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Etiology, Prevention, and Early Intervention of Overuse Injuries in Runners: a Biomechanical Perspective

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Runners sustain injuries at an alarming rate. According to various epidemiologic studies [1–7], between 27% and 70% of recreational and competitive distance runners can expect to be injured during any 1-year period. The wide range in the results of these epidemiologic studies may be attributed, in part, to differences in the definitions of the terms "runner" and "injury" [8]. Typically, a "runner" has been defined as a person who runs a minimum distance per week (20–30 km is cited often) on a regular basis, and has been running consistently for some minimum period of time (1 to 3 years is cited typically). The definition of "injury" also varies between studies; however, a common definition for a running injury is a musculoskeletal ailment that is attributed to running that causes a restriction of running speed, distance, duration, or frequency for at least 1 week [3,4,9,10].

The most common site of running injuries is the knee. In a recent clinical study [11], an analysis of data from more than 2000 patients who attributed their injuries to running, revealed that approximately 42% of the injuries occurred at the knee. Although the incidence of specific knee injuries that were cited varies slightly, other studies also determined that knee injuries make up close to half of all running injuries that are reported [5,12,13]. The foot, ankle, and lower leg make up almost 40% of the remaining injuries that are reported by these researchers, whereas less than 20% of the running injuries reported occur above the knee. This suggests that there may be some common mechanisms in the etiology of running injuries.

Runners do sustain some acute injuries, such as ankle sprains and fractures, but most running injuries could be classified as "overuse" injuries. An overuse injury has been defined as an injury of the musculoskeletal system

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that results from the combined fatigue effect over a period of time beyond the capabilities of the specific structure that has been stressed [14,15]. These injuries occur when several repetitive forces are applied to a structure (eg, muscle or tendon); each is less than the acute injury threshold of the structure. The most common overuse injury that is attributed to running is patellofemoral pain syndrome [11,12,13,16]. Other common overuse running injuries include stress fractures, medial tibial stress (shin splints), patellar tendinitis, plantar fasciitis, and Achilles tendinitis [5,11,12].

Although repeated stresses on various structures of the musculoskeletal system often result in an overuse injury, this does not imply that stresses to the musculoskeletal system should be minimized to avoid injury. All biologic structures, such as muscles, tendons, ligaments, and bones, could adapt positively and negatively to the level of stress that is placed upon them. This phenomenon, which was recognized more than 100 years ago [17], articulates that repeated applied stresses that are less than the tensile limit of a structure will lead to positive remodeling, provided that there is an adequate time period between stress applications, whereas any single stress beyond the tensile limit, or repeated stresses that are less than the tensile limit with insufficient time period between stress applications ultimately will lead to an injury [14,15,18].

A stress-frequency curve illustrates how the amount of stress applied to a structure and the number of repetitions of the applied stress are related to injury potential of a particular structure. The theoretic stress-frequency curve (Fig. 1) depicts a simple situation of a load being applied to a structure at regular intervals. The structure represented could be a joint, muscle, bone, or any other structure of the musculoskeletal system that is subjected to stress. The exact limits of stress or frequency would be different for each specific structure, but the stress-frequency curves of each would share a characteristic shape, and convey similar information. Injury would result when the structure is subjected to a stress/frequency combination that is in

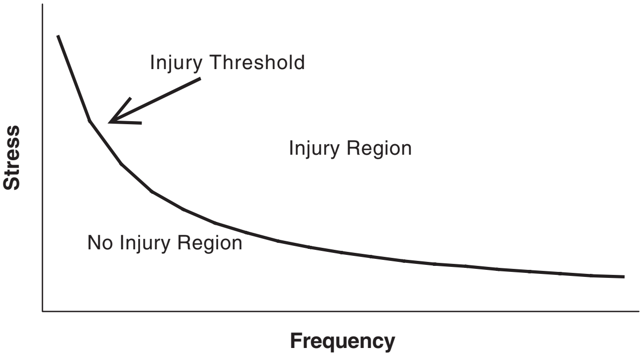

Fig. 1. Effect on overuse injury occurrence due to the theoretical relationship between stress application and frequency.

the “injury region” of the graph (above, and to the right of the curve), whereas injury would be avoided in situations in which the stress/frequency combination falls within the “no injury region” of the graph (below and to the left of the theoretic curve).

This simplistic looking graph (see Fig. 1) gives the impression that predicting an overuse injury should be an easy and straightforward procedure. Rather than being a two-dimensional curve, a true stress-frequency relationship for any given structure is multidimensional, with stresses being applied in all directions, and from a variety of sources (external and internal). In addition, there are multiple structures at each joint (and in each segment) to which stresses are applied; this makes it difficult to estimate the exact level of stress that is placed upon any single structure. To complicate the situation further, a true stress-frequency relationship is not static, but dynamic. When applied stresses are maintained at low levels or removed completely, which happens in several situations, such as prolonged bed rest [19,20] or space flight [21,22], tissue resorption generally occurs. This weakens the structure, shifts the stress-frequency curve downward and to the left, and increases the area of the injury portion of the graph. Conversely, when applied stresses are maintained close to the theoretic curve, but still in the noninjury portion of the graph, positive tissue remodeling likely would occur. This strengthens the structure, shifts the stress-frequency curve upward and to the right, and increases the area of the noninjury portion of the graph.

Not only is the vertical axis of this theoretic relationship more complex than it first appears to be, the horizontal axis (frequency) also has multiple aspects to it. The “frequency” actually can refer to the number of repetitions of an applied stress, the time between each repetition, or the time period between sets of stress applications. All of these aspects of frequency are relevant in a running situation. The number of repetitions of an applied stress is related to the distance traveled or the number of steps taken by a runner. The time between each repetition is related to running speed or stride frequency, and the time period between sets of stress applications is associated with the rest period that is taken between runs, or the number of weekly runs.

Forces on the body during running

External and internal stresses are applied to the musculoskeletal system during running. The external stresses (forces) that act on the body during running include air resistance, gravity, and ground reaction forces (GRFs). The GRF is the only one of these forces that is likely to contribute to running injuries. When studying gait, GRFs generally are measured by a floor-mounted force platform, and are resolved into their three component directions (anterio–posterior, medio–lateral, and vertical). Internal forces, which include muscle and tendon forces, act upon specific structures of the musculoskeletal system (eg, joints) and also may contribute to running injuries. Because direct measurements of internal forces can only be done invasively, these forces generally are estimated indirectly in a noninvasive manner using an inverse dynamics approach. This approach uses a combination of kinetic, anthropometric, and kinematic data to estimate the forces and torques at joints. With the addition of electromyographic data, various simulation models have been developed that estimate forces that are generated by specific muscles.

Most distance runners are heelstrikers and make first ground contact with the posterior third of the foot [23,24]. This running style produces characteristic GRF-time curves in the anterio–posterior and vertical directions. The anterio–posterior GRF-time curve generally is biphasic. A braking force is apparent for most subjects during approximately the first half of stance. This is followed by a propulsive force of similar magnitude for the remainder of the stance period (Fig. 2). The magnitude of these forces are somewhat speed dependent, but typically are in the range of 0.3 to 0.6 body weights [25].

The vertical GRF-time curve of heelstrike runners generally exhibits two distinctive peaks (Fig. 3). The earlier peak often is referred to as the impact force peak and occurs within the first 10% of the stance period. The magnitude and rate of change (loading rate) of the impact force during running is determined by what a runner does before contact with the ground. Depending upon speed and landing geometry, the vertical impact force peak varies in magnitude from about 1.2 to 3.5 body weights [26,27]. Because this portion of the vertical GRF curve has a brief duration (<30

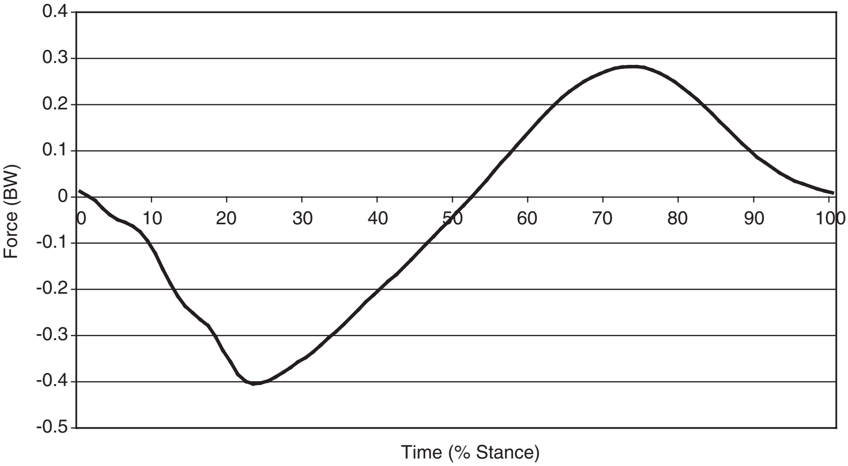

Fig. 2. Representative curve of the anterio–posterior ground reaction force during the stance phase of running. BW, body weights.

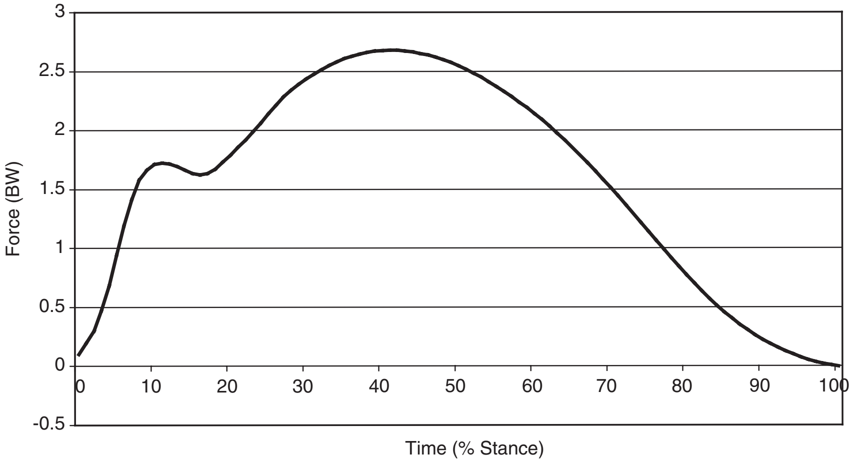

Fig. 3. Representative curve of the vertical ground reaction force during the stance phase of running. BW, body weights.

milliseconds), it is considered to be the high-frequency component of the GRF. Several variables have an effect on impact forces, including the foot and body center of mass velocity at contact, the effective mass of the body at contact (which is influenced by body geometry), the area of contact, and the material properties of the damping elements (eg, soft tissue, shoes, and the surface of contact) [28–30]. The second vertical force peak generally is referred to as the active peak, and occurs at approximately midstance. Active forces take place over the latter 60% to 75% of the stance period, and are considered to be the low-frequency component of the vertical GRF and last up to 200 milliseconds, depending upon speed. Active forces are determined primarily by the movement of a runner during foot contact [31]. Although impact forces have been implicated most often in overuse running injuries [9,32,33], some research exists which suggests that active forces also may play a significant role in a variety of overuse running injuries [34].

GRF-time curves in the medio–lateral direction are variable and have low magnitudes. Primarily for these reasons, medio–lateral forces have been ignored by most researchers when investigating the causes of running injuries. In recent studies, however, the contribution of the medio–lateral forces to varus and valgus moments have been examined [32]. Although it has yet to be determined, it is possible that the medio–lateral forces do contribute to a variety of overuse running injuries.

Etiology of running injuries

Despite the great deal of literature that has been dedicated to the subject of running injuries, comparatively little empiric evidence exists concerning the causes of these injuries. Many of the articles that have been written regarding the etiology of running injuries are speculative in nature. Several researchers who have conducted biomechanical studies that used only healthy subjects have made conclusions regarding the possible effect of various factors on running injuries, even though no evidence exists to suggest that the factors in question are risk factors for running injuries. Many other articles have been written by health care providers who have treated several people who had injuries that were attributed to running. Generally, using sound reasoning (as done by the biomechanists), along with survey data (but little experimental evidence), these researchers have attempted to identify risk factors that are associated with various overuse running injuries. Scientific research has not been able to verify or refute most of the speculations that were made in these retrospective clinical studies. All that can be stated with certainty is that the etiology of overuse running injuries is multifactorial and diverse [5,18,35].

The variables that have been identified as risk factors for overuse running injuries vary slightly from study to study, but they can be placed into three general categories, including training, anatomic, and biomechanical factors. Although it occasionally has been suggested that particular running injuries or sites of injuries are associated with specific risk factors, current scientific research has yet to reach the point of being able to distinguish between the causes of specific running injuries, nor is it likely that exact mechanisms for specific injuries ever will be determined. Some researchers concluded that no anatomic or biomechanical factor correlates with a specific type of injury in a reliable fashion [36,37]. There are, however, several risk factors that may be associated with a variety of running injuries. In the subsequent discussion of these factors, ‘‘running injuries’’ often have been grouped together, rather than being examined specifically.

The training variables (errors) that have been identified most often as risk factors for running injuries include excessive running distance, too high of a training intensity, and rapid increases in weekly running distance or intensity [2,5,36–40]. The general mechanism by which each of these training errors could lead to overuse injuries may be understood by the examining how these variables affect the stress-frequency relationship. Running a greater distance without an increase in running speed obviously increases the number of repetitions of the applied stress because the number of steps taken is increased. Thus, running an excessive distance places the various musculoskeletal structures of a runner further to the right on the stress-frequency curve and increases the possibility that one or more structures enter the injury region of the graph. A high-intensity running program relates to running at faster speeds. Faster running generally produces greater GRFs, as well as greater stresses on bones, joints, muscles, and tendons [26,41,42]. This places all of these structures higher on the stress-frequency graph and increases the likelihood of injury.

Rapid changes in distance or intensity are more complex to explain by the stress-frequency relationship. When a structure is subjected to a stress-frequency combination that is close to the stress-frequency curve, yet below and to the left of the curve, positive remodeling of the structure may shift the curve upward and to the right. Increases in distance or intensity (or both) may place the structure further upward and to the right on the stress-frequency curve. If increases in running distance and intensity (frequency and stress) are gradual, it is possible for the upward and right shifting of the stress-frequency curve that is due to positive remodeling to outpace the upward and right direction movement that is due to increases in distance and intensity. But, rapid increases in distance or intensity may cause the structure to cross the curve from the noninjury region to the injury region, even when some positive remodeling and shifting of the curve has occurred.

Two related training variables also have been implicated as risk factors in running injuries—the surface and shoes that are chosen for training [43–45]. It was suggested that running with worn-out shoes or on harder (less compliant) running surfaces may produce greater stresses on the body [30,46,47], and therefore, are risk factors for injury. These variables, however, are examples for which there is a lack of empiric evidence to link them with overuse running injuries, even though there are logical reasons to speculate that they are associated with these injuries. It is possible that these factors may be determined to be true risk factors for running injuries, but at the present time, the association between these factors and overuse running injuries is purely conjecture.

Performing stretching exercises before running is another training-related variable that has been examined as a possible risk factor for running injuries. There have been conflicting conclusions drawn regarding the association of this factor with overuse running injuries. Although several researchers reported that people who stretch regularly before running experience a greater injury rate than those who do not stretch regularly [2,6,48], others did not find an association between stretching before running and injuries [4,9,49]. No empiric study has reported that regular stretching before running reduces the number of running injuries, even though this practice has been advocated as a means of preventing running injuries [50]. Data that are related to the stretching and warm-up habits of runners generally rely upon surveys or self reporting; therefore, these results must be considered cautiously. It is possible that stretching before running is important for some runners, whereas it may not be necessary for others.

Several clinical studies have estimated that more than 60% of running injuries could be attributed to training error [3,12,37,38,51]. Pragmatically, it could be stated that, in actual fact, all overuse running injuries are the result of training errors. To sustain an overuse injury, a runner must have subjected some musculoskeletal structure to a stress-frequency combination that crossed over to the right and above the current stress-frequency curve (into the injury region) for that specific structure. This is accomplished only when an individual makes an error in his/her training program by exceeding his/her current limit of running distance or intensity in such a way that the negative remodeling of the injured structure predominated over the repair process as a result of the stresses that are placed on the structure. It is obvious that the location of the stress-frequency curve for a given structure varies from structure to structure, and from individual to individual; however, there is no doubt that every overuse injury that is sustained by runners could have been avoided by training differently based upon individual limitations, or in some cases, by not training at all. There are some people who should be advised (correctly) against running as a form of exercise because the risk for injury would be excessive merely because of participation.

The idea that all overuse running injuries are a result of training errors is appealing from a medical practitioner's viewpoint. Obviously, training variables are factors over which a runner has control; therefore, advice regarding training methods could be given easily. By correctly determining the specific aspects of an individual's training program that had been producing deleterious effects, a medical practitioner would be able to advise a runner properly regarding how to modify his/her training program to minimize the chance of a subsequent injury. Knowledge of the training variables that are associated with overuse running injuries has a great clinical value, but this knowledge does not allow a scientist to understand the mechanisms that lead to an overuse running injury.

With most, if not all, overuse injuries, there must exist some underlying anatomic or biomechanical factors that would prevent one runner from training for as long, as often, or as intensely as another runner before incurring an overuse injury. Stated in another way, the question could be asked "Why does each individual runner (and each individual musculoskeletal structure) have a different injury threshold?". It is conceivable that two individuals who have comparable anatomic and stride characteristics train together, but only one of the individuals sustains an overuse injury. In this case, and in most cases of overuse running injuries, it is logical to hypothesize that some anatomic or biomechanical variations between individuals could account for differences in injury susceptibility.

Abnormalities or variations in anatomic or anthropometric variables may place an individual at an increased risk for an overuse running injury. Even if the level of external biomechanical stresses (GRFs) that is applied to the body is within a "normal" range, anthropometric variations between individuals may result in increased amounts of internal stresses applied to various musculoskeletal structures. This would affect an individual's tolerance level to injury in terms of distance, intensity, and frequency. Generally, these anthropometric variables are not within the control of a runner or medical practitioner, but some variables can be modified or manipulated with appropriate interventions.

Anthropometric variables that have been implicated as causes of overuse running injuries include high longitudinal arches (pes cavus), ankle range of motion, leg length discrepancies, and lower extremity alignment abnormalities. There is no consensus among researchers, however, regarding the effect of most of these variables on overuse running injuries based upon the conflicting results that are reported in the literature. Pes cavus has been implicated as a risk factor for running injuries, according to several studies [39,44,52,53], but others concluded that arch height is not a risk factor in running injuries [54–57].

The relationship between ankle flexibility and overuse running injuries is even more controversial. Runners who had a greater sagittal plane ankle range of motion were determined to be at greater risk for overuse injuries than runners who had less ankle mobility, according to some researchers [37,39,53]. Other studies reported that sagittal plane ankle range of motion does not differ significantly between groups of runners who had sustained lower extremity injuries and groups of uninjured control subjects [9,50]. Still, one other study disagreed with both of these possibilities, and concluded that reduced ankle flexibility is a risk factor in overuse running injuries [54]. This study was based upon an examination of military recruits who sustained stress fractures during training. The recruits who sustained stress fractures tended to have less ankle flexibility than recruits who did not sustain these injuries.

There also is controversy regarding anthropometric variables that could be grouped together as lower extremity alignment abnormalities, such as leg length discrepancies and excessive Q-angle. These variables were shown to be associated with overuse running injuries by some investigators [3,15,38], although others determined that lower extremity alignment abnormalities are not associated with an increased risk for overuse injuries in runners [54–57].

Some of the discrepancies in studies that search for a link between anthropometric variables and running injuries may be due to differences in experimental methodology (measuring techniques), and in the definition of the various anthropometric abnormalities that were analyzed. In addition, it is likely that people who possess severe abnormalities could not have participated in many of the studies because of the protocols that generally included people who were engaged in running activities at the time of the study. It is possible that people who had severe problems realized that running is an activity in which they could not participate safely. Another reason for discrepancies in these studies may be the fact that anthropometric variables must act in combination with biomechanical factors to produce an injury. These biomechanical variables often differ significantly between subjects.

It is possible that a runner who has an identified anthropometric risk factor exhibits "favorable" biomechanical conditions that could allow the runner to avoid injury. Similarly, in a situation in which all anthropometric variables are similar between subjects, variations in biomechanical variables may result in an overuse injury to one individual and not another. Several early biomechanical studies speculated that a link exists between various biomechanical variables and overuse running injuries [30,43,58–60]. Most of these biomechanical factors could be classified as kinetic or rearfoot kinematic variables. The mechanism whereby kinetic variables increase the risk for an overuse injury is obvious. Abnormally large external or internal stresses on the musculoskeletal system could shift a specific structure into the injury portion of a stress-frequency curve. It is generally believed that rearfoot kinematic variables that are outside of the physiologically ‘‘normal’’ range may redistribute forces in such a manner that a particularly vulnerable structure would be affected.

Among the kinetic variables that have been speculated to be a cause of overuse running injuries are the magnitude of impact forces [58], the rate of impact loading [24], the magnitude of active (propulsive) forces [60], and the magnitude of knee joint forces and moments [59]. The assumption that these kinetic variables lead to overuse injuries generally has been based upon theoretic models and sound reasoning; however, until recently, there has been little experimental verification of these speculations. In a study in which female subjects who had a history of stress fractures were compared with a control group of uninjured subjects, the injured subjects were exhibited greater peak vertical impact GRFs, impact loading rates, and peak tibial accelerations [32]. Similar results that were reported by Grimston et al [33] found that female runners who had experienced stress fractures produced significantly greater vertical impact forces than subjects who did not have stress fractures. These results were in agreement with another recent study in which previously injured runners (men and women) were compared with runners who had never sustained an overuse injury [9]. The investigators reported that the group of previously injured runners exhibited greater vertical impact forces and loading rates than the uninjured runners. In a study that used similar methodology, it was reported that runners who developed patellofemoral pain syndrome displayed greater active vertical forces than uninjured control subjects [34]. Although no other studies have found vertical active (propulsive) forces to be a risk factor for overuse running injuries, many researchers who have studied the contribution of kinetic variables to overuse running injuries have not reported active forces in their studies. Therefore, it is possible that this variable may be a risk factor that has not been examined extensively.

Injury risk may differ between subjects, even when external kinetic variables are similar. One possible explanation of this phenomenon is that slight (and possibly undetected) anatomic variations between people could result in differences in internal joint kinetics. To estimate these forces and moments noninvasively, the technique of inverse dynamics is used. Until recently, this technique had not been applied to research that was related to running injuries. In a study that compared a group of runners who had suffered from patellofemoral pain syndrome with a group of control subjects, increased knee joint forces and moments were a contributing factor in the development of patellofemoral pain syndrome in runners [61].

The rearfoot kinematic variables that have been suggested most often to be associated with overuse running injuries are the magnitude and rate of foot pronation. Excessive pronation was implicated as a contributing factor to overuse running injuries in several clinical studies and reviews of overuse running injuries [18,34,36–38,43,44,62]. In many of these studies, a static evaluation of pronation was conducted on injured runners; the results suggested that injured runners often were overpronators. The little experimental evidence that exists in relation to these parameters is conflicting. One study that partially supported the speculation of these clinical studies, reported that groups of injured runners exhibited greater maximum pronation angles and had greater maximum pronation velocities than a group of uninjured control subjects [39]. The results were most evident in the group of subjects who suffered from shin splints. Similar results were reported in a comparison between shin splint sufferers and uninjured control subjects during barefoot running [63]. Contradictory results were found in a more recent study which found that runners who had never sustained an overuse injury exhibited a greater pronation velocity than runners who had sustained an overuse injury previously [9]. Another study that compared runners who suffered from patellofemoral pain syndrome with a group of uninjured control subjects found no differences in any rearfoot variable between groups [34].

The effect that a particular level of impact force has on a body during running is related to the amount and rate of pronation. Pronation is a protective mechanism during running because it allows impact forces to be attenuated over a longer period of time than would occur without pronation. For this reason, some researchers have suggested that it is conceivable that a higher level of pronation is favorable during running, provided that it falls within “normal” physiologic limitations, and that it does not continue beyond midstance [9,64]. After midstance, it is necessary for the foot to become more rigid in preparation for toe-off. In a recent review of overuse injuries in runners, Hreljac [65] concluded that “runners who have developed stride patterns which incorporate relatively low levels of impact forces, and a moderately rapid rate of pronation are at a reduced risk for incurring overuse running injuries.” Severe overpronators may be at an increased risk for injury because of the potentially large torques that are generated, and the potential instability that is associated with running in this style.

Early intervention

Although a retrospective treatment of running injuries may assist runners to heal following an overuse injury, a preferable approach to the problem would be to act proactively. A proactive approach could take many forms, such as the education of current and prospective runners regarding a sensible approach to training; proper fitting and selection of shoes; and the establishment of a screening process whereby medical practitioners could identify runners who are at high risk for overuse injuries, and advise these runners accordingly.

For a screening process to have widespread appeal, it must be simple to administer and it must be reliable. No such screening process is available for running injuries assessment; however, some researchers have taken the first steps in the establishment of such a screening process. Studies are underway in which researchers are attempting to establish whether a combination of anthropometric and biomechanical factors could be used to predict the occurrence of an overuse running injury [65]. Even if these studies are successful, however, they would have limited usefulness because the screening tests would require a researcher or clinician to take several anthropometric measurements and conduct a series of biomechanical tests. Because of the limited availability of biomechanical testing facilities, and the need for trained personnel, this type of screening process realistically could not become widespread. But, assuming that a small number of anthropometric and biomechanical parameters that are associated with overuse running injuries could be identified, follow-up studies could be conducted that would attempt to find easily measurable variables that are correlated highly with these variables. If this can be established, then the widespread screening of runners and prospective runners could become realistic. Currently, that goal is not within reach.

One intervention that is within reach of most runners is the proper selection of running shoes. Running shoes are the only pieces of protective equipment that are worn by a runner, and as such, it is critical that a runner chooses shoes wisely. The number of running shoe choices that is available might be overwhelming to some people [66]. Because it has been suggested that low levels of impact forces and a moderately rapid rate of pronation are stride characteristics that appear to reduce the risk for incurring overuse running injuries [65], it follows that an ideal pair of running shoes minimizes impact forces and provides stability while allowing the foot to pronate naturally.

One running shoe design parameter that has an effect on cushioning and stability properties of a shoe is the midsole density (hardness). Although material tests on shoes consistently demonstrate that softer-soled shoes attenuate forces to a greater extent than harder shoes when subjected to an impact tester, there have been conflicting reports regarding the effects of varying the midsole density on cushioning and stability parameters during subject tests [67]. Although some researchers found that subject tests agree with the results of material tests regarding cushioning variables, with shoes that have softer midsoles producing lower initial vertical GRFs [68], others reported that softer shoes produced greater initial vertical GRFs than harder shoes [69–72]. Still others have reported that there are no differences between soft and hard shoes in terms of impact forces [43,73]. Conflicting results also have been reported in variables that are believed to be indicative of stability characteristics. Some researchers found that softer shoes allow greater amounts and rates of pronation than harder shoes [43,74], whereas others reported the opposite [71]. Still others have concluded that there are no differences in the amount of pronation that is allowed by softer or harder shoes [47].

In an attempt to review the available data objectively, Hreljac and Marshall [75] conducted a meta-analysis of the existing literature. They determined that shoes with harder midsoles reduce the initial impact forces while allowing greater rearfoot movement during the initial ground contact phase. They also noted that there was a large amount of variability between subjects and between studies, which indicated that individuals respond uniquely to changes in midsole hardness. Thus, the "proper" selection of running shoes would require an individual runner to conduct biomechanical tests on several running shoes to determine which shoe best attenuated impact forces while allowing a reasonable amount and rate of pronation. This could only be done in a limited number of facilities, so it is not a feasible alternative.

Although conducting a series of biomechanical tests on several shoes would be preferable, the selection of running shoes for any individual could be based upon two simple guidelines. It was suggested that the most important criteria in the selection of running shoes are fit [66] and comfort [76,77]. Running shoes that meet these criteria are likely to provide optimal levels of cushioning and stability.

In the absence of a simple screening process, the education of current and prospective runners probably is the most feasible approach to proactively prevent running injuries. Besides being informed of the simple criteria that could be followed in selecting running shoes, runners should be taught how to incorporate sensible training habits into their schedules. It may not be possible or practical to teach people to run with a stride that incorporates lower impact forces and moderate rates of pronation, but there are training habits that runners could adopt which reduce impact forces and minimize the effects of these forces on the body. Among the advice that should be given to, and followed by, runners who are at risk for sustaining an overuse running injury, is to reduce training speed as a means of reducing impact forces. It was concluded in several studies that impact forces increase as speed increases [26,27,41,78]. Sufficiently long rest periods should be encouraged to assure that positive remodeling is able to occur between training sessions. A guideline for increasing weekly running distance that has been suggested often is that runners should not increase running distance by more than 10% per week [35,36,38,49]. The same suggestion likely would apply to intensity of training. A sensible suggestion for runners who have sustained repeated injuries would be to reduce the distance run during each session, and overall weekly distance. But, as pointed out by Marti et al [5], it probably would be as difficult to motivate determined runners to reduce running distance as it would be to motivate sedentary people to take up running as an activity.

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