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Title

Friction blisters on the feet: A critical assessment of current prevention strategies

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Abstract

Friction blisters are a common injury of the feet suffered by individuals participating in sporting, recreational and military activities. The high incidence of friction blisters brings into question the effectiveness of common prevention strategies. The purpose of this article is to review current evidence for established blister prevention strategies and explore how these interventions address the factors which cause friction blisters. Preventive strategies will be proposed focusing on previous overlooked elements of the blister-causing mechanism. Areas of future research will be outlined which are much needed to reduce this common skin injury in active individuals.

Keywords: Shear, Foot blister, Friction blister, Blister prevention, Skin injury, Running injury

Key Points

- Blisters are an intraepidermal tear caused by repetitive shear deformation.
- Opportunities for blister prevention present with either:
    - Maximizing the intrinsic resilience of the skin to shear deformation
    - Reducing the number of shear deformation episodes
    - Reducing the magnitude of shear deformation

Abbreviations

COF: Coefficient of friction

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Introduction

The continued high incidence of friction blisters of the feet brings into question the effectiveness of common prevention strategies. Effective prevention of friction blisters prior to participation in long distance walking and running has been a daunting task for participants as well as treating clinicians. This may be due in part to a long-held over-simplification or misunderstanding of the pathomechanics of blister formation.

The friction blister injury is not the result of materials or objects rubbing on the skin surface. Rather, friction blisters are an intraepidermal tear as a result of shear deformation beneath the skin surface.[1–5] Specifically, the underlying bones move back and forth during ambulation, while high friction forces acting between the skin surface and footwear interfaces provide traction to cause the skin surface to remain stationary for push off.[6] The resulting shear deformation, when repetitive, results in a mechanical fatigue within the stratum spinosum[1,3,5–8] which later fills with plasma-like fluid to resemble a blister.[9,10]

The three fundamental components of the mechanism causing friction blisters are: moving bone,[6,8] high friction force,[2,3] and repetition of the resulting shear events.[1,3–5,11] Until now, the contribution of bone movement causing friction blisters has been largely ignored or unrecognized,[6] and represents fruitful ground for new strategies in blister prevention. The second element of friction is widely accepted, although often inappropriately assumed to be a rubbing phenomenon against the skin rather than the actual mechanism whereby the skin surface and footwear interfaces remain stationary and unable to move in synch with the underlying bone.[8] Finally, the third element of repetition can be appreciated as blisters are known to occur primarily in endurance activities.[12–23] Since all three elements-- bone movement, high friction force and repetition are required for blister formation, appropriate preventive strategies can focus on each component.

The purpose of this article is to review the evidence for established blister prevention strategies and explore how these interventions address the factors that cause friction blisters. Preventive strategies will be proposed focusing on previously overlooked elements of the blister-causing mechanism. Areas of future research will be outlined which are much needed to reduce this common skin injury in active individuals.

Prevention of Friction Blisters

A friction blister results from mechanical fatigue within the stratum spinosum layer of the epidermis. The pathomechanics of the blister event is dependent upon three factors: 1) the number of shear cycles; 2) the intrinsic resilience of the skin to shear deformation and; 3) the magnitude of shear deformation. Each of these factors can be targeted as part of a friction blister prevention strategy, as shown in Figure 1.

Fig 1:

1) Reduce the Number of Shear Cycles

Repetition of shear deformation within the skin is a requirement for blister formation.[1,3–5,7,11] Comaish[4] observed that the blister injury results from epidermal fatigue to repetitive shearing forces, perhaps in association with increased tissue temperature. At the same time, it was emphasized that friction injury is not dependent upon wear, enzymes, pressure, stretching or ischemia occurring, and that repetition of the mechanical insult was an important causative factor.[4] This notion is supported by the fact that blisters are more common in activities where repetition of steps occur such as long-distance running, hiking, endurance military training and protracted tennis matches.[14,19–21,24–27]

Experimental blister studies have used both frequency and duration of shear cycles as data endpoints for creation of a blister.[1,3,5] Indeed, there is an inverse relationship between the magnitude of shear and the number of shear cycles required to produce intraepidermal mechanical fatigue.[6,11] Therefore, in spite of high shear loads, the risk of blistering can be reduced by limiting the number of shear cycles.[1,3,5] Implementing a strategy to reduce shear cycles may be feasible during training for a specific event. However, on the actual day of the event, the total number of shear cycles (foot strikes) will be determined by the requirements to achieve exercise completion, and in most cases cannot be modified.

2) Increase the Intrinsic Resilience of the Skin to Repetitive Shear Deformation

There is a large individual variation in time-to-blister as shown in experimental blister studies, suggesting some individuals are more susceptible to blisters than others.[26] Naylor produced blisters on the anterior shins of 19 volunteer British medical students and doctors and found the number of shear cycles required to cause a blister ranged from 27 and 138.[1] Sulzberger et al. conducted experimental blister research on the palms of 54 military personnel.[3] A consistent frictional force was applied repetitively and the time to blister was recorded. Some soldiers blistered in 3 minutes and others had not blistered after 50 minutes. More recently, repetitive shear load was applied to the soft tissues of the posterior heel of 30 volunteers and recorded the time to blister.[5] Blister onset ranged from 4 to 32 minutes.

While there is large variation among individuals in terms of their own skin's resilience or tolerance of shear stress, scientific evidence supporting the notion that the skin is capable of adaptation to resist repetitive shear deformation damage.[3,28–31] Therefore, in anticipation of participation in activities which impose significant numbers of shear cycles, individuals can embark on training programs which gradually increase shear loads on their feet.

Adaptation occurs when skin is subjected to the very forces that threaten to damage it – repetitive shear deformation. MacKenzie examined changes to the skin of mouse ears that were rubbed every day for 1, 7, 14, 28 or 35 days. The frictional stimulus applied each day was 10 revolutions of a rotating brush at a force of 8-9gm.[28,29] He found that in the ears which received rubbing there were more cells in the epidermis which were larger and more resistant to mechanical damage compared to ears that received no rubbing. Of significance, the changes seen at 7 days were identical to those at 14, 28 and 35 days, indicating adaptations were maximized by 7 days.

Studies have looked at the skin's response to shear and friction on the palms,[32] thigh,[33] anterior tibial surface,[1,2] back, buttocks, shins, forearms upper arms, thighs, palms and soles,[3] the palms and soles of monkeys,[34] mouse ears[28,29] and rat gums.[35] Adaptive changes that lead to an increased resistance to epidermal fatigue include an increased size and density of cells at the basement membrane and a thicker stratum corneum.[30] More recently, it has been demonstrated that skin adaption occurs by forming new collagen fibrils with larger diameters, as opposed to increasing diameters of existing fibrils. At the same time, there is breakdown of existing small diameter fibrils.[31]

Several studies of endurance activities lasting days to weeks, like marching, hiking and ultramarathon have found blister incidence to be at its highest earlier, rather than later in the event. This may verify that skin has the ability to adapt to mechanical strain. Foot blister risk factors were studied in military cadets who underwent an abrupt increase in walking, running and general physical activity during 6 weeks of summer Army Reserve Officer Training Corps training.[24] Blisters occurred in 42.1% of cadets with 95% of all blister cases occurring in the first 3 weeks (Week 1 = 34.6%; Week 2 = 51.2%; Week 3 = 9.3%). Separately, blister incidence was studied in 357 male Marine recruits undergoing basic training over 12 weeks.[36] They found highest blister incidence in weeks 1-3 compared to weeks 4-6, weeks 7-9 and weeks 10-12. In a group of 142 Korean college student volunteers who undertook a 21 day, 580km road march, the majority of blisters occurred on the second day.[14] Just over 95.1% of students developed their first foot blister in the first 5 days, with very few blisters occurring after that time period.

In terms of preventive strategies, there appears to be a role regarding familiarity with the activity and footwear which may affect overall blister incidence. Previous hiking or military experience offered some protection to blister formation in 189 recruits going through basic military training.[37] Blisters were most noticeable early on in recruit training[36] and troops who did not "break in" their boots were more likely to suffer with blisters during a 12-month deployment in Iraq.[38] In a study involving 2,617 cadets at Army Reserve Officer Training Corps training, cadets that wore their boots more than 20 hours per week in the two weeks immediately prior to training were less likely to get foot blisters than those that did not, 29.70% compared to 44.41% ($p = 0.001$).[24] Gardner and Hill found hikers who had not preconditioned their footwear were more likely to get blisters (32% versus 25%).[21] Finally, in a group of 221 male lieutenants taking part in their first training hike, it was found the likelihood of blister formation depended on the running habits of the individual.[39] Incidence of blisters was highest in the early rather than later stages of training, suggesting adaptive changes took time to occur.

In conclusion, preventive strategies focusing on the skin's ability for structural adaptive changes should be maximized to increase its resistance to mechanical fatigue, including gradual familiarization with the activity and terrain.[36,37,39] Familiarization with footwear should also be considered.[21,24,38] There are two cautionary notes to make however. Although some level of thickened stratum corneum appears advantageous, excessive hyperkeratosis is generally accepted to be counterproductive in blister prevention.[11,40,41] Shear deformation continues to occur in the soft tissue under a thickened stratum corneum. Certainly, if blisters occur in the presence of thickened stratum corneum, the aim should not be to affect further thickening to the point of callous formation. In this case, shear deformation is likely to be larger in magnitude due to increased focal pressure and therefore friction force and shear stress. Secondly, it should be recognized that many well-conditioned, seasoned competitors in sport still develop friction blisters as do experienced hikers during wilderness activities.[26,42] Whether it be a low intrinsic shear resistance, an exceptionally long duration or unaccustomed activity, unfavorable climatic conditions, pre-existing structural abnormalities or altered gait patterns due to pain-avoidance or injury, there are times when additional blister prevention strategies are needed to ensure effective blister prevention.

3) Reduce the Magnitude of Shear Deformation

Reducing the magnitude of shear deformation imparted to the skin is the aim of the majority of blister prevention products and techniques. Figure 1 shows there are four ways to reduce shear deformation magnitudes: reduce friction force; use shear absorbing materials; spread shear load over a larger area; and reduce bone movement.

3a) Reduce Friction Force

Friction is the force that opposes the movement of one surface over another at an interface. An interface exists between two materials in parallel contact. Sliding or rubbing can occur at an interface which is resisted by a friction force. The likelihood of sliding or rubbing motion is dependent upon two factors: 1) the coefficient of friction (COF) existing between the two surfaces; 2) and the compressive force pressing them together.

3ai) Reduce Coefficient of Friction (COF)

Coefficient of friction (μ or COF) is the common expression for frictional behaviour at a material interface. Coefficient of friction is dimensionless and represents the ratio of friction force to the normal force pressing two surfaces together. A low value of COF corresponds to a low force required for sliding to occur while a high COF requires a higher force for sliding to occur. Examples of low, medium and high values of COF include: polished oiled metal surfaces (less than 0.1); glass on glass (0.4); rubber on tarmac (close to 1.0).[43] COF will determine the sliding capacity or the stickiness between two surfaces which form an interface. Common interfaces related to blister prevention are the skin-sock interface, the sock-shoe lining interface, the skin-skin interface within the interdigital spaces, the sock-sock interface in the case of double socks, and the shoe-ground interface.

Sulzberger and Akers described COF management by way of the purposeful selection of materials in footwear design and manufacture to reduce friction over the most at risk points.[44] Carlson suggested that materials placed between the skin of the foot at various interfaces has the potential for changing friction.[6] Indeed, Veijgen iterates the study of skin friction combines tribology, materials science, dermatology, product development and rehabilitation.[45]

Blister prevention techniques which focus on reducing COF target either the surface of the skin or the various interfaces which exist between the foot and the shoe. By lowering the COF, these interventions encourage slippage at a specific interface. The end result will theoretically allow increased motion across the interface so that the superficial integument can move in response to, or “in synch” with, the movement of the underlying bone, thereby reducing the magnitude of the shear deformation within the skin. Strategies include lubricants, powders, all moisture-management strategies including moisture-wicking socks, double sock systems, polytetrafluoroethylene (PTFE) patches and some dressings.

3aii) Reduce Pressure

Pressure management strategies have the potential to reduce blister formation by reducing friction force. By reducing friction force, slippage at various material interfaces will theoretically enable the skin surface to move “in synch” with the underlying bone. The most well-known examples of pressure reduction blister prevention strategies include cushioned insoles, pressure-deflective padding, thick socks and toe-socks for the interdigital space. Pressure by itself is not the primary deforming force in the pathomechanics of the friction blister.[6,46–49] Naylor’s research showed that when friction loads were doubled, skin damage occurred three times as fast, without any increase in vertical force indicating friction force has a greater role in blister injury than vertical compression force.[2]

However, friction force is directly proportional to normal force (compression force) and the coefficient of friction between two surfaces. Therefore, higher friction forces are found in areas of the foot which have higher pressure against the skin. Elevated compressive force against the skin is found in areas of bony prominence where the compressive force is concentrated over a smaller surface area. In relation to the foot, plantar pressures are generally higher in the forefoot than the rearfoot.[50,51] This pattern is further amplified in cases of pes cavus and equinus deformity.[52–58]

Pressure mapping technologies are primarily limited to measuring compressive forces on the plantar surface of the foot. However, other situations where bone deformity concentrates compressive force would include apices and dorsal interphalangeal joints of claw toes, interdigital contact points from adductovarus digital deformity and the posterior calcaneus (Haglund’s deformity). In summary, the higher the compressive force, the greater resistance to synchronous movement between the skin surface and the underlying bone.

3b) Apply Shear Absorbing Materials

Most cushioning materials not only reduce pressure, they also absorb shear strain by undergoing shear deformation themselves. In so doing, these materials allow the skin surface to move in synch with the movement of the underlying bone, reducing shear strain within the body's soft tissues.[6,11,44] A material's ability to resist shear deformation is known as the *shear modulus*. Shear modulus is a measure of the elastic shear stiffness of a material. A low shear modulus indicates the material easily deforms when a shear force is applied.

Shear-absorbing materials investigated in the prevention of foot blisters include insole materials such as Spenco® and Poron®.[59–61] Thick socks have been presumed to afford a level of blister protection by way of shear absorption.[62] Without any clinical testing to date, gel toe devices intuitively hold significant potential to prevent toe blisters due to the apparent low shear modulus of the material. The challenge in applying shear absorbing materials is matching the shear modulus of the material with the functional requirements of the area in question.

3c) Spread Shear Load

A purely speculative mechanism of action of adherent tapes, moleskin and dressings in the prevention of blisters is by spreading shear load, while not necessarily reducing COF or compression force. Blisters occur at discrete locations, usually at a bony prominence where both compressive and shear forces are concentrated over a small surface area. It has been postulated that adhesive materials affixed to an area of skin larger than the bony prominence itself may broaden the area of skin subjected to shear deformation.[11,63] In this way, shear deformation per unit area is reduced. To date, no research and very little commentary exists of this mechanism of blister prevention.

3d) Reduce Bone Movement

During ambulation, at initial contact, the foot strikes the ground at a tangential angle rather than a purely vertical direction. This creates shear forces exerted to the foot resulting in anteriorly directed shear deformation of the soft tissues. Similarly, during push off the forefoot experiences a second shear event in the opposite direction as the shear force at initial contact, creating shear strain which is also in the opposite direction as seen at initial contact. The force of friction keeps the skin surface and external footwear material interfaces in stationary contact for maximum efficiency, as the bones move and press into the ground for push off. Because of the compliance and varying physical properties of the epidermis, dermis and subcutaneous layers, this bone movement does not cause immediate or uniform motion of the soft tissue located beneath. Temporospatial gait parameters and foot biomechanical factors causing excessive joint mobility influence the overall movement of bone.[64]

Bone movement and its critical influence on shear force and resultant shear deformation occurring in the multi-layered overlying soft tissue "sandwich" is an overlooked contributing factor to blister formation. Evaluating excessive bone movement at specific locations in the foot offers potential for implementing preventive methods, yet remains underappreciated to date. For example, digital deformities such as hammertoes and claw toes compromise the plantar purchase or load bearing capacity of the affected digit.[65] In claw toes, the action of the flexor digitorum longus (FDL) to directly plantarflex the digit to the supportive surface is compromised due to reverse buckling of the toe at the proximal and distal interphalangeal joints.[66] In the healthy intact toe, these joints remain in full extension, enabling the action of the FDL to exert pure plantarflexion moment at the metatarsophalangeal joint.[67] With loss of the extensor apparatus of the toes, the FDL will fail to plantarflex the digits at the metatarsophalangeal joint and instead will pull the phalanges in a plantar and proximal direction, accentuating shear forces at the apices of the toes during push off.[68]

On a more global level, kinetic and kinematic variables may create gait abnormalities which increase shear forces at various locations of the foot. For example, some individuals demonstrate an "abductory twist" or "medial whip" of the rearfoot during the heel rise phase of walking or running. This transverse plane motion of the foot creates shear forces which can manifest along the medial border of the first metatarsal head as well as the hallux. Excessive pronation of the foot during midstance has been speculated to cause the abductory twist motion during heel rise.[69]

The take home message here is that clinicians should evaluate the location of recurrent blisters in patients and consider the contribution of biomechanical mechanisms which may have increased shear load at the site of skin injury. Instead of focusing solely on reducing friction at the skin surface, consideration should be made for addressing the abnormal motion of bones beneath the skin, as indicated in Figure 2, which is the fundamental element of the pathomechanics of the friction blister.

Fig 2:

Individual Blister Prevention Strategies That Aim to Reduce Shear Deformation Magnitudes

Antiperspirants

Hydration levels on the feet are known to increase skin friction and the likelihood of blisters.[1–3,49,70–74] Naylor[1] recognized the protective effect of dried skin to blister formation, confirming that moisture reduced the number of shear applications the skin can withstand before blister damage. As a result, antiperspirants have been proposed to potentially have an indirect COF reduction blister prevention effect by reducing skin surface friction.

Research performed in military settings has demonstrated antiperspirants that reduce blister incidence concurrently cause significant irritant dermatitis.[22,75,76] These include aluminum chlorohydrate[75], aluminum zirconium tetrachlorohydrex glycine[75] and 20% aluminum chloride hexahydrate in anhydrous ethyl alcohol[22]. In an effort to reduce this adverse effect, researchers added emollient additives to 20% aluminum zirconium tetrachlorohydrex glycine concentration plus water.[76] While irritant dermatitis was not noted, blister incidence was not statistically significant among groups.

More recent research observed the rate of temperature change during shear loading to the skin at the posterior heel on dry and hydrated skin on twenty healthy subjects.[73] The skin on one foot was hydrated by soaking the foot in water. The contralateral foot acted as a control. Intermittent loading was carried out until an observable change of 3°C was evident. A 3°C increase in temperature was used as the end point of testing as previous experimental blister research had identified this as the temperature change indicative of imminent blister formation.[5] The rate of temperature change of the hydrated group was significantly greater than that of the non-hydrated foot group ($P = 0.001$) and showed a strong positive correlation ($r = 0.520$) with skin surface hydration.[73] Later, investigations found an antiperspirant (Boots Anti-Perspirant Foot Spray) did not affect foot skin hydration or rate of temperature change, thought to be predictive of imminent blister formation.[77]

Overall, the evidence indicates that non-irritating antiperspirants do not provide a blister prevention effect.

Moisture-Wicking and Moisture Absorbing Socks

Socks have the potential to prevent blisters by reducing moisture content on the surface of the foot, thereby reducing the COF. Additional to this, it has been suggested sock fiber properties and construction that may affect friction blister rates include moisture regain, swelling properties, water transport, heat transfer and friction coefficient.[78]

Cotton is a hydrophilic fiber which inhibits moisture-wicking ability.[78] Cotton fibers absorb three times the moisture as synthetic acrylic fibers.[79] Once wet, cotton has a ten-fold greater drying time compared to synthetic fibers.[80] Conversely, synthetic fibers such as acrylic, polypropylene and polyester are hydrophobic and facilitate wicking by transporting moisture along the fiber surfaces.[79] A specialized polyester fiber known as Coolmax® has a scalloped oval cross-sectional fiber geometry designed to increase its surface area by 20% to facilitate moisture transport.[81] When comparing synthetic fibers, polyester fibers (Coolmax) have a 15% faster drying time compared to acrylic fibers.[81]

Herring and Richie[82] looked at 35 long-distance runners and compared blister incidence in padded socks of identical construction but different materials – either 100% cotton or 100% acrylic fibers. There were twice as many blisters in the cotton sock group and they were three times the size, suggesting acrylic fibers were beneficial over cotton fibers in athletic socks. The authors proposed that the results were explained by lower friction force on the skin surface due to superior moisture-management of acrylic. However, in their follow-up study, socks with reduced padding were implemented, contrary to the dense padding in the first study, and found no difference in blister frequency when comparing cotton and acrylic fiber socks.[62] The authors concluded that the superior blister prevention capacity of acrylic fibers over cotton fibers depends upon sock construction. They speculated that the wicking capacity of acrylic fibers is enhanced by denser padding within the sock enabling better moisture movement from the skin surface. Alternatively, they proposed that a sock's ability to prevent blisters could depend upon some other mechanism related to its thickness, such as pressure reduction or shear absorption.

In regard to pressure reduction, athletic hosiery has been found to dissipate pressure against the skin of the foot, dependent on the fiber composition as well as the thickness or density of the fibers in the construction of the sock. Howarth and Rome studied the plantar shock attenuation provided over 72 hours by 5 types of athletic socks compared to barefoot, including: cotton socks; wool cushion sole sports socks; acrylic cushion sole hiking socks; double layer cotton socks; and toweling cushion sole sports socks.[83] Only the wool cushion sole sports sock and the acrylic cushion sole hiking sock demonstrated a significantly increased shock attenuation compared to barefoot walking. The cotton sock, double layer cotton sock and the toweling cushion sole sock did not. Other studies of padded hosiery have demonstrated reduced peak plantar pressures in the forefoot in patients with rheumatoid arthritis and diabetic neuropathy.[84–88]

While socks can affect moisture management to reduce COF, the inherent frictional properties of the sock itself should also be considered.[7] A study was undertaken to determine if PTFE (polytetrafluoroethylene, Teflon®) could reduce friction blisters when incorporated into the construction of an athletic sock at the heel, forefoot and toe area. In this study, blister incidence in a subject group of 77 university students participating in aerobics classes over 4 weeks showed no significant protective effect from the PTFE sock.[89] Separately, a 3-D finite element model was used to simulate the foot-sock-insole interfaces and investigate the effects of wearing socks with different combinations of frictional properties on plantar foot contact.[90] They found that wearing socks with low friction against the foot skin was found to be more effective in reducing plantar shear force than a sock with low friction against the insole.

Knapik recognized the multiple mechanisms by which socks may reduce blister formation, including moisture reduction, the ability to resist compression and undergo deformation.[7] This underscores the fact that socks can be part of three strategies which can reduce the risk of foot blisters: COF reduction, pressure reduction and shear absorption.

Several laboratory studies have been conducted measuring friction force and coefficient of friction of various sock fabrics and sock fibers.[78,91–93] While these studies of friction force at the sock-skin interface offer insight into how fabric structure and sock fibers may affect coefficient of friction, conclusions about how these factors relate to blister formation in the feet should be made cautiously. Laboratory studies vary in methodology and none fully replicate the in-vivo condition of a sock worn by a person inside a shoe. While laboratory studies suggest that fabric structure is more important than fiber composition in terms of friction force, other factors such as wicking, thermal dissipation and pressure reduction by socks must also be considered. Wicking capacity of socks demonstrated in laboratory studies is not always replicated in studies of sock performance during actual physical activity inside of footwear. Without exposure of the entire sock to the outside ambient environment, moisture absorptive capacity of the sock may be more important than wicking in order to keep the skin of the foot dry. Sweat production in the foot has been estimated to range between 381 to 447 grams per hour which can often times overwhelm the simple wicking capacity of the sock fibers.[94,95]

A field study was conducted with 37 military recruits marching over a period of four consecutive days.[96] This study was designed to measure moisture content on the skin surface of the feet of the participants as well as moisture content retained by the socks after marching. Also, the participant’s perception of skin temperature, overall dampness, friction and comfort was measured by questionnaire. Inexplicably, these parameters were all proposed by the authors to be critical to the formation of friction blisters on the feet, yet actual documentation of blister events was not carried out. Of the two socks tested, a 50% Merino wool and 33% polypropylene blend was rated to be cooler, less damp, and more comfortable than a 99% polypropylene sock. Surprisingly, in this study of soldiers wearing prototype military boots equipped with a GORE TEX membrane, the wool blend socks kept the surface of the foot drier than the polypropylene sock in two foot locations (dorsal metatarsals and posterior calcaneus) while the entire plantar surface of the foot showed no difference in moisture content when comparing the two different socks. In this study, the wool blend sock absorbed 2.9 times the moisture of the polypropylene sock. The authors speculated that the superior moisture storage benefits of the wool blend sock outweighed the wicking capacity of a polypropylene sock inside a closed boot where moisture evaporation is compromised. Thus, to reduce moisture content on the skin surface, the absorptive capacity of a sock becomes most important when the footwear has resistance to vapor evaporation.[96]

Finally, the thermal conductive properties of sock fibers are important considerations for blister prevention. Reducing or evacuating heat from the skin surface depends upon the thermal conductivity of the sock fibers. Cotton fibers have low thermal conductivity of 0.07W/m.K. Polyester has average thermal conductivity of 0.14W/m.K and polyamide (nylon) has a high thermal conductivity of 0.25 W/m.K but has 6-fold greater moisture regain than polyester.[79]

Overall, while many hosiery products are advertised to prevent blisters, studies are lacking which verify that they deliver this therapeutic effect. The only evidence that exists comes from the combined results of two double-blind studies which demonstrate acrylic socks reduce blister risk when they are dense and padded, not thin.[62,82]

Socks Versus No Socks

When an individual places their foot inside and sock and then inside a shoe, multiple interfaces are established. Each interface has its own COF and slip will occur where there is the lowest COF. This concept was studied when researchers compared skin-material, sock-material and skin-sock COFs.[97] The materials chosen were those used in the orthotic and prosthetic profession (Spenco®, Poron®, nylon-reinforced silicone, Soft Pelite®, Medium Pelite®, Firm Plastazote®, Regular Plastazote®, and Nickelplast™) and the sock material was wool. The COFs at skin-material interfaces were significantly higher than those at skin-sock interfaces. This confirms the beneficial effect of wearing socks which provide a skin-sock interface, rather than when wearing shoes without socks, where only a skin-material interface is in place. While the majority of running and walking athletes wear socks, triathlon is a sport with a high blister incidence where many individuals prefer the time-saving aspect of forgoing socks (skin-material interface) as they transition from the swim to the run leg of the race.[98]

Double Sock Systems

Double layer sock systems are a COF reduction strategy and are used to create an additional material interface. The intention is for the sock-sock interface to exhibit a lower COF compared to both the skin-sock and shoe-sock interfaces so slippage occurs between the two sock layers. There has been considerable interest from various military organizations in studying how these sock systems can prevent friction blisters on the feet of marching soldiers.

Blister incidence and severity was investigated in 357 marine recruits participating in basic Marine Corps training. Training took place 6 days per week for 12 weeks and included road marches, endurance activities, combat courses and drills. Recruits wore either standard issue socks or one of two double sock systems: a standard issue sock plus a thin polyester inner sock, or a very thick, dense, wool-polypropylene prototype outer sock over the thin polyester inner sock.[99] The standard issue sock was described as a one twist per inch sock, thicker at the heel and sole where the fabric composition is 50% wool, 50% cotton with spandex, with the remainder of the sock 50% wool, 30% cotton and 20% nylon. The authors provided no further description of the white polyester liner sock other than describing it as thin. The prototype sock was described as a uniformly thick 50% wool, 50% polypropylene sock with a thread density of seven twists per inch. Blister incidence for each group was 69% (standard), 77% (standard plus inner sock) and 40% (prototype plus inner sock). Severe blisters requiring medical attention occurred in 24%, 9% and 11% of the study groups respectively. This study showed that the double sock systems were somewhat more protective of blisters than a single sock. The standard issue sock plus liner reduced blister severity, but the dense prototype wool sock combined with a polyester liner reduced both overall blister incidence and blister severity.

Researchers compared blister incidence and severity on a group of 221 male lieutenants on their first training hike using one of three sock/powder conditions: standard issue sock only; white athletic sock plus nylon sock plus powder; and standard issue sock plus white athletic sock plus powder.[39] Blister incidence was 59%, 41% and 22% respectively. Blister severity was highest in the standard issue sock only. Separately, the effect of different socks systems was investigated on 189 Belgian military recruits undergoing basic military training.[37] The control group wore the standard issue military sock (70% combing wool and 30% polyamide). A second group wore padded polyester socks (88% polyester, 11% polyamide, and 1% elastane), while a third group wore a double-sock combination of a thin inner sock (45% polyester, 45% viscose, 8% polyamide, and 2% elastane) under a thick cotton–wool sock (40% cotton, 40% wool, 18% polyamide, and 2% elastane). Blister incidence was 51%, 16% and 32.3% respectively showing the single sock condition of the padded polyester sock provided greater blister protection than the double-layer sock system. This increased level of blister protection may suggest the hydrophobic polyester fibers created lower friction conditions at the skin-sock and/or sock-shoe interfaces, compared to the lower friction conditions between the layers of the double-sock system. Separately, the protective effect may have been more the result of the thickness of the sock, providing a pressure reduction or shear absorption mechanism.

Overall, the evidence for double sock systems is equivocal. One study found both double sock systems tested reduced blister incidence compared to a single sock.[39] Another found only one of two double sock systems tested to reduce blister incidence compared to a single sock.[99] A third study found a single sock condition was more protective compared to a double sock system.[37] The material composition and thickness of the two socks is likely to affect the outcome and varied considerably in the three studies.

Toe-socks

Toe-socks have become popular in endurance running and hiking. Their most obvious mechanism of action is pressure reduction by adding cushioning bulk to the interdigital space. Of importance, any pressure-relief from this interdigital padding will be dependent upon the available room in the toe box of the shoe. Alternatively, toe-socks have the potential to offer a COF reduction function by way of the double sock layers introduced to the interdigital space.

To date, there has been no research to demonstrate their effectiveness. However, while testing the effectiveness of paper tape, where all toes were taped on the experimental foot, Lipman and colleagues found the simultaneous use of Injinji toe-socks to be associated with an increased blister occurrence. Specifically, 34% of feet that were taped and wore toe-socks sustained blisters, while 27% of feet that were taped and wore toe-socks did not sustain blisters.[100] It is not explicitly stated that these blisters occurred on the toes. An increased blister incidence with the simultaneous use of paper tape and toe-socks was not commented on in the follow up study two years later.[101] Overall, toe-socks have not been adequately tested to draw any conclusions.

Lubricants

Lubricants reduce the coefficient of friction between two surfaces and are usually applied to the skin, targeting the skin-sock footwear interface. There are two types of 'wet' lubrication: boundary and fluid. Boundary lubrication describes the separation of two surfaces by a lubricant film. In this case, friction is influenced by the nature of the underlying surfaces as well as by the lubricant. Fluid lubrication describes the separation of two surfaces by a thick lubricant film. In this case, friction is entirely dependent on the physical properties of the lubricant itself. Of the two, fluid lubrication appears more effective at reducing friction.[2]

Fluid lubrication is dependent on the amount of lubricant applied and its ability to stay in situ on the skin. Researchers added 50 µl (1 µl = 1 cubic mL) of mineral oil to one square inch of skin and measured friction against a rotating nylon head.[72] A substantial and prolonged decreased friction level was found. However, when the rotating nylon head was cleaned at one-minute intervals with hexane-treated tissue, after an initial drop in friction levels, there was a gradual increase in friction levels which reached a maximum after 15 minutes.

Investigations into boundary lubrication of the skin of the abdomen[102] and volar forearm[103] and its effect on skin friction found that water and both mildly and moderately greasy moisturisers increased friction levels. Only viscous lubricants (petrolatum, mineral oil and glycerin) reduced friction levels, for a duration of approximately 90 minutes. At 3 hours, friction levels rose 35% above baseline.[103]

In spite of numerous lubricant products aimed at the blister prevention market, research is lacking for their use in preventing foot blisters.[41] Only skin friction studies such as those mentioned above exist, none of which include foot skin. However, it is intuitive that the friction reducing effect of lubricants is limited, owing to absorption and the dissipation of the product in active situations.[7] If found to be effective, the requirement to reapply lubricants to the feet to provide ongoing blister protection limits its use in many situations, including running events and military settings.

Powders

Powders have been used in skin friction studies based upon a strategy of producing a drier integument.[2,104] They have two COF reduction effects to reduce friction force at the skin surface. First, powders absorb moisture to encourage drier skin.[1,2] Secondly, powders work as a dry lubricant.[104] However, British Army research has shown talcum powders have either shown no difference when compared with a control group or a higher blister incidence among those using the powder.[7] When powder becomes wet, frictional forces have been found to increase.[77,104] It has also been suggested that when sweat and powder combine, the material clumps and becomes abrasive.[7,104]

The effectiveness of self-chosen prevention strategies was investigated in 50 participants of two 5-day 219km multistage ultramarathons.[20] At the end of each day, blister frequency and severity were recorded as well as the preventive measures used. Two runners used talcum powder alone. A further five runners used talcum powder with combinations of lubricants, antiperspirants and taping. No reduction in blister formation was seen in runners using talcum powder, antiperspirants, lubricants, or any combination of these. However, the sample size may have been too small to show any significant difference.

Other research tested three topical agents for their effect on skin surface hydration and rate of temperature change while shear cycles were imparted to the posterior calcaneal skin of participants.[77] These products were Flexitol® Blistop (a film forming compound), Boots Anti-Perspirant Foot Spray (an aerosol antiperspirant spray), and 2Toms® Blister Shield® Powder (a powder comprising polytetrafluoroethylene and polyethylene wax). In the study, the powder was shown to reduce skin surface hydration, suggesting a potential blister preventive effect. However, it had no impact on rate of temperature change, which the authors thought to be predictive of blister formation. The other products had no effect on either.

Currently, the evidence indicates powders are either ineffective or increase blister risk.

Tapes, Moleskins and Dressings

The use of adhesive tape on the feet to prevent blisters is an extremely common intervention used by clinicians and individuals.[11,20,63,100,101] Brennan and Richie have stated that the scientific evidence behind the use of adhesive tape for blister prevention is lacking.[8,105] Since then, two prospective randomized comparative studies have been performed on the use of paper tape to prevent blisters in ultramarathon runners.[100,101]

In the first study on 136 participants during a series of six-stage ultramarathons, paper tape was applied to "the majority of common blister sites" on one randomly selected foot, with the untreated foot acting as the control.[100] Ninety subjects finished the study. All participants developed blisters. No protective effect with paper tape was demonstrated. In fact, blister incidence was higher on the experimental foot, with 47 runners (52%) sustaining blisters on the taped foot versus 35 runners (38%) sustaining blisters on the control foot. Eight participants sustained blisters on both feet.

In the second prospective randomized study with 128 participants competing in a series of six-stage ultramarathons, paper tape was applied to a randomly selected foot, either to participants' self-reported blister-prone areas, or to one randomly selected location if there was no blister history.[101] This time, the un-taped areas of the same foot served as the control, not the contralateral foot. Eighty three percent of participants developed blisters. Of the 109 participants completing the study, 8 participants sustained blisters on taped areas, 74 participants sustained blisters on un-taped areas and 7 participants remained blister-free. These results demonstrated paper tape was effective in reducing blister incidence when applied to areas of the foot deemed blister prone by the participant, with an absolute blister reduction of 40% and with a number needed to treat of 1.31.

The mechanism by which paper tape prevents friction blisters is worthy of consideration. It may be assumed that tape affects a COF reduction strategy to prevent blister formation.[7] While it is possible that tape-sock COF is lower than that of the skin-sock interface, it is unfortunate that friction data of tapes used in blister management is lacking. Some friction data exists for other adhesive products including moleskin and blister dressings. Polliack and Scheinberg determined the frictional properties of 11 bandages used to treat blisters, including Compeed®, two types of moleskin, two Band-Aid® products and their own bandage called Bursatek®.[46] Figure 3 shows the COF data ranged from 0.57 to 1.54. The authors also evaluated the thickness of the bandages, recognizing that thick products have the potential to add pressure to the blistered area. In this study, thickness and COF were not proportional as Tegaderm® was found to be the thinnest bandage but also exhibited the highest COF. Bursatek® was the second thinnest bandage but provided the advantage of exhibiting the lowest COF, a presumed desirable combination in terms of blister treatment.

Fig 3:

A friction reducing blister prevention effect may be assumed of tapes, moleskin and certain dressings.[7] However, there is question regarding how effectively some of these materials reduce friction.[63,106] Moleskin is a durable cotton fabric and many tapes are made from cotton including RockTape®, KT Tape® and some athletic tapes.[106–109] Cotton is known for poor moisture management capabilities.[80,110]

A theoretical mechanism of shear load spreading has been proposed as a strategy to reduce the magnitude of shear deformation using adhesive products applied to the skin including tapes, moleskin and dressings.[11,63,106,111] While lacking any substantiating research, the concept assumes that by adhering a material to an area of skin larger than the bony prominence or blister site itself, shear gradients are reduced as the shear load is spread over a wider area. Theoretically, a rigid tape would perform this function more effectively compared to a flexible tape.[63] It is worth noting that paper tape used in the two Lipman studies of 2014 and 2016, is non-elastic and would therefore be considered a rigid tape[100,101]

Overall, the only evidence that exists involves paper tape. That evidence is drawn from two high quality prospective randomized comparative studies. However, the evidence is equivocal with one study showing a higher incidence of blisters, and the other showing a strong preventive effect. Further research is needed to determine the effectiveness of this particular tape. Additionally, clinical trials testing other tapes commonly used in blister prevention are required.

Callous

Shear-induced epidermal adaptations that increase the skin's resilience to shear load have been discussed. In addition to this, a protective shear load spreading effect from a thickened stratum corneum, as described for taping, may also provide a level of blister protection.[30] It is postulated that the increased epidermal volume through which to distribute shear load results in lower shear stress gradients and therefore may reduce the risk of intraepidermal failure.[30] However, a thickened stratum corneum can reach a point where it forms a physical callous which is a known risk factor for causing a friction blister on the foot.[11,40] Presumably there is a middle ground to be found between a moderate and excessive stratum corneum thickening.

Polytetrafluoroethylene (PTFE) Patches

Focusing on COF reduction, laboratory friction testing has been performed on five materials commonly used in the orthotics and prosthetics profession: ShearBan® (PTFE), russet leather, Poron®, Spenco® and Plastazote®, interfaced with either cotton or polyester CoolMax® socks in both dry and 30% moisture conditions.[112–114] In data from Payette, all orthosis materials exhibited lower COFs in dry compared to moist conditions except for the Plastazote-cotton sock interface. Overall, ShearBan had the lowest COFs in both dry and moist conditions compared to leather, Poron®, Spenco® and Plastazote®.[114]

Separately, Carlson measured the COF between cotton and four of the above-mentioned materials: ShearBan® (PTFE), Poron®, Spenco® and Plastazote®.[6] Moisture content of the cotton sock was the independent variable and was varied from 0% to 100% by weight. The data in Figure 4 shows the COF of the sock against PTFE and against Plastazote were 0.17 and 0.47 respectively, and those values are not significantly affected by increases in sock moisture content. Spenco an insole material, shows a rather continuous COF increase as the sock gains moisture, and PPT-Poron showed a significant jump in COF to a moisture content of about 35%, then little further increase. In spite of these favourable laboratory investigations, no blister incidence research has been conducted with clinical trials testing this product.

Fig 4:

Cushioned Insoles

Cushioning materials present a pressure reduction strategy for blister prevention. The entity known as friction force is directly proportional to pressure (compression force) and the coefficient of friction between two surfaces. Therefore, higher friction forces are found in areas of the foot which have higher compressive forces against the skin.

Cushioning materials and fixed volume gel materials reduce peak pressures by increasing the area of contact, thereby spreading the vertical load.[6] This concept can be applied to cushioning at any anatomical location of the foot, including insoles used under the feet and toe cushions. The effectiveness of the material will depend on its thickness versus effects on mechanical efficiency, understanding that excessive cushioning can negatively affect energy expenditure of locomotion.[6]

Tong and Ng studied the effects of four Poron®/Plastazote® cushioned insoles to reduce peak pressure at plantar locations of the foot.[115] They found that a combination Poron®/firm Plastazote® material was most effective. However, other researchers compared two different insoles for effectiveness in preventing blisters.[116] In this study, a group of 1,416 recruits used a standard flat 3mm course-weave PVC Saran insoles aimed at thermoregulation, while 1,338 recruits received 3mm shock-absorbing insoles. The shock-absorbing insole was a 3-mm-thick layer of cellular polyurethane foam with felt top sheet, an underlay composed of 99% polyester and 1% polyethylene, and a 3-mm-thick cellular polyurethan foam heel pad. The shock absorbing insole did not prove protective of blisters with blister incidence of 17.2% and 18.6% respectively.

Cushioning materials can also provide a shear absorption strategy for blister prevention based upon their ability to deform and rebound, a physical property defined as the shear modulus.[11,44] Spence and Shields described the concept of the shear absorption function of cushioned insole materials as a “ball-bearing effect”.[59,60] They described how the cells of closed-cell rubbers or foams, as opposed to open-cell materials, are independent of each other and allow lateral movement of one cell relative to adjacent cells. A new closed-cell neoprene was discussed that was able to absorb 1cm of fore, aft and lateral shear and 25 degrees of rotary shear, as well as vertical forces. The insole developed by Spence and Shields was 1/8th of an inch thick and had a stretch nylon top cover to additionally lower the surface friction force to aid the sock-clad foot sliding into the shoe. This insole was studied to determine effectiveness in preventing blisters in 200 athletes with self-reported blister issues or general foot discomfort. The insole was used in one shoe while the other foot served as the control, for a period of 3-12 months. Only one athlete sustained a blister with the insole. Thus, 99.5% of feet with the neoprene insole remained blister-free while 75% of feet without the insole were blister-free.

The same closed-cellular neoprene polymer rubber (Spenco®) was compared with an open-cellular polyurethane (Poron®) on blister and callous formation in a group of 90 recruits from the US Coast Guard Training Center undergoing an 8 week training regime.[61] Among the 30 subjects in each of the three groups (control group / Poron insoles / Spenco® insoles), most blisters and callouses occurred in the control group (8 subjects), compared to Poron (4 subjects) and Spenco® (1 subject).

In both 1968 papers, Spence and Shields discuss a silicone gel material that proved successful in preventing decubitus ulcers in bedridden patients.[59,60] They performed preliminary experimentations using the same material for blister prevention. While it proved successful at reducing shear within the skin, its high elasticity (low shear modulus) produced instability under the foot.

Overall, there is evidence to support the use of neoprene or Spenco® insoles for blister prevention.

Footwear fit

Ill-fitting shoes are often cited as a primary factor causing foot blisters.[41,117] Tightly fitted shoes may increase compressive forces against bone prominences and thus increase friction forces. Alternatively, loosely fitted shoes may allow excessive sliding of the foot which could increase shear. However, no scientific studies have been conducted to verify the role of properly fitted footwear or lacing techniques and blister prevention.

Pressure Deflective Padding

Deflective padding in the form of donut pads are a common blister management technique using a pressure reduction strategy.[41,105] This padding typically utilizes moleskin with an aperture cut into the middle of it and placed over the hotspot or blister-susceptible area of skin. Presumably, the thicker the padding, the better the pressure reduction. The effectiveness of felt deflective paddings of different thickness to reduce peak pressure have been documented on the following studies:

- 5mm felt reduced pressure by between 24-31%[118]
- 7mm felt is more effective than 5mm at reducing peak pressure[119]
- 7mm felt modified donut pad was found to reduce pressure by 25%[120]
- 20mm felt deflection was found to reduce peak plantar pressure 49%[121]

These results indicate a thicker material has the potential to reduce peak plantar pressures better than thinner materials. However, the relevance and effectiveness of pressure reduction with deflective pads to prevention of friction blisters has not been investigated.

Loose-packed Wool

Another strategy for blister prevention that has yet to be verified is the use of loose-packed wool. While loose-packed Merino wool has been used predominantly by the hiking community to prevent blisters around the toes, there has been no research on its true efficacy. Similar to the incorporation of wool fibers into hosiery, the application of loose packed wool around the toes may locally reduce pressure against the integument acting as a pressure reduction strategy. Another expected benefit of wrapping wool around the toes would be reducing moisture content on the skin, thus acting as a friction reduction strategy. Alternatively, loose packed wool around the toes may be a shear absorption strategy with wool fibers moving independently across one another. In doing so, the wool sample undergoes shear deformation within, reducing shear force applied to the foot. Whether the intervention prevents blister events during physical activity needs to be verified with future clinical trials.

Biomechanical Alterations

Shear stress distribution on the plantar surface of the forefoot and toes was investigated in three groups of 11 volunteers while walking barefoot over a shear and pressure platform: adult runners with frequent blister complaints; an adult control group who were moderately active and without blister issues; and a pediatric control group (aged 10-17 years) who were typically physically active and without blister issues.[26] The blister group had significantly increased pressure and shear stress magnitudes compared to the control groups and the authors suggested contact time may play a role in blister formation. They postulated these disparities may be due to differences in frictional properties of the skin, intrinsic muscle activity, or increased pressure magnitudes. Contrary to this notion, two studies have found no differences in blister incidence between pes cavus/high arches, pes planus/flat feet and normal feet, where foot type was self-reported via questionnaire.[37,122]

Clinicians commonly implement biomechanical interventions to address pressure and shear induced pathologies in the human foot. These interventions include:

- Foot orthoses with specific design features[123–127]
- Footwear with specific design features[128,129]
- Gait alterations and athletic taping[130,131]
- Digital orthoses[132,133]
- Stretches, strengthening, manual therapies and surgical procedures to reduce joint stiffness and increased ranges of motion[134–139]

Currently there are no published studies verifying that any type of foot orthosis, taping technique, shoe, digital device, manual therapy or gait pattern can provide a preventive effect on blister formation in the foot, and this offers opportunity for future research. At the same time, it should be recognized that interventions such as inserts and taping intended to treat other conditions of the foot may actually inadvertently contribute to blistering events.

Miscellaneous Blister Prevention Strategies

Environmental debris that enters the shoe, such as sand, pebbles and rubber from synthetic turf fields, may cause blisters. While bulky detritus will increase focal pressures and therefore friction force, it is more likely to cause a superficial-to-deep abrasion injury. Regardless, it is important to prevent entry into the footwear. Gaiters are frequently used in hiking, trail running and desert ultramarathons for this reason (ref).

Creases in socks should be avoided as they create increased focal pressure. Similarly, the occurrence of folds and excess bulk following application of athletic taping of the foot and ankle can be minimized with appropriate tape selection, appropriate application technique and the use of adhesive enhancer to prevent loosening. Regular inspection of socks, insoles and footwear linings should be performed for signs of excessive compaction and wear. These areas of material degradation will be less able to absorb shear strain, and intuitively increase friction force either by increasing focal pressure or coefficient of friction, predisposing to blister formation, if not abrasive injury.

Summary of Clinical Evidence

Many of the interventions in common use for preventing friction blisters lack evidence. Some have been tested in the laboratory, yet few have been tested for efficacy in real-life situations. As it stands, there is evidence for the use of:

- Strategies that allow adaptive skin changes including a familiarity with footwear and the activity[21,24,36–39]
- Neoprene or Spenco® insoles[59,61]
- Densely padded acrylic socks[62,82]

Evidence does not support the use of:

- Antiperspirants, as they do not reduce blister risk[75,76,140]
- Talcum powder, as it either has no effect or increases blister risk[7,20]

There is equivocal evidence for the use of:

- Double sock systems, with three studies finding inconsistent blister outcomes.[37,39,99]
- Paper tape, with only two similar studies performed, one showing blistering was worse[100] and the other showing a strong preventive effect.[101]

Finally, there are many strategies that have theoretical benefit but either have insufficient or no evidence to support their use. These include optimized footwear fit, lubricants, Blistershield powder, PTFE patches, tapes other than paper tape, pressure-deflective padding, gel materials, loose packed wool, toe-socks, socks of specific yarn/fiber composition or construction technique or biomechanical interventions including stretches, strengthening, physical therapies, foot orthoses, digital orthoses, specific footwear properties, or gait alterations.

It is clear more research is needed to support or disprove commonly-used, theoretically-coherent and anecdotally successful blister prevention strategies. Further, research should focus on the primary mechanism of friction blister pathomechanics which involves the asynchronous motion of bones relative to the overlying integument. Additionally, it would be helpful to determine if specific strategies are useful at specific anatomical sites.

Conclusion

Very few blister prevention products, methods or practices are backed by clinical evidence. Currently, evidence supports the use of dense padded acrylic socks, neoprene insoles and strategies that allow adaptive skin changes including a familiarity with the footwear and the activity. Conversely, antiperspirants and powder have been found to be non-protective. The evidence is equivocal for paper tape and double sock systems. Other strategies, even those that make intuitive sense or are in popular usage, such as optimized footwear fit, most athletic tapes, lubricants and biomechanical improvements, have not been confirmed with clinical research, sufficiently or at all.

Finally, it must be understood that the aim of every blister prevention strategy is to prevent shear-induced mechanical fatigue resulting in the intraepidermal tear. As such, effective opportunities for blister prevention present with either maximizing the intrinsic resilience of the skin to shear deformation, reducing the number of shear deformation episodes, or reducing the magnitude of shear deformation. In regard to the latter, this can be achieved by reducing friction force by way of reducing COF and pressure at the various skin and footwear interfaces, absorbing shear with materials external to the body, spreading shear load over a larger area with products adhered to the skin, and reducing the motion of bones adjacent to the blister location.

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Legend to figures

Fig 1: Blister prevention strategies

Fig 2: A diagrammatic representation of the opportunities for blister prevention.

Fig 3: COF data of 11 blister dressings. Reprinted from Wilderness and Environmental Medicine, 17(2), Polliack, A and Scheinberg, S, A new technology for reducing shear and friction forces on the skin: Implications for blister care in the wilderness setting, page 116, Copyright (1996), with permission from Elsevier.

Bursatek bandage: Advanced Wound Systems, Newport, OR

Dr Scholl's Moleskin Plus: Schering-Plough Corp, Kenilworth, NJ

Moleskin: PPR Inc, Brooklyn, NY

Band-Aid: Johnson & Johnson, New Brunswick, NJ

Band-Aid Plastic: Johnson & Johnson

2nd Skin Blister Pads: Spenco Medical Corp, Waco, TX

New-Skin: Medtech, Jackson, WY

Nexcare Comfort: 3M Health Care, St Paul, MN

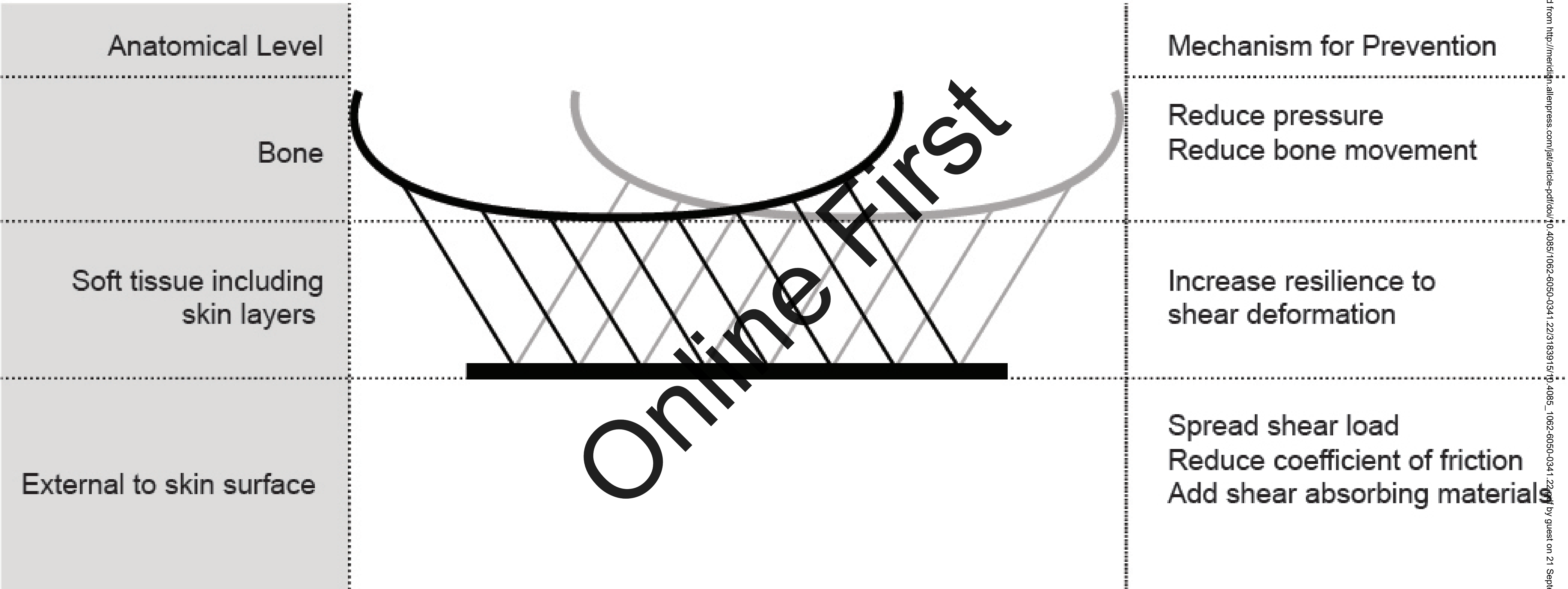
Dr Scholl's Blister Treatment: Schering-P lough Corp

Blister Block (Compeed): Johnson & Johnson

Tegaderm: 3M Health Care

Fig 4: Coefficient of friction data of 4 materials interfaced with cotton of varying moisture content from 0% to 100% by weight. Reprinted from Journal of Prosthetics and Orthotics, 18(4), Carlson, J.M., Functional limitations from pain caused by repetitive loading on the skin: A review and discussion for practitioners, with new data for limiting friction loads, page 102, Copyright (2006), with permission from Wolters Kluwer Health, Inc.


BLISTER PREVENTION STRATEGIES
Reduce the number of shear cycles
Reduce the magnitudes of shear deformation
Increase the skin's resilience to repetitive shear deformation
Reduce friction force
Absorb shear deformation
Spread shear load
Reduce bone movement
Reduce coefficient of friction
Reduce pressure

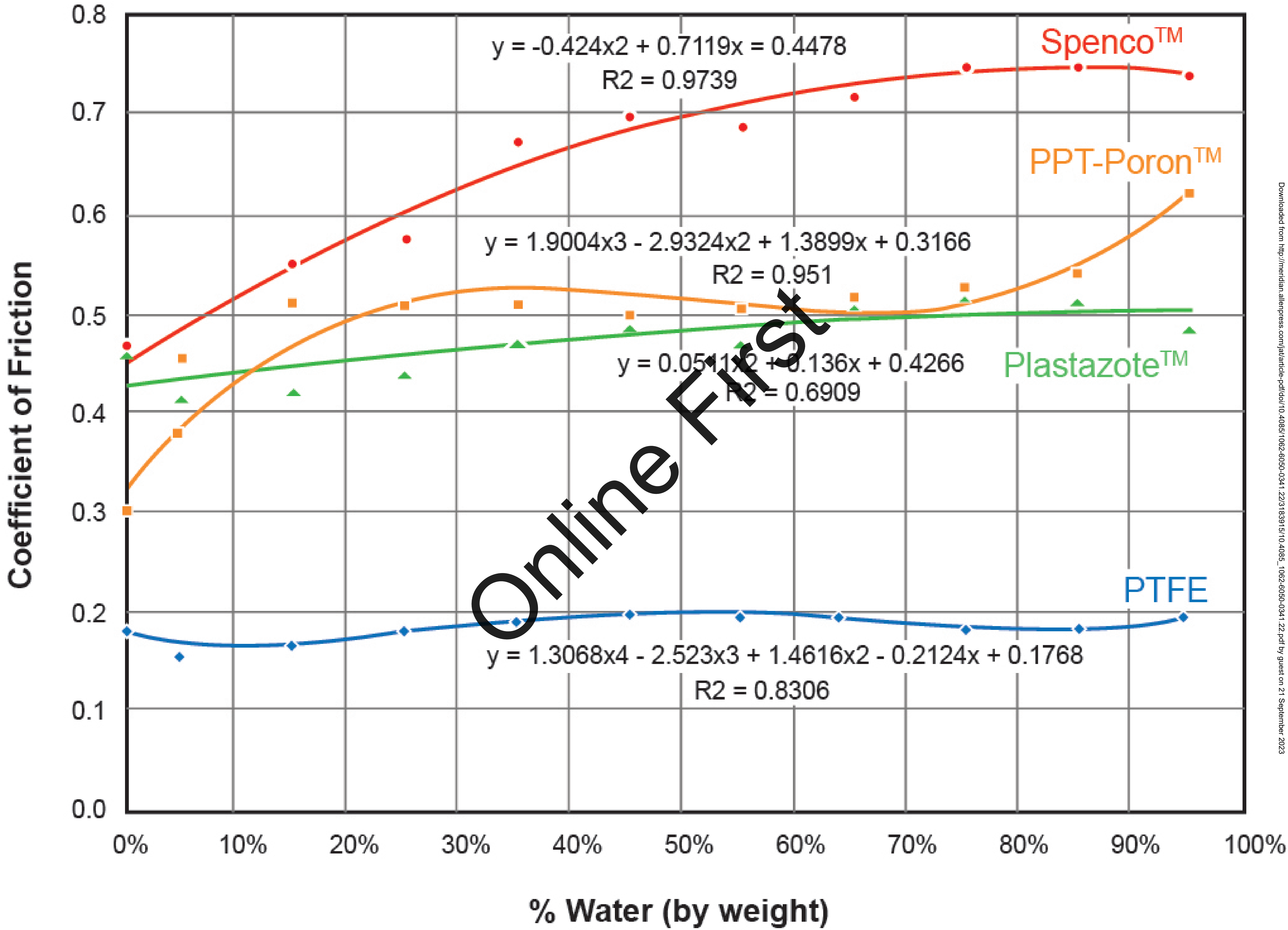


Anatomical Level
Mechanism for Prevention
Bone
Reduce pressure
Reduce bone movement
Soft tissue including skin layers
Increase resilience to shear deformation
External to skin surface
Spread shear load
Reduce coefficient of friction
Add shear absorbing materials

Product	*Manufacturer*	*Average CoF†*	*Difference, %*	*Thickness, mm*	*No. of tests*
Bursatek bandage	Advanced Wound Systems, Newport, OR	0.57	—	6	3
Dr Scholl’s Moleskin Plus	Schering-Plough Crop, Kenilworth, NJ	0.69	+21	31	3
Moleskin	PPR Inc, Brooklyn, NY	0.94	+64	26	3
Band-Aid	Johnson & Johnson, New Brunswick, NJ	1.01	+77	22	3
Band-Aid Plastic	Johnson & Johnson	1.03	+80	18	3
2nd Skin Blister Pads	Spenco Medical Corp, Waco, TX	1.04	+82	35	3
New-Skin	Medtech, Jackson, WY	1.05	+84	9	4
Nexcare Comfort	3M Health Care, St Paul, MN	1.08	+89	35	3
Dr Scholl’s Blister Treatment	Schering-Plough Corp	1.20	+110	32	3
Blister Block (Compeed)	Johnson & Johnson	1.37	+139	40	3
Tegaderm	3M Health Care	1.54	+169	1.5	3

†CoF indicates coefficient of friction/ 237-g normal applied load to end probe.

‡Compared with the Bursatek device.


y = -0.424x2 + 0.7119x = 0.4478
R2 = 0.9739
Spenco™
PPT-Poron™
y = 1.9004x3 - 2.9324x2 + 1.3899x + 0.3166
R2 = 0.951
y = 0.0511x2 + 0.136x + 0.4266
R2 = 0.6909
Plastazote™
Online First
PTFE
y = 1.3068x4 - 2.523x3 + 1.4616x2 - 0.2124x + 0.1768
R2 = 0.8306
Coefficient of Friction
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Water (by weight)