.9-15.0%), iliotibial band syndrome (1.8-9.1%), hamstring injury (10.9%) and tibial stress fracture (9.1%) (Lopes, Junior, Yeung, & Costa, 2012). In ultra-distance runners, Achilles tendinopathy and patellofemoral syndrome (PFS) are most common. The relatively low reported incidence of the latter (5.5%) was based on only one study in this review.

Medial tibial stress syndrome

Also commonly referred to as shin splints, MTSS is especially prevalent in military personnel (Sharma, Weston, Batterham, & Spears, 2014), yet also frequent in runners. It is loosely defined as a pain on the inner side of the tibia. The pain is diffuse and not localized, as in tibial stress fractures. The onset of MTSS usually happens in the early stages of the season, or anytime the volume and intensity of training increases suddenly (Putukian, McCarty, & Sebastianelli, 2010). The pain is worsened by exercise.

The exact mechanism for developing MTSS is still to be determined. Most textbooks state that the pain originates from the periosteum along the medial tibia. Several trials have been conducted in order to link a specific muscle to MTSS. The conflicting evidence gathered has led to mixed opinions among experts (Franklyn & Oakes, 2015). However, we know more about risk factors. Increased hip external rotation during the stance phase (in males only), higher body mass index, prior use of orthotics, navicular drop (indicator of resting foot pronation) and fewer years of training experience were all linked to higher risk for sustaining MTSS (Newman, Witchalls, Waddington, & Adams, 2013). Interestingly, females are at higher risk than males are. Newman and colleagues (2013) pointed out that this may indicate a bone-related mechanism behind MTSS development, since women have been shown to have lower bone mineral density.

Treatment of MTSS is dependent on the severity of the injury. Rest alone can cure most cases. Athletes are recommended to participate in cross-training activities that do not overload the area (e.g. swimming) in order to maintain their fitness until the injury ceases. They should then return to running and running-involving activities gradually. Some may benefit from stretching, if there are deficits in the range of motion. Implementation of proprioceptive training and ankle strengthening exercises is also encouraged (Galbraith & Lavallee, 2009).

Tendon injuries

Terminology on tendon injuries is inconsistent and often confusing. Tendinopathy is an umbrella term, describing painful conditions in tendons and surrounding areas due to overuse (Rees, Maffulli, & Cook, 2009). Other terms should be used after histopathological confirmation. Tendinitis is an injury with accompanying inflammation of the tendon (Andres & Murrell, 2008). Tendinosis is defined as a degenerative injury of the tendon with no or few inflammation cells present. Along with changes in the collagen matrix, there is an increased vessel and nerve ingrowth (Ackermann & Renstrom, 2012). Other conditions affecting the tendon include tenosynovitis (inflammation of tendon's synovia (a tendon's sheath)) and peritendinitis (inflammation of muscle-tendon junction and paratendon (the tissue filling the interstices of the fascial compartment in which a tendon is situated)) (Kurppa, Waris, & Rokkanen, 1979). Age and gender, among others, seem to be important risk factors for sustaining a tendinopathy, with males and the elderly being at higher risk (Rees et al., 2009).

Achilles tendinopathy is most prevalent among runners. It is further classified into two major categories based on location: insertional and non-insertional. Patellar tendinopathy is sometimes called jumper's knee, since it is common in sports involving frequent jumping (e.g. volleyball, basketball). However, it is also common in runners.

Several biomechanical risk factors have been linked to development of both aforementioned conditions. These include unequal leg length, poor plantar flexor flexibility, strength imbalances, sudden changes in training load, inappropriate footwear, poor running technique and excessive foot pronation during stance phase, with the latter perhaps being the most significant in Achilles tendinopathy. In patellar tendinopathy, the volume of training (particularly the volume of jumping tasks) seems to play a much bigger role (Rutland et al., 2010).

Plantar fasciitis

Plantar fasciitis is one of the most common causes of pain in the foot. In the general population, it is most frequent at ages 40-60, whereas runners are at the greatest risk at younger ages. Pain is usually limited to the posterior part of the foot, under the heel. It is exacerbated while taking the first few steps after longer inactivity (Waclawski, Beach, Milne, Yacyshyn, & Dryden, 2015). The origin of the pain is the plantar fascia, a connective tissue spanning from the inferior surface of the calcaneus towards the bones in the front of the foot. It was thought that plantar fasciitis is caused by the inflammation of the fascia. Today, the majority of experts believe that degenerative changes are responsible for the onset of injury. A study by Lemont, Ammirati, and Usen (2003) showed an absence of inflammation in samples collected during plantar fasciitis surgery. As with tendinopathies, the dilemma of inflammation versus degenerative changes is not entirely closed, but does lean to the degeneration theory side.

Knowledge of the predictors for sustaining plantar fasciitis is limited. A recent meta-analysis found only an increased body mass index to postulate a higher risk. Other frequently listed risk factors include excessive foot pronation during the stance phase, high foot arch and tight Achilles tendon (Goff & Crawford, 2011).

Many interventions for treating plantar fasciitis have been advocated, but few have been proven effective. Stretching of the Achilles tendon and plantar fascia is generally a good idea, along with strengthening calf muscles. Other non-surgical treatment options are corticosteroid injections, plantar iontophoresis, and extracorporeal shock wave therapy (Molloy, 2012).

Iliotibial band syndrome

Iliotibial band (ITB) syndrome is an injury often associated with running, though it is also common in cycling, weight lifting, skiing, and soccer (Lucas, 1992). ITB is a connective tissue on the lateral aspect of the leg, extending from the pelvis to the knee, entering the lateral tibial condyle. It encompasses the m. tensor fascia latae and is connected to the muscles of the gluteal region and to the lumbar fascia. The pain in ITB syndrome is present around the lateral side of the distal femur, between the lateral femoral condyle and ITB.

ITB syndrome was strongly believed to be caused by repeated rubbing of the band over the lateral femoral epicondyle during flexion-extension cycle, which would cause inflammation of the local bursa or the band itself. In the past decade, several authors have expressed disagreement with this theory. Fairclough et al. (2007), for example, pointed out that ITB movement across the epicondyle is probably an illusion and that only a tension shift from anterior to posterior part of the distal ITB occurs. However, they stated that some medial-lateral movement is present. When the tract moves medially, it compresses the intermediary tissues, which are highly innervated; therefore, they are a good candidate for a pain source.

Kinematic risk factors, associated with ITB syndrome include excessive hip adduction, excessive peak knee internal rotation, and excessive peak trunk ipsilateral flexion during stance phase (Aderem & Louw, 2015). Fredericson et al. (2000) found that long distance runners with ITB syndrome had lower hip abduction strength of the affected leg compared to the unaffected leg and compared to unaffected runners. In contrast, Grau, Krauss, Maiwald, Best, and Horstmann (2008) found no difference in either abduction or adduction strength comparing runners with ITB syndrome with controls. A trial by Willy and Davis (2011) may support this. Their hip-strengthening intervention significantly increased hip abduction and external rotation strength but did not correct the excessive hip adduction during the stance (all the participants in the study were exhibiting increased hip adduction prior to intervention).

Other more or less proven risk factors are tightness of the ITB, increased knee flexion range of motion during stance phase and the dominance of the quadriceps over the hamstrings (Lavine, 2010).

Patellofemoral syndrome

As with many other conditions, there is a lack of universal definition for PFS. It can be described as a painful condition that involves patella and patellar retinaculum, with no apparent specific cause (Holmes & Clancy, 1998). It is often mistaken for patellar chondromalacia, a condition with similar symptoms, but differentiated from PFS by patellar cartilage damage and softening (Salehi, Khazaeli, Hatami, & Malekpour, 2010). The term "runner's knee" is often used when referring to PFS, but we do not recommend using it, since it has been attributed to other conditions. PFS is characterized by pain around patella and sometimes by crepitation in the knee. The pain is exacerbated with squatting, running, cycling and sitting with flexed knees for prolonged period (Heintjes et al., 2004).

The primary culprit for PFS development is probably patellar maltracking. In the majority of cases, the patella is translated laterally during knee flexion. The causes of maltracking are a matter of debate. Pal et al. (2011) found that delayed activation of vastus medialis is one of the possibilities. Maltracking can also be a result of structural abnormalities, such as the increased Q-angle (the angle between femur and tibia). However, of all known risk factors, dynamic knee valgus should perhaps be the primary concern, as it could be eliminated or minimized with proper interventions (Ford et al., 2015). Increased foot pronation during the stance phase and weakness of the hip abductors can both elicit a knee valgus, and both were found to be a predictor for PFS. Moreover, women exhibit knee valgus more often and have a significantly higher risk for PFS (Petersen et al., 2014). This is another reason to consider dynamic valgus when attempting to treat or prevent PFS.

PFS is mostly treated conservatively. Sometimes, it recedes with sufficient rest and progressive return to activity. Recommendations for exercise selection are mixed. In their systematic review, Bolgla and Boling (2011) concluded that quadriceps strengthening is the only proven method for eliminating PFS. Hip strengthening protocols also appear promising.

Stress fractures

Repeated submaximal loading on the bones can result in stress fractures. Microscopic injuries develop and accumulate over time, leading to macro-structural breakdown. Stress fractures are most frequent in lower limbs and spine. The pain associated with a stress fracture is usually localized and subsides with rest. Progress through successive workouts is common. Runners and military recruits are at highest risk (Welck, Hayes, Pastides, Khan, & Rudge, 2015). Additionally, females are affected much more often than males are (with estimated incidences of 9.8% and 6.5%, respectively) (Wentz, Liu, Haymes, & Ilich, 2011). This may be attributed to gender-related risk factors, such as the female athlete triad (a syndrome of three interrelated conditions: amenorrhea, eating disorders, and low bone mineral density) (Nattiv et al., 2007).

Tibial stress fractures are most prevalent in runners (Lopes et al., 2012). As said before, if the pain is spread over a larger surface of the tibia, it is more likely to be caused by MTSS. Heel-strike technique and increased ground reaction forces are most often linked to increased incidence for sustaining tibial stress fractures. Milner, Ferber, Pollard, Hamill, and Davis (2006) found female runners with tibial stress fracture history to exhibit increased ground reaction force-related parameters (instantaneous and average vertical loading rates, and tibial shock, i.e. a measure of peak positive acceleration of the tibia). The same conclusions were reached in a research design for runners in general (Davis, Milner, & Hamill, 2004).

Prevention of Running Injuries

We have seen that many injuries share common risk factors, with ground reaction forces, excessive foot pronation, and excessive hip adduction during stance phase being mentioned the most often. Some problematic kinematic abnormalities are shown in Figure 2. One might suspect that designing prevention program should be fairly straightforward, or that there are many interventions proven to lower running injury risks.

FIGURE 2 Kinematic parameters, associated with increased injury risk

Legend:
1 – Pelvic drop
2 – Hip adduction
3 – Knee valgus
4 – Foot pronation

Possibly the most comprehensive review of the literature, regarding running injury prevention, is the one done by Yeung, Yeung, and Gillespie (2011). They focused only on soft-tissue injuries but included a wide range of interventions in their systematic search and further analysis. Twenty-five trials were identified, with the participants being military recruits (19 trials), runners (3 trials), prisoners (2 trials) and soccer referees (1 trial). Strong evidence for a preventative effect was found only for wearing a knee brace. There was also some moderate evidence for the effectiveness of heel pads. No evidence was found to support the preventative effects of stretching, strengthening or balance exercises. The authors concluded that the evidence for the effectiveness of interventions for preventing running injuries is weak and limited. Enke and Gallas (2012) reviewed the literature on treating and preventing four of the more common running injuries: MTSS, PFS, ITB syndrome, and Achilles tendinitis. Concerning prevention, they concluded that individualized programs should be formed, based on the risk factors an athlete is exhibiting. Craig (2008) focused on prevention of MTSS in his systematic review. The interventions found were shock-absorbing insoles, foam heel pads, Achilles tendon stretching, footwear selection, and graduated running programs. None of these prevention methods was effective. Shock-absorbing insoles were the most promising.

Additionally, Saragiotto et al. (2014) reviewed the studies that investigated risk factors for sustaining running-related injuries in general. The main risk factor identified was a previous injury. Weekly distance, weekly training frequency, and increased Q-angle were the only other risk factors identified in at least two trials. Reducing training volume is probably an effective, but impractical method for most runners, especially professionals. Rudzki (1997) showed that reducing the running distance (and adding more weighted marching instead) results in lower injury rates among military recruits. These findings are clearly not relevant for runners, but if they are able to afford some cross-training, they could lower the injury risk.

Certainly, there are interventions that could benefit almost all runners. For instance, lowering ground reaction forces is a good idea in general. Clansey, Hanlon, Wallace, Nevill, and Lake (2014) successfully reduced ground reaction forces-related parameters with gait retraining method. They used what is referred to as biofeedback or real-time feedback method. Participants ran on a treadmill, receiving information about peak tibial acceleration. They were instructed to correct the technique in a way to minimize this parameter. After only six 20-minute sessions spread over three weeks, peak tibial acceleration and both average and instantaneous vertical force loading rates were significantly decreased. Crowell and Davis (2011) managed to lower the same three parameters in their trial. What is more, the reductions were preserved until one-month follow-up measurements. It seems that feedback methods could provide an effective way to lower ground reaction forces and thus reducing injury risk.

Sharma et al. (2014) combined biofeedback methods with an exercise program. This combination substantially reduced the incidence for sustaining MTSS among military recruits over 26 weeks of a military training program. The exercises used were (unlike in most other, unsuccessful, trials) judiciously chosen. Some good examples include bird dog, single-leg squats, drop jumps, single-leg hops, star-excursion stability exercise (touching several marked points on the ground with the free leg in single-leg stance), hip flexors stretch, hip extensors stretch and ankle plantar flexors stretch.

Snyder, Earl, O'Connor, and Ebersole (2009) conducted an interesting trial. Participants underwent a six-week resistance training intervention (3 training sessions per week) that included three exercises in one-legged support: pelvic rotation in the frontal plane, and two hip rotation exercises, with different directions of the load applied by cables. Participants exhibited lower foot pronation but greater hip adduction range of motion during running after the intervention. This is another indication that prior assessment of the athlete should be carried out in order to identify which (if any) risk factors he/she is exhibiting. This intervention may benefit runners with excessive pronation but may do even more harm to those exhibiting excessive hip adduction. Another important aspect of individualized treatment is footwear selection. Motion control shoes, for instance, do reduce injury rates, but only in runners with excessive foot pronation (Malisoux et al., 2016).

Since the greatest risk factors for sustaining running-related injury are mostly unmodifiable (e.g. previous injury, training volume), it seems that individualized treatment is the best approach to prevention. Every individual needs to be assessed in order to find risk factors he/she is exhibiting. Then, these factors should be addressed with appropriate interventions. Such an approach would likely be more effective than generalized prevention programs.

Conclusion

Runners are particularly prone to developing overuse injuries. Evidence regarding prevention methods is weak and limited, with only a few interventions showing benefits. Two of the greatest risk factors are previous injury and training volume. We obviously cannot control the first, while training volume may be modifiable in recreational runners. It seems that designing individualized prevention programs is the best bet for now. Methods for gait retraining are showing some promising results for reducing ground impact forces. More trials to evaluate the effects of interventions on risk factors are desired, along with incidence studies, to determine the direct impact of interventions on injury risk.

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