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Factors Associated with Ankle Injuries

Preventive Measures

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Summary

A sense of foot position in humans is precise when barefoot, but is distorted by athletic footwear, which accounts for the high frequency of ankle sprains in shod athletes. It is unclear whether taping and rigid and semi-rigid devices protect against ankle sprains, as all of the studies suggesting this are flawed by inadequate controls. If these devices do protect the ankle, it is not through added support but rather through a partial correction of the decreased foot position awareness caused by footwear. Since taping and rigid and semi-rigid devices interfere with normal movement, there is concern that these might actually increase the frequency of injury at the ankle and/or at different locations. In this respect, taping is less of a concern because it interferes least with normal movement. The best solution for reducing ankle sprains in shod athletes is the use of more advanced footwear to retain maximal tactile sensitivity, thereby maintaining an awareness of foot position comparable to that of the barefoot state or perhaps even improving on it.

Ankle sprains are the most common injuries in sports and probably account for the greatest loss of playing time of any injury.[1-3] This review of preventive measures for ankle sprains is a thorough update of the subject and looks at ankle sprains from the perspective of incorrect foot position caused by footwear, the physiological mechanism most often causing this injury. It concludes by considering whether, in the future when technically advanced footwear may be able to retain (or improve on) the precise sense of foot position inherent to humans, fewer ankle sprains and improved athletic performance will be achieved.

1. Epidemiology

Ankle sprains are pervasive in all industrialised countries and most people have sustained at least one. Although they occur frequently during normal locomotion, they are probably most common in sports. For example, over half of the ankle sprains reported in one series were incurred in basketball alone.[2] Professional basketball players average 1 or more sprains per season, causing loss of playing time. Paradoxically, most individuals from less developed countries, where barefoot activity is the norm, do not recall spraining an ankle, thus confirming the impressions of physicians in these regions that ankle sprains are much less common in humans when barefoot. This difference may be explained by the superior awareness of foot position (the precision of estimates of position and orientation of the plantar surface with respect to the leg) when barefoot compared with when shod, as is discussed in section 3.1.[4,5]

The precise incidence of ankle sprain in any population is not known. All available data come from industrialised countries, usually from cohorts of participants in a sport in a specific locality.[1] However, these data usually represent a medical consultation frequency rather than an ankle sprain incidence.[6] Such data are biased by the popularity of sports, availability of medical care, desire of those injured to seek medical attention and ease of access to medical care. Furthermore, most of those who sustain ankle sprains probably never seek medical attention because most sprains are not severe.

With these limitations in mind, it is worthwhile to consider the following statistics. Approximately 85% of ankle sprains presented at a sports medicine clinic in the US were inversions involving the lateral ligaments.[2] Since eversion sprains produce a more severe disability, requiring medical attention in most cases, these data are biased towards eversion injury, which explains why lateral sprains accounted for 95% of the total sprains in the only study which surveyed all injuries in sports.[7] Data from medical clinics reveal that 20 to 50% of people who have an ankle sprain will have some type of chronic pain or instability.[8] Between 20 and 25% of the time lost in sports involving running and jumping was due to ankle injury.[1]

1.1 Inversion Sprains

In one series, the anterior talofibular ligament alone was torn in two-thirds of those sustaining inversion injuries to the ankle and seeking medical attention. However, damage to this structure probably represents a much higher percentage when considering the population as a whole (i.e. including those who do not seek medical attention).[9] The calcaneofibular ligament was also torn in approximately one-quarter of inversion sprains:[10] it is rare to have an isolated calcaneofibular ligament injury. Inversion also results in talar fractures and fractures to the base of the fifth metatarsal, following the same inversion mechanics.[1]

1.2 Eversion Sprains

Eversion injuries more commonly result in persisting pain and chronic instability.[11] Avulsion and fibular fractures often accompany eversion injuries, because these structures often fail before the robust deltoid ligament. Unlike inversions, with eversions the injured individual feels a ‘pop’ or feels that their ankle briefly ‘went out of joint’.[12] The magnitude of the damage from eversion injuries varies from the partial tearing of the anterior and posterior tibiofibular ligaments and interosseous membrane to the complete tearing of these structures or the complete deltoid ligament in more severe injuries.[6]

2. How Ankle Sprains Occur

2.1 Inversion of the Ankle

Considering the prevalence of ankle inversions, few reports have surveyed the events causing them. In volleyball, which had the highest incidence of ankle sprains in one series,[3] 86% of inversion sprains occurred at the net when landing from jumping during blocking or attacking, an action with limited forward or lateral body movement.[13] Of these, 66% were initiated by landing on someone else's foot. Positions associated with rapid lateral body movement accounted for few ankle injuries. Similarly, ankle sprains in basketball also occur when landing from a jump, and frequently when landing unexpectedly on someone else's foot.[14] In gymnastics, ankle injuries occur most commonly when dismounting from apparatus or performing floor exercises, actions which involve landing from heights with no significant lateral movement.[15] Many of the ankle sprains sustained in ballet occur when landing from jumps and while in *demipointe* – supporting bodyweight on the ball of the foot.[16] In neither case is there any significant lateral body movement. These data on the causes of inversion sprains are consistent with the now generally accepted theory of proprioception regarding the cause of ankle inversion injury (see section 3.1).

2.1.1 Mechanical Stability

Possibly because of the ubiquitous marketing of 'ankle support devices', a prevalent misconception accounts for inversion injuries by the presence of forces greater than the maximal resistance capacity of ankle muscle support musculature. For example, forces associated with acute changes in forward direction (i.e. cutting) are thought to lead to inversion sprains, thereby justifying the augmentation of muscle strength through taping or semi-rigid and rigid devices.[6] The above reports indicate that these movements explain a few types of injuries in several sports such as soccer and American football, but even in these cases the external factor of tackling is usually involved, and the forces involved are far beyond what little additional support is provided by tape and semi-rigid and rigid devices.[17] The notion that ankle sprains are prevalent in humans because ankle support is inherently insufficient (i.e. the 'support' theory of the cause of ankle inversion) is no longer seriously considered because it inadequately explains how ankle sprains occur.

2.1.2 Proprioception

To summarise, most inversion sprains occur during foot contact on landing or locomotion associated with either unanticipated foot placement on a sloped surface (e.g. someone's foot) or inappropriate positioning of the foot in space before contact with a surface. In both cases, humans perceive the amplitude of inversion to be less than it actually is and command the muscle support that is adequate for the perceived, but inadequate for the actual, foot position.[5,13,14] Thus, ankle sprains are caused by impaired proprioception that results in the inadequate use of anticipatory muscular movements under dynamic conditions when there is insufficient time to respond to the actual loading event. These studies[5,13,14] corroborate the 'proprioception theory' of the cause of ankle sprains that was first introduced over 2 decades ago (see section 4.2.3).

Since the incidence of ankle sprains appears to be lower in barefoot populations, frequent ankle sprains are thus not inherent to humans but rather are caused by the effect of footwear on the awareness of foot position.[4,5] Therefore, the prevention of most ankle sprains requires an understanding of the factors influencing human judgement of the position and orientation of the plantar surface with respect to the leg.

2.2 Eversion of the Ankle

Unlike inversion injuries, most eversions of the ankle are unrelated to poor congruity between the plantar and support surfaces, and are also less closely related to inadequate ankle support muscle commands.[18] Rather, the ankle is usually acted upon by massive external forces. These injuries are commonly caused by body contact, e.g. by the foot suddenly becoming fixed to the ground by the foot of another player and body momentum carrying the original player forwards, or by tackling with the foot fixed to a surface by cleats.[6]

3. Effect of Footwear Sole Properties on Foot Position Awareness

Footwear affects an individual's perception of the position and orientation of the plantar surface with respect to their leg, both under quasi-static and dynamic conditions.[4,5] In young men, error in foot positioning when standing was found to be 1.96° and 3.97°, respectively, when barefoot and when wearing athletics shoes;[4] position error when walking was 1.55° and 5.99°, respectively.[5] The thickness and hardness of shoe soles affected the error in foot position under dynamic conditions. In one report, the shoe with the thinnest and hardest sole produced a position error of 3.83° whereas the thickest and softest sole caused an 8.41° error. Position error correlated well ($r = 0.901$) with the maximum amplitude of supination allowed by footwear when bearing weight.[5] Since supination is known to vary with sole hardness (softer soles produce greater supination), it is suggested that the amplitude of frontal plane movement caused by the compression of sole materials accounts for the differences in foot position error between shoes of different sole construction.[5]

3.1 Physiology of the Sense of Foot Position When Barefoot and When Shod

The sense of foot position falls within the category of kinaesthetic sense, which itself is a part of proprioception. McCloskey defines kinaesthetic sense as pertaining to '. . . perceived sensations about the static position or velocity of movement (whether imposed or voluntarily generated) of those parts of the body moved by skeletal muscles and perceived sensations about the forces generated during muscular contractions even when those contractions are isometric'.[19]

Neurophysiological and perceptual investigations indicate that precise kinaesthetic sense is derived almost entirely from muscle and tactile receptors.[20-22] Older notions assumed contributions from joint capsule receptors, unspecified articular surface receptors, ligament receptors and tendon organs.[23] It is agreed that joint capsule and articular receptors play no significant role in kinaesthetic awareness since total joint replacement, which presumably eliminates these facilities, has no effect on this sense.[24] Furthermore, anaesthesia of joint ligaments causes no decline in kinaesthesia.[25] Finally, discharge from primary afferent fibres of tendon organs does not vary with small changes in joint position and therefore is not accountable for the precise awareness of joint position.[26]

The plantar tactile receptor that is relied upon for kinaesthesia is probably the slowly adapting mechanoreceptor with myelinated afferent fibres (SAII mechanoreceptor). This mechanoreceptor responds to plantar deformations but, perhaps most importantly, displays a directional sensibility, a property essential for any explanation of how tactile information is transformed into a sense of position.[27] Further support of this role is provided by psychophysical experiments which indicate that the psychophysical function relating perceived and actual foot positions when barefoot is identical to the values obtained from primary afferents of SAII receptors.[4,28]

The precision of judgements of foot position varies with the type of receptor. Data from recent experiments suggest that information provided by plantar tactile receptors affords a precise awareness of foot position, presumably because afferent discharge does not vary in relation to previous stimulation.[28,29] Information provided by muscle receptors less precisely reflects actual foot position since discharge from muscle receptors is influenced by previous muscle contraction.[30,31] Following intense muscle contraction or vibration of a muscle tendon there is a persistent afferent discharge, usually referred to as a 'postcontraction sensory discharge', or 'after effects', which can explain the increased error in foot position when tactile information is unavailable.[30,32]

Humans prefer to use plantar tactile receptor–generated information in making foot position judgements, which accounts for the precise awareness of foot position under these conditions.[4] When barefoot, the elderly rely on muscle receptor input presumably because tactile information is less available in this cohort because of the decline in plantar tactile sensation with aging, thus explaining the less precise awareness of foot position in this cohort.[4] Shod humans of all ages rely on muscle receptors rather than tactile receptors in providing foot position information. This is probably because tactile information is less available when shod as footwear attenuates local deformations and plantar shear, mechanical transients that are transformed into position information through tactile receptors.[29,33,34]

3.2 Kinaesthetic Awareness in the Injured Ankle

Many individuals who sustain more severely sprained ankles demonstrate neurological deficits at the injured foot and ankle which usually last 1 week and occasionally longer than a month.[35] These data should be distinguished from the reports indicating that ankles that have sustained multiple sprains have long-lasting diminished kinaesthetic sensibility.[36,37] When comparing the repeatedly injured ankle with the uninjured one, humans detect passive movement less well and replicate ankle position with less precision.[37,38] They also balance less well on the injured side, which might be accounted for by diminished awareness of foot position. However, all of these reports are retrospective and are therefore unable to distinguish the cause from the effect of injury.

It is possible that the sense of foot position in humans is inherently asymmetrical, predisposing the ankle on the less sensible side to more frequent injury. This is reasonable considering that muscular strength and co-ordination in humans have strong sidedness. This explanation is more consistent with scientific data that attribute the sense of foot position to tactile and muscle receptors, the afferent pathways of which have never been shown to be permanently damaged as a consequence of ankle sprains.

4. Preventive Measures

4.1 Proprioceptive Exercises

Proprioceptive exercises are used after injury and for the prevention of reinjury, however, they have also been advocated for the prevention of initial injury.[12] They are based on the hypothesis that '. . . residual functional ankle instability may be the result of damage to the afferent nerve fibres in the capsule and ligaments controlling reflexes that aid in the stabilisation of the ankle'.[39] These exercises often involve the use of such devices as tilt boards, ankle disks, bongo boards and the like, which demand activity of the musculature that pronates and supinates the foot.[12,39]

The belief that improved proprioception might prevent ankle sprains is consistent with the generally accepted 'proprioception theory' of the cause of ankle inversion injury. However, there is no evidence that these exercises actually affect the awareness of foot position, therefore the use of the term 'proprioceptive' is misleading. Since it has been shown that capsule and ligament receptors play no significant role in the precise awareness of foot position, use of these exercises is based on pseudoscientific notions. These manoeuvres may, however, help to restore the range of motion, muscular support and reaction time in ankles that have been in disuse because of severe injury.[39-41] Nevertheless, there are no data to show that they prevent injury in uninjured individuals or reinjury.

4.2. Taping and Rigid and Semi-Rigid Devices

4.2.1 Do They Prevent Injury?

Despite their number, studies regarding the effectiveness of ankle taping and the use of rigid and semi-rigid devices for preventing injury are unconvincing because all of them are on a small scale, retrospective, without adequate controls and often sponsored by manufacturers, and they also utilise self-reporting of injuries or diagnoses made by coaches.[42,43] Perhaps their greatest deficiency is the lack of control for suggestion associated with active interventions and new devices, since these interventions elicit inflated expectations on the part of injured individuals. Most ankle sprains produce mild pain, little or no disability and no external manifestations of injury that can be precisely measured, so suggestion can be expected to reduce certain symptoms, particularly mild pain (the 'placebo effect'), which could account for the underreporting of sprains in intervention groups.

With these limitations in mind, the preponderance of admittedly inadequate reports suggest that both taping and the use of rigid and semi-rigid devices effectively prevent first ankle sprains and are perhaps more effective still in preventing re-injury.[40,44,45] Perhaps the earliest report of protection from the taping of ankles was in 1946 when Quigley et al.,[46] in a poorly controlled study, showed a 50% reduction of ankle sprains with taping. Other authors have reported comparable results.[44,47,48] Elastic tape gives protection comparable to inelastic tape and the benefit of taping in preventing ankle sprains seems greater in previously injured ankles.[45] No method of taping seems to be superior to another. The only consistent requirement of taping is that the skin of the leg must be united to plantar skin via the tape.[45]

4.2.2 How Might They Prevent Injury?

Many ankle sprain prophylactic devices (particularly rigid and semi-rigid devices) are claimed to protect by providing ankle support. The suggestion that primary prevention of ankle inversion sprains can be achieved through added support runs against current thinking on the cause of ankle sprain – inadequate awareness of foot position. Furthermore, the exact force required to injure ankle ligaments *in vivo* has never been calculated; however, most authors believe that even the support provided by the rigid and semi-rigid devices in current use is insufficient to significantly decrease the chance of engagement of these ligaments.[49-51]

Studies that measure the support provided by taping and rigid and semi-rigid devices do not simulate the forces involved in ankle sprain, therefore they overstate the ability of devices to limit range of motion. In the case of taping, support function is lost 20 minutes after application,[52] whereas with rigid and semi-rigid devices it is largely retained during use.[53-55] For instance, Greene and Hillman[56] found that rigid orthosis and freshly applied tape provided equally effective restriction of range of motion. Total range of motion was 130° before the application of tape, 106° after 20 minutes, and 126° after 3 hours, of exercise. Conversely, the orthotic device showed no significant loss in its restriction of total range of motion with values of 131° before its application, 78° after 20 minutes, and 84° after 3 hours, of exercise.

In another study, the greatest degree of restriction by taping following an exercise session compared with pretaped levels was 4° for plantarflexion, 6.38° for inversion and 5.81° for plantarflexion in inversion: movements associated with inversion injuries.[47] This represented a 15% decrease in the active range of motion following taping. We conclude that although studies have shown that rigid and semi-rigid devices provide more restriction of range of motion than taping, the supporting role of all protective devices is probably insignificant when considering the forces associated with injury sustained through sport. As discussed in section 5, restricting the range of motion is unrelated to the prevention of injury and may in itself be injurious.

4.2.3 Improved Awareness of Foot Position

The effect of taping on the awareness of foot position has been examined in detail. In a controlled study, the sense of foot position was measured in 24 university students to determine the effect of exercise and taping.[31] Exercise consisted of playing basketball and running for 30 minutes, which ensured tape adhesive deterioration. Testing on slopes of ≥10°, the range of concern when considering ankle sprains, position error was 3.95° before exercise and 4.81° after; a 22% greater error following exercise (average values for both taped and untaped). Untaped participants had 5.7° of foot position error before exercise and 6.78° after. Taped participants showed a 1° error before exercise and 2.52° after. This probably explains why elastic tape, while providing little decrease in the range of motion, is as effective as inelastic tape in preventing injury. There is no evidence that any taping method is superior to another for the prevention of ankle injury, although there are differences in the time taken to lose adhesiveness, and therefore they differ in their ability to limit range of motion for a brief period after application.[57] Rigid and semi-rigid devices are capable of improving awareness of foot position.[25]

To summarise, if ankle taping and the use of rigid and semi-rigid devices do give protection, it is now thought that they act by improving the judgement of position and orientation of the plantar surface with respect to the leg.[31,58,59] In physiological terms, this theory supposes that traction on the skin of the foot or leg via ankle taping, or the pressure of rigid and semi-rigid devices on the leg associated with ankle movement, provides cutaneous sensory cues of plantar surface position and orientation. Presumably, humans use this information in anticipation of foot contact with a surface. This is done both to position the plantar surface before the support phase, reducing the forces causing inversion, and to command muscle support to sustain these forces thereby preventing ligament loading. Footwear decreases plantar skin tactile receptor activity to the point where it is not relied upon when shod.[28] Judgements of foot position are based on muscle receptor afferent input which varies in relation to previous extrafusal stimulation and, therefore, can distort the sense of position. Taping restores tactile sensory cues.

5. Taping, Semi-Rigid and Rigid Devices and Athletic Performance

Whereas taping, semi-rigid and rigid devices are probably incapable of resisting the forces associated with sprains, they are capable of interfering with movement sufficient to impair athletic performance. Freshly applied tape and other devices affect objective measures of speed, balance and agility and vertical jumping in elite soccer players.[60] They have also been shown to decrease force production and total work as measured by an isokinetic dynamometer in 10 male volunteers.[61] The Air-Stirrup™ orthosis significantly impaired a softball player's ability to run between bases.[62] In another study of performance, the Swede-O-Brace™, Kallassy Brace™ and taping were compared with no-taping controls. Four events were performed: broad jump, vertical leap, 10-yard (9.1m) shuttle run and 40-yard (36.5m) sprint. Compared with controls, the authors found that taping the ankle decreased performance in the vertical jump (4%), shuttle run (1.6%) and sprint (3.5%). The Swede-O-Brace™ similarly decreased performance in the vertical jump (4.6%), broad jump (3.6%) and sprint (3.2%). The Kallassy Brace™ decreased performance only in the vertical jump (3.4%).[57] The degree by which these devices affect performance appears generally to be related to the degree of restriction of ankle movement, with rigid and semi-rigid devices generally causing greater decrease in performance than taping.

Greene and Hillman[56] measured vertical jumping ability with the ALP [ankle ligament protector; DonJoy Orthopedic, Carlsbad (CA)], a semi-rigid orthosis, adhesive taping and no ankle support. No statistical differences were found between the 3 groups, with mean values for no support, ALP and taping of 58.78, 57.69, and 55.39cm, respectively. Although no statistical differences were found, ankle support using tape or other orthotic devices had a detrimental effect on performance.

There is concern that the use of prophylactic devices for ankle sprain actually increases incidence of injury because of interference with normal movement. This concern arises from reports indicating that the use of prophylactic knee braces results in an increased incidence of knee injuries.[63-66] Additionally, a prospective controlled study found that prophylactic knee braces used by highschool football players resulted in a significantly greater incidence of both knee and ankle injuries when compared with unbraced controls. This suggested to the authors that alterations in normal gait associated with such devices can be injurious.[42] Since ankle taping and the use of other rigid and semi-rigid devices impair stability and athletic performance by altering normal movement, it does not seem unreasonable to propose that prophylactic measures for ankle injury might result in a higher injury frequency, perhaps at sites other than the ankle.[54,62] This possibility has yet to be examined.

6. Footwear of the Future

Future footwear will have a thinner and firmer sole than most current examples since thin, firm soles are associated with superior foot position awareness and stability.[4,5] This development will not increase the impact to the foot associated with sporting activity, because no clear relationship between impact and sole thickness has been established, perhaps because humans vary impact to achieve optimum stability.[67]

Methods need to be developed to heighten awareness of foot position while wearing shoes. One possibility might be the use of insoles which produce plantar deformation, which is an adequate stimulus for SAII mechanoreceptors. However, even this method may be incapable of causing sufficient shear stress on the plantar surface to provide accurate signals of stimulus direction, the information that is probably essential for precise awareness of foot position. Moreover, even if plantar tactile receptor activity could be provided it is hard to envisage a solution that will not damage plantar skin after long-duration use.

7. Conclusions

The sense of foot position is precise and sprains are rare when humans are barefoot. Ankle sprains occur frequently when humans wear shoes because they impair the awareness of foot position by attenuation of plantar tactile events which are adequate stimuli of SAII mechanoreceptors. This requires humans to use less reliable information from muscle receptors in making judgements of the position and orientation of the plantar surface relative to the leg. Studies which show that taping and the use of rigid and semi-rigid devices protect against injury are so poorly controlled that it is fair to say that their protective value is yet to be determined. If they do protect it is by partly correcting for the loss of awareness of foot position caused by footwear through restoring tactile cues of foot position: skin pressure (rigid and semi-rigid devices) or skin traction (tape).

Despite an improvement in proprioception with the use of these devices, there is concern that their interference with normal movement might actually increase injury frequency at the ankle and/or at other locations. Taping is least likely to be hazardous because it interferes least with normal movement. The best solution to ankle sprains must deal with their ultimate cause – footwear. The use of taping to improve the awareness of foot position will be replaced by more advanced footwear that allows the wearer to retain the tactile sensibility of the barefoot state, or perhaps improve on it.

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