THE ADVANCED GUIDE TO BLISTER PREVENTION

Helping athletes and sports medicine professionals manage foot blisters with confidence

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PART 1: FOOT BLISTER CAUSES

PART 2: BLISTER PREVENTION STRATEGIES

INTRODUCTION

WHY WRITE THIS GUIDE?

Blisters are one of the most common injuries in sport and everyday life. In fact, blisters are so common they're not taken seriously, even when they're exceptionally painful and limiting. It's not that they're an insignificant injury. But it seems that because they are an injury of the skin rather than the musculoskeletal system, they tend to be relegated to an injury of lesser importance. A big part of the problem is that misinformation is rife and management ill-informed.

WHO IS THIS GUIDE FOR?

This guide is for runners and endurance athletes, sports people and active people of all persuasions and anyone who suffers with foot blisters. It's for podiatrists, sports medicine practitioners and anyone who is responsible for dealing preventative foot care, particularly in sport. If optimal performance and maximum enjoyment matters to you, then truly successful blister prevention is important to you and you should read this guide. Foot blisters deserve more attention and improved outcomes considering their prevalence.

HOW TO USE THIS GUIDE?

You can cut to the chase and read Chapters 5, 6 & 7 detailing specific blister prevention strategies. But to get the most of the guide it would make sense to read it all the way through at least once, and then return to it as a reference when needed.

PART 1: FRICTION BLISTERS ON THE FEET

Chapter 1: The Problem Of Blisters

Foot blisters are a common injury experienced by active people: runners, hikers and court sport players in particular. But anyone can get blisters, and most of us have! Too often, prevention is neglected and treatment is the fall-back. The problem with this approach is it rarely provides 100% pain relief, requires ongoing intervention and you need to have the right gear on-hand, at that very moment in time.

Chapter 2: The Injury Mechanism

The mainstream understanding of what causes foot blisters is a very simplistic one – to the point of being incorrect. Misinformation is widespread and it is holding the state of mainstream blister prevention at a standstill. There is a desperate need for this to change.

Chapter 3: Why We Get Blisters On Our Feet

The type of skin, the micro-climate and the forces encountered by your feet are unique compared to any other area of your body. These factors combine and contribute to blister formation. Find out what these factors mean for blister prevention.

Chapter 4: Blister Risk Factors

Research has identified a number of risk factors for blisters. Some are very easy to explain – they are directly involved in the cause of blisters. Others are less intuitive and might surprise you.

PART 2: BLISTER PREVENTION STRATEGIES

Blister prevention fails for a reason. Part 2 of this guide is all about why it fails and how to make the most of what each prevention strategy can offer.

Chapter 5: Your Shoes & Socks

Blister prevention starts with optimal shoe fit. Then there's things you can do with your sock choice (moisture-wicking socks and double-sock systems) to prevent blisters. And see how insoles, orthotics and special patches applied to the shoe or insole work. We'll look at some simple things you can do yourself and some others that a sports medicine professional can help you with.

Chapter 6: Your Skin

Training your skin to adapt to blister-causing forces is a blister prevention consideration not to be ignored – it's a rookie mistake to overlook this one. And discover the truths about how applying certain products to the skin can reduce blister incidence - drying preparations, lubricants and taping. This chapter is a must-read!

Chapter 7: Your Activity

Blister-causing forces on the skin can be reduced by modifying aspects of your running form and training regime. This chapter probably won't hold practical value for most people, but it's brief and still worth a read.

Chapter 8: Comparisons – Pros & Cons

We'll wrap it all up with a comparison table that outlines the pros & cons and a 3-star rating of the strategies discussed. So, you can see at a glance how one strategy compares to another.

Chapter 9: References

As you read through this guide, you'll see little numbers above the writing. You can click on these links to find the source of the information quoted – they're all on this reference page.

CHAPTER 1 – THE PROBLEM OF BLISTERS

BLISTER INCIDENCE

Blisters are one of the most common injuries in running sport and everyday life. Their incidence has been measured in runners, hikers and the military.

- 2% of male marine recruits during initial training (Bush et al, 2000)
- 16% of runners during a 10-mile race over 6 years (Pasquina et al, 2013)
- 20% of marine recruits over 32 weeks of training (House et al, 2013)
- 22% after a 5-day 21km cross-country hike (Reynolds et al, 1999)
- 29% of long-distance hikers in Vermont (Gardner and Hill, 2002)
- 33% of soldiers during Operation Iraqi Freedom (Brennan et al, 2012)
- Up to 39% of marathon runners (Mailler-Savage and Adams, 2006)
- 42% of military cadets during a training camp (Paterson et al, 1994)
- 48% during a 21km cross-country hike (Knapik et al, 1998)
- 57% during 6 weeks of basic military training (Van Tiggelen et al, 2009)
- 77% of military recruits during training (Knapik et al, 1996A)
- 95% of college students on a 580km road hike (Choi et al, 2013)

Blisters are not just a common injury – they often rank as the number one injury. Research into distance running, hiking and military injuries regularly find foot blisters are more common than musculoskeletal injuries of the knee, back, ankle and foot (Mailler-Savage and Adams, 2006; Pasquina et al, 2013; Reynolds et, 1999; Knapik, 2000).

In fact, blisters are so common we tend to not take them seriously, even when they're exceptionally painful and limiting. What happens next is blister *treatment* becomes the focus – not *prevention*. This is not acceptable. As an athlete, you should not be satisfied with this. And as a sports medicine professional, you should be even less satisfied with this approach.

It's not that blisters are an insignificant injury. But it seems that because they are an injury of the skin rather than the musculoskeletal system, they tend to be relegated to an injury of lesser importance.

> *"With such a high incidence and potential for disability, one would think that the prevention of friction blisters would be better understood… many myths continue to be propagated regarding the prevention and treatment of friction blisters." Richie (2010)*

BLISTER PRONE

Research has shown that there is such a thing as being blister prone. Blisters are seen to form quicker in some people compared to others when the same rubbing force is applied to the skin. Just look at the results of the three pieces of research below from Naylor (1955), Sulzberger et al (1966) and Hashmi et al (2013).

Year of research	Time to blister range	Subjects
1955	27-138 rubs	19 British medical students and doctors
1966	3-50 minutes	54 American army personnel
2013	4-32 minutes	30 university volunteers

Figure 1: The large individual variation in time to blister

WHAT IS NEEDED FROM HERE

With foot blisters being so common, there needs to be a better understanding of:

1. what causes blisters
2. where opportunities for blister prevention exist
3. how each blister prevention strategy works ... and doesn't work!
4. where there are gaps in our knowledge

There is an alarming amount of bad information available about blisters. It results in poor management practices. The right information is available. There's a lot of good stuff that has come from military research. There's some really good information in diabetic foot and prosthetic limb skin management literature. And there's a lot of information from the field of tribology (the study of friction). But there's nothing that has taken information from all of these sources, applied it specifically to foot blisters and made it easy to understand and freely available.

This guide bridges that gap. It is the easy-to-understand and freely available resource you can use to improve your blister prevention outcomes, whether you're an athlete or a sports medicine professional. And it comes from someone who knows about feet and foot function and who is blister-prone herself.

Please feel free to share this with your friends and colleagues. Together we can change the state of blister management for the better.

SUMMARY

A. Blisters are one of the most common injuries in running sport and everyday life.

B. There is a large individual variation in blister susceptibility.

C. You should not be satisfied with relying on blister treatment.

CHAPTER 2: THE INJURY MECHANISM

THE BLISTER INJURY

Step 1 Place the tip of your right index finger on the back of your left hand.

Step 2 Wobble it back and forth but keep it stuck to the same bit of skin. Notice how your skin stretches? *This is shear and this is what causes blisters*. Keep wobbling as you read:

Shear might look like rubbing but it's not. Notice how your finger tip has not moved relative to the skin of the back of your hand? But the skin on the back of your hand has moved relative to the underlying bone. Shear is the sliding of tissue layers over one another and it happens internally, below the skin's surface (whereas rubbing happens on the outer skin surface). It's that last little bit of shear that is damaging, when there is maximum skin stretch. When shear is excessive and repetitive, blisters form.

Here's the significance of friction – friction is what keeps the tip of your finger stuck to the back of your hand! Shear needs high friction to be able to approach blister-causing levels.

Below is a visual representation of what blister-causing shear looks like at the back of the heel (a common site for blisters):

Orange=shoe   White=sock   Brown=skin   Purple=soft tissue between skin surface and bone

Figure 2: Soft tissue shear at the back of the heel. The foot remains stationary in the shoe as the heel bone moves up and down. This causes the soft tissues (skin, fatty tissue, fascia, ligaments, periosteum) between the skin surface and bone to stretch (shear).

Contrary to popular belief, you don't need rubbing to cause blisters (Comaish, 1973; Zhang and Mak, 1999; Carlson, 2006). This is one of the main misconceptions of blister formation. In fact, rubbing can save you from blisters. Which brings us to another misconception - friction is not rubbing. Friction resists movement!

That's not to say rubbing isn't harmful. It's just that the "rub" doesn't cause the blister. Shear is the blister injury. Rubbing (in the presence of high friction) causes further abrasive skin damage.

> "The injurious effects of friction on the skin and the underlying tissues can be divided into two classes, those *without slip* [no rubbing] and those *with slip* [rubbing]. The former may rupture the epidermis and occlude blood and interstitial fluid-flows by stretching or compressing the skin [blisters]. The latter adds an abrasion to this damage [deroofed blisters]." (Zhang and Mak, 1999).

INFLUENCING FACTORS

The four requirements for blister-causing shear are:

1. A certain type of skin
2. High friction and pressure (*the coefficient of friction*)
3. Moving bone
4. Repetition

Friction is the force that resists movement of one object over another. Skin friction is different to other types of friction because the skin is a living and compressible tissue. Skin friction has two components: surface adhesion and tissue deformation. The degree to which one predominates over the other depends on the characteristics of the two surfaces (Comaish and Bottoms, 1971; Highly, 1977; El-Shimi, 1977; Wolfram, 1983; Zhang and Mak, 1999; Sivamani et al, 2003A; Derler et al, 2007; Savescu et al, 2008; Derler et al, 2009B; Derler and Gerhardt, 2012; Hendricks and Franklin, 2010; Veijgen, 2012). This gets a bit technical but if you would like more information, Hendricks and Derler (2010) is a recommended read.

The common expression for frictional behaviour is the *coefficient of friction* (Veijgen, 2013). It is a dimensionless number (a ratio) that represents the 'slipperiness' or 'stickiness' between two surfaces and is defined by the equation: Coefficient of friction = Friction force / Force of contact.

The table below gives you an idea of the coefficient of friction of several pairs of materials. There are two different values (static and dynamic) simply because the friction coefficient will be different when the surfaces are in stationary contact (static) or when they are moving relative to each other (dynamic – think rubbing). See how friction is higher when there is no rubbing (except for Teflon)!

SURFACES	COEFFICIENT OF FRICTION (static)	COEFFICIENT OF FRICTION (dynamic)
Steel on steel	0.74	0.57
Glass on glass	0.94	0.40
Metal on metal (lubricated)	0.15	0.06
Ice on ice	0.10	0.03
Teflon on Teflon	0.04	0.04
Tyre on concrete	1.00	0.80
Tyre on wet road	0.60	0.40
Tyre on snow	0.30	0.20

Figure 3: Coefficient of friction data is for inanimate materials. The static friction coefficient is always higher (except for Teflon on Teflon) http://ffden-2.phys.uaf.edu/211_fall2002.web.dir/ben_townsend/staticandkineticfriction.htm

GOOD FRICTION BAD FRICTION

Without friction, your foot would slide around too much in your shoe causing injuries to the feet (eg: black toenails, toenails falling off) and making your muscles work harder for balance, propulsion and overall functional efficiency. Your foot requires traction within the shoe and it gets it from friction. This concept of "not all friction is bad" is a very important one (Carlson, 2001; Carlson, 2006; Richie, 2010). By design, socks, insoles and shoe linings provide high friction – this is good. Friction only becomes bad when it's high enough to cause skin injury (that threshold will be different for each person). And is usually exists in small localized areas, not the whole foot.

> "A certain amount of frictional force is necessary on the plantar surface of the foot (sole) in order to develop traction and stability for propulsion" Richie (2010B).

Friction is a force *parallel* to the skin surface. It works in the opposite direction to the movement force from the bone. Then there are the compressive forces that are *perpendicular* to the skin surface that we know as pressure. These forces are shown below. While the bone acts to pull the skin & soft tissue one way, the force of friction resists it, effectively pulling it the other way. Combined with the compressive force, these forces define the shear load on the skin and soft tissue.

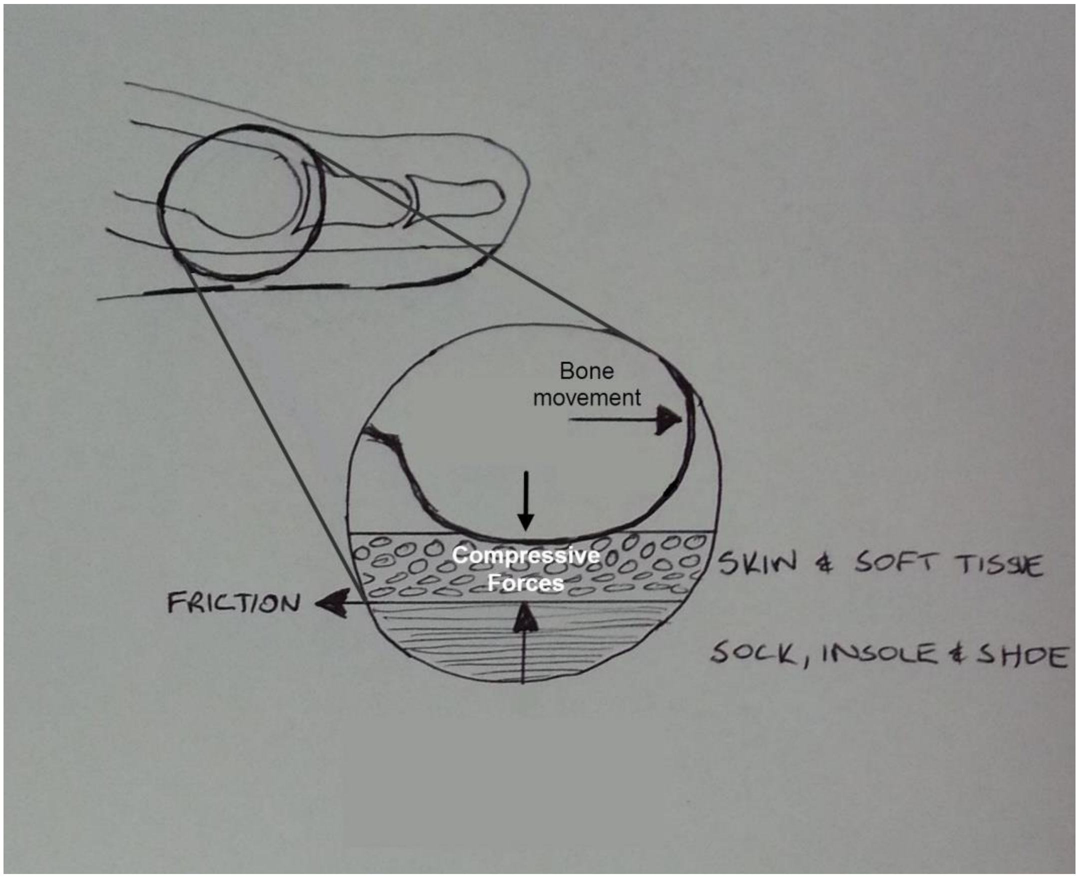


Figure 4: The forces determining the magnitude of soft tissue shear.

"Shear forces are applied to the human foot during walking and running because of the mechanics of foot alignment during contact and propulsion. The foot approaches the ground at a tangential angle (not a purely vertical angle) and then pushes off in a similar tangential direction. The foot [*bones*] must skid to a stop and then push into the ground to propel forward. The skidding will occur in both an anterior-posterior and medial-lateral direction, depending on the activity and demands of the sport" Richie (2010B).

SUMMARY

A. Blisters are an injury of shear.
B. Shear is the internal parallel stretching of soft tissue between skin and bone.
C. Friction is necessary for shear to reach blister-causing levels.
D. You do not need rubbing to cause blisters. Rubbing adds abrasion injury.

CHAPTER 3: WHY WE GET BLISTERS ON OUR FEET

SKIN ANATOMY

Skin is the barrier between the internal and external world. It has three layers: the epidermis, the dermis and the subcutis. A layer of fascia under that connects the skin to underlying tissues including the bones. Here are a few interesting things to know:

- Blisters occur in the epidermis
- The epidermis is made up of several layers – blisters form within the stratum spinosum (prickle layer) (Naylor, 1955; Sulzberger et al, 1966; Cortese et al, 1969; Akers and Sulzberger, 1972).
- The soles and palms are made of "glabrous skin" – skin with no hair and a higher proportion of sweat glands. Other areas of skin contain hair and less sweat glands (Veijgen, 2013).
- Bones are indirectly connected to the skin surface
- Bone movement has an impact on the tension in more superficial skin and soft tissue (Carlson, 2011)

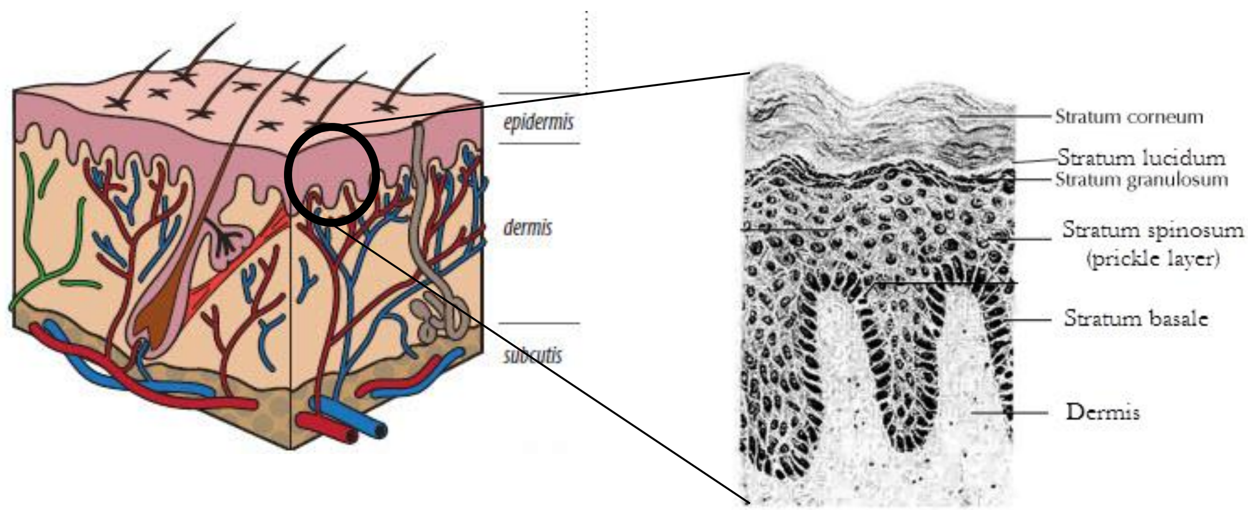


Figure 5: The layers of skin with a focus on the epidermal layers. Blisters occur within the stratum spinosum (prickle layer) (Make this a magnification of the previous image to highlight the epidermis layer)

BLISTER FORMATION

The earliest blister research by Naylor in 1955(B) and Sulzberger and colleagues in 1966 found blister formation to have two stages. These findings still hold true today:

1. the formation of an intra-epidermal split
2. the filling of this split with fluid

Blisters form when the shear stress exceeds the shear strength of the skin, resulting in a separation within the prickle layer of the epidermis (Comaish, 1973). The higher the shear magnitude, the less repetitions required to cause a blister (Naylor, 1955B).

The stratum spinosum (prickle layer) is the epidermal layer where friction blisters occur and presumably the layer of cells with the least resistance to shear. As shear becomes excessive, the structural connections between these cells stretch too far, they fatigue and fail. These microscopic tears are the initial blister injury. Knapik (undated) summarises the observable changes of rubbing the skin:

"A relatively uniform series of events are involved in blister formation. At first there is a slight exfoliation of the stratum corneum, and erythroderma [redness] is noted around the zone of the rubbing. With continued rubbing the subject may suddenly experience a stinging or burning sensation and a pale, narrow area forms around the reddened region. This pale area enlarges inward to occupy the entire zone where the rubbing is applied. The pale area becomes elevated over the underlying skin as it fills with fluid. Histological studies indicate that the pale area is a separation of cells at the level of the stratum spinosum, presumably due to mechanical fatigue" (Knapik, undated). Most recently, Hashmi et al (2013) found the same changes in their experimental blister study on the back of the heels.

A blister does not fill with fluid immediately after the epidermal split but it is fully filled within 2 hours (Sulzberger et al, 1966; Cortese et al, 1969; Akers and Sulzberger, 1972).

WHY DO WE GET BLISTERS ON OUR FEET?

One of the main reasons foot blisters are common is because of the thickness and immobility of the skin on the feet (Sulzberger et al, 1966; Comaish and Bottoms, 1971; Knapik et al, 1995; Zhang and Mak, 1999). Earlier, you saw what shear looks and feels like on the back of your hand. Here's an extension to that which shows you why the skin of the feet are susceptible.

Step 1: Place the tip of your right index finger on the ***back*** of your left hand.

Step 2: Wobble it back and forth but keep it stuck to the same bit of skin. Notice how far your skin can stretch (shear) back and forth.

Step 3: Now do the same thing on the ***palm*** of your left hand. Notice how your skin doesn't move as much as it did on the back of your hand? The skin on the back of the hand is thinner – you can pinch it and move it around easily. Most skin on your body is like this. On the palm it feels thicker and less mobile. It's just like this on the sole of the foot, even more-so because of weight-bearing. This is the type of skin that blisters form on most readily, as explained below.

- The skin is relatively **immobile** as it is adhered firmly to underlying structures. This is a functional requirement of the foot. But it means shear reaches a peak sooner (Knapik et al, 1995). Thankfully, the soft tissues of our feet are able to deal with a lot of shear … to a point.
- The very outer layer of skin (the stratum corneum) is very **thick** on the feet, particularly on the soles. A thick corneum makes the skin surface able to withstand rubbing without abrading, and able to withstand the underlying pressure of a fluid-filled lesion (blister). Conversely, the thinner the skin, the quicker it tends to abrade (either before or as soon as the skin blisters).

There are other reasons why blisters are common on the feet. And these have to do with the **in-shoe microclimate** (Hendricks and Franklin, 2010; Deng et al, 2009). Conditions within the shoe are hot and humid at the best of times (Deng et al, 2009) and consider the unique structure and function of the foot:

- There are more sweat glands on the sole of the foot compared to other areas of the body. These sweat glands secrete a certain amount of perspiration all the time, and even more-so when you exercise and when the outside temperature is hot (and some people perspire more than others). Blister and skin friction studies consistently show higher friction levels on moist sweaty skin (compared to very dry or very wet skin) and on the soles and palms compared to other parts of the body (Sulzberger et al, 1966; Akers and Sulzberger, 1972; Cua et al, 1990, El-Shimi, 1977; Savescu et al, 2008; Derler et al, 2007; Derler et al, 2009; Hendricks and Franklin, 2010).
- Few other parts of the body are wrapped up like the feet are in socks and shoes. Air circulation is poor so cooling and evaporation are compromised (Deng et al, 2009).
- No other body part sustains weightbearing pressures like the feet do

- The nature of gait is repetitive and force repetitions are a requisite for blister formation.

THE BLISTER THRESHOLD

Shear is a normal consequence of transferring weight from one foot to the other and it happens with every step you take. It is present at well-tolerated levels most of the time as we walk, run and play sport. But shear can become excessive. Excessive shear is the last little bit of shear – where it reaches its maximum. We call this the shear peak.

To put it simply, when the shear peak exceeds a *certain limit* blisters will form. You can think of this limit as your *blister threshold* and it's represented by the dotted line. In essence, the position of the blister threshold (the height along the y axis) defines where an individual sits on the continuum between "blister prone" and "blister resistant".

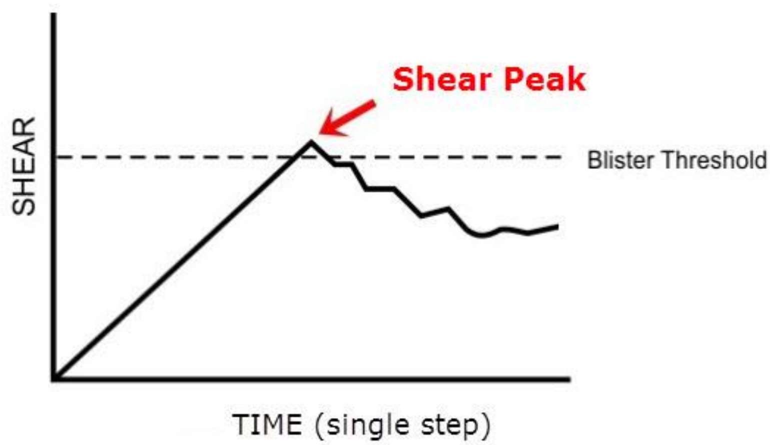
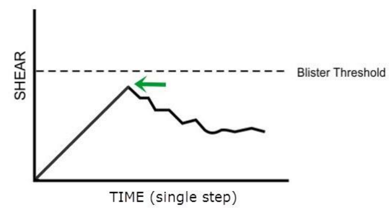


Figure 6: Shear peak

Blister prevention and shear peaks

The aim of blister prevention is to get this shear peak below the blister threshold. So let's look at how reducing the horizontal forces (friction and bone movement) can get the shear peak to somewhere below the blister threshold so blisters are avoided.

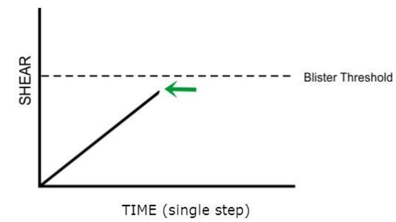


REDUCING FRICTION

By reducing friction, you make the environment (an area large or small) more slippery. An earlier slide, of the skin *relative to* the shoe, means the skin moves more in sync with the bone, with less shear the result. This slide can be between the skin and sock, the shoe and sock, or both!

Examples of friction-reducing blister prevention strategies include lubricants, ENGO Patches, moisture-wicking socks, powders and antiperspirants.

Figure 5: Reducing friction to lower the shear peak to below the blister threshold



REDUCING BONE MOVEMENT

Rather than dealing with friction, if bone movement is reduced, quite simply, the shear peak will be lower, even in the presence of high friction.

Skeletal movement can be reduced by altering biomechanics or form or by altering the intensity, duration or frequency of the activity. This can only be taken so far before it impacts negatively on sporting performance.

Figure 6: Reducing bone movement to lower the shear peak to below the blister threshold

A REAL-LIFE BLISTER PREVENTION SCENARIO

Let's apply our knowledge of friction and shear peaks to a real-life blister scenario.

Let's say you're a runner and you're having a bad time with blisters, which is unusual for you. It's a hotter summer than usual and you think that might have something to do with it. Let's say we could measure your blister threshold - your blister-causing coefficient of friction (COF) was 0.6. You wear good runners, cheap socks from Target and you run three times a week for between 5-8kms on a mainly flat terrain. Your form and biomechanics are good. So, it seems we can't do much about bone movement, but we can definitely have an impact on friction, because you think the extra sweat is causing higher friction levels. If you measured the COF between your foot and the sock at the end of a run, you might get a value of 0.7 (above your blister threshold). So, your aim would be to make your skin stay drier for longer (let's say you used an antiperspirant and moisture-wicking socks) so you got the COF down to 0.5. At this level, you'll have a successful blister prevention strategy.

If you still got blisters but they only developed on your 8km runs, it's an indication the antiperspirant and socks keep the COF below 0.6 for longer, but not long enough for your bigger runs. Presumably the antiperspirant lost effect and the moisture-wicking socks exceeded their absorptive and wicking capacity. The next step could be to keep your running distance to 5kms. But you're understandable not happy with that. So, you try an ENGO Patch on your insole in an effort to reduce friction between it and the sock. Thankfully, even on your big runs you remain blister-free. It's an indication the COF remained below 0.6 for the duration of the run, in spite of the extra sweating due to the extreme summer heat.

Notice how we've just addressed the four influencing factors of blister-causing shear?

1. Thick and immobile skin – actually not much we could do about this one
2. A high coefficient of friction – minimised with antiperspirant, moisture-wicking socks and ENGO patch
3. Moving bone – we know our mechanics and shoes are good and the terrain is flat
4. Repetition – could have stuck to 5km runs but it would have been as a last resort

SUMMARY

A. The thickness and stiffness of the skin on the feet (particularly the soles) is most likely to form blisters.
B. The in-shoe microclimate is suited to blister formation.
C. The blister threshold explains why some people are more blister-prone than others.
D. The blister threshold helps explain the aim of blister prevention strategies.

CHAPTER 4: RISK FACTORS FOR FRICTION BLISTERS

BLISTER RISK FACTORS

Remember the four requirements for shear are:

5. Thick and immobile skin
6. A high coefficient of friction (friction and pressure)
7. Moving bone
8. Repetition

Factors contributing to these conditions are quite obvious risk factors for blister development.

And research has identified other factors that seem to correlate to blister development too - factors that from the outside, seem unlikely to have any bearing. Factors like gender, ethnicity and tobacco use. There are conflicting results with some and the research base is not exactly substantial for many. So, it's not clear how relevant they are as risk factors. But they have been the subject of research and so will be reported in the table below.

PLEASE NOTE: A risk factor does not necessarily imply causation.

"Risk factors or determinants are correlational and not necessarily causal, because correlation does not prove causation" (Wikipedia: 'risk factor'). "A famous slogan in statistics is that correlation does not imply causation. We know that there is a statistical correlation between eating ice cream and drowning incidents, for instance, but ice cream consumption does not cause drowning. Where any two factors A and B are correlated, there are four possibilities:

1. A is a cause of B
2. B is a cause of A
3. the correlation is pure coincidence
4. as in the ice cream case, A and B are connected by a common cause. Increased ice cream consumption and drowning rates both have a common cause in warm summer weather" (Mumford and Anjum, 2013).

RISK FACTOR	INCREASED BLISTER INCIDENCE	REDUCED BLISTER INCIDENCE
FRICTION	Higher friction	Lower friction
FORCE OF CONTACT (PRESSURE)	Higher force	Lower force
NUMBER OF SHEAR CYCLES (REPETITION)	More cycles	Fewer cycles
Friction, pressure and number of shear cycles: The magnitude of frictional forces and the number of times a material or object cycles over the skin determines the probability of blister development. The higher the COF the fewer the cycles necessary to produce a blister (Naylor, 1955A; Comaish, 1973, Akers, 1985; Knapik et al, 1995). And heavy carried loads (higher pressure) have been shown to increase blister incidence (Reynolds et al, 1999; Knapik, 2000).		
SKIN CHARACTERISTICS	Thick and immobile	Thin and mobile
SKIN MOISTURE	'Moist'	Very dry or very wet
Skin characteristics and skin moisture: Every experimental blister study has shown that blisters form most easily on thick and stiff skin of the feet, especially the soles (Akers and Sulzberger, 1972; Sulzberger et al, 1966). And research shows skin friction increases in the presence of moisture, compared to very dry or very wet skin (Naylor, 1955 A&B; Sulzberger et al, 1966; Akers and Sulzberger, 1972; Highly, 1977; Nacht et al, 1981; Sivimani et al, 2003a).		
TEMPERATURE	Higher temperature	Colder temperature
Temperature: In almost every discussion you'll read on blisters, heat is always mentioned as a causative factor. To the point that some believe friction blisters to be a burn. Research shows this not to be the case. Higher ambient or skin temperatures increase perspiration which increases skin friction. Blisters form and fill quicker in higher temperatures, but heat is not required for blister development. The temperature–blister association is multifactorial and is discussed in more detail below this table.		
GENDER	Female	Male
Gender: There is conflicting research evidence here … Some studies found women to be more susceptible: Patterson et al (1994 – abstract only) found women were 1.6 times more likely to blister. Brennan et al (2012) found women were more likely – 47% vs 30%. And Veijgen et al (2013 A) found that women were more likely to have a higher skin coefficient of friction compared to men … Other studies have found no correlation between blisters and gender: Twombly and Schussman (1995) showed an equal blister incidence of 46% for males and females. Boulware (2004) showed similar blistering results for men (65%) and women (63%). And Choi et al (2013) found blister incidence to be equal between male and female. Skin friction studies by Cua et al (1990 and 1995), Savescu et al (2008), Van Tiggelen et al (2009) and Sivamani et al (2003C) found no skin friction differences between men and women.		
AGE	?	?
Age: There is conflicting evidence on blister incidence and age. Reynolds et al (1999) found a younger age to be a risk factor for blisters on a 5-day 161km cross country march of 218 light infantry males. Brennan et al (2012) found 26-34 year olds were more likely to get blisters than younger and older troops. Yavuz and Davis (2010) found that plantar shear is not dependant on age, comparing adult and paediatric subjects. Veijgen et al (2013 C) found COF values highest in the over 50 years of age group compared to younger subjects. And Cua et al (1990 and 1995) and Sivamani et al (2003 C) found no COF differences in skin friction between young and old subjects.		
ETHNICITY	Caucasian	African-American

Ethnicity: Patterson et al (1994), Reynolds et al (1999) and Van Tiggelen et al (2009) found Caucasian ethnicity to be a risk factor for blisters compared to those of African-American. But as far as skin friction research goes, Sivamani et al (2003C) found no skin COF measurement differences between Caucasian, African-American, Hispanic or Asian ethnicities.		
TOBACCO SMOKING	Tobacco smoking	
Tobacco use: Reynolds et al (1999) found blisters were more likely to develop among tobacco cigarette smokers (but not in chewing tobacco users). Van Tiggelen et al (2009) did not find any association.		
FOOT STRUCTURE	Orthopaedic foot deformity	
Flat feet and foot deformity: Van Tiggelen et al (2009) found an increased blister incidence in those with orthopaedic foot deformities. Other than “high arched or flat feet”, no information about these deformities is given.		
PREVIOUS BLISTER HISTORY	Previous blisters	
Previous history of blisters has been found to be a reliable indicator of blister risk by both Patterson et al (1994) and Brennan et al (2012). Van Tiggelen et al (2009) found there was a non-statistically significant increase in blister incidence when blisters were suffered the previous year.		
BODY MASS	Low body mass	
Body mass: Reynolds et al (1999) found a low body mass to be a risk factor for blisters.		
FITNESS	?	?
Runners: There is conflicting evidence. Knapik et al (1997) found low aerobic fitness as a risk factor. But Reynolds et al (1999) found physical fitness was not a risk factor for blisters, and Van Tiggelen found no association between fitness based on hours of “sports practice” undertaken per week. Caselli and Longobardi (1997) found shear injuries incidence (blisters, calluses and corns combined) was higher in marathon runners with lower training miles ran per week. Yavus and Davis (2010) found that runners’ skin underwent more shear than non-runners.		
PREVIOUS ACTIVITY EXPERIENCE	No previous experience in activity	Previous activity experience
Previous experience: Van Tiggelen et al (2009) demonstrated that the lack of previous hiking experience was a risk factor for blisters in military personnel, suggesting this was a result of not having their “boots already broken in”, a lack of skin adaption and not knowing “how to manage their personnel equipment.” Edholm (1969) found a lack of heat acclimatization to also increase blister incidence.		

Figure 7: Blister risk factors

BLISTERS AND TEMPERATURE

Friction blisters are not a burn

Despite popular belief, friction blisters are not a burn.

- Thermal burns that produce blisters are second degree burns, and second-degree burns go deeper - into the dermis. Friction blisters exist within the epidermis.
- Research has found that rubbing causes only moderate increases in skin temperatures, of between 41 degrees and 50 degrees Celsius which are insufficient to cause a burn (Naylor, 1955A; Griffin et al, 1969; Akers and Sulzberger, 1972; Comaish, 1973; Knapik, undated; Li et al,

2012). Hashmi et al (2013) demonstrated only mild increases in skin temperature from baseline temperature during and after blister formation in 30 participants.

- Friction blisters do not resemble thermal burns either clinically or histologically (Naylor, 1955B; Griffin et al, 1969; Cortese et al, 1969; Knapik et al, 1995).

The relevance of heat to blister development

In almost every discussion you'll read on blisters, heat is always mentioned as a causative factor. Although not directly a cause (not a burn), the involvement of temperature is multi-factorial:

a) The act of rubbing produces heat – The act of rubbing two surfaces together causes the production of heat and this is no different for the skin (El-Shimi, 1977, Li et al, 2012). Li et al (2012) demonstrated that rubbing causes a moderate increase in skin temperature, and that warmer area of skin increases sweat production, which increases skin friction. But the theory that localised surface heat generated by rubbing is a primary factor in blister formation is not supported by research (Naylor EFB, 1955; Griffin et al, 1969; Akers and Sulzberger, 1972; Comaish, 1973; Knapik, 1995; Li et al, 2012; Hashmi et al, 2013B). Besides, if heat transfer from the skin surface to the stratum spinosum is a major factor in blister development, one would expect the thicker corneum of the soles and palms to afford a level of blister protection. But a thick corneum is one of the requisites for blister formation (Naylor, 1955; Akers and Sulzberger, 1972).

b) Ambient and skin temperature – Higher ambient temperatures cause more perspiration (Naylor, 1955). And as you'd expect, increased walking speed causes higher in-shoe temperatures (Covill et al, 2003; Hall et al, 2004) which results in increased sweating. (Deng et al, 2009). Increased perspiration provides a 'moist' environment, and a moist environment (neither very wet nor very dry) is known to increase friction coefficients (Naylor, 1955; Akers and Sulzberger, 1972; Nacht et al 1981) which increases blister incidence (Sulzberger et al, 1966; Akers, 1985) by way of shear (Comaish, 1973). Although blisters occur more readily in hot temperatures, blisters still occur in cold climates. Griffin et al (1969) produced experimental blisters on chilled, warmed and "normal" temperature skin and noted:

- blisters formed quicker when initial skin temperature was higher
- blisters took longer to form on chilled skin (14 degrees) compared to normal (30 degrees) and warmed skin (46 degrees)
- when the initial skin temperature was low, the skin temperature at the time of blistering was also lower

c) The inflammatory process – Hashmi et al (2013) measured temperature changes during and after blister formation. They demonstrated temperature increases due to inflammation indicating heat is a result of the epidermal injury (Knapik et al, 1995; Hashmi et al, 2013).

Overall, heat causes sweating which increases skin friction, leading to a higher likelihood of blisters. And heat is a result of the blister injury.

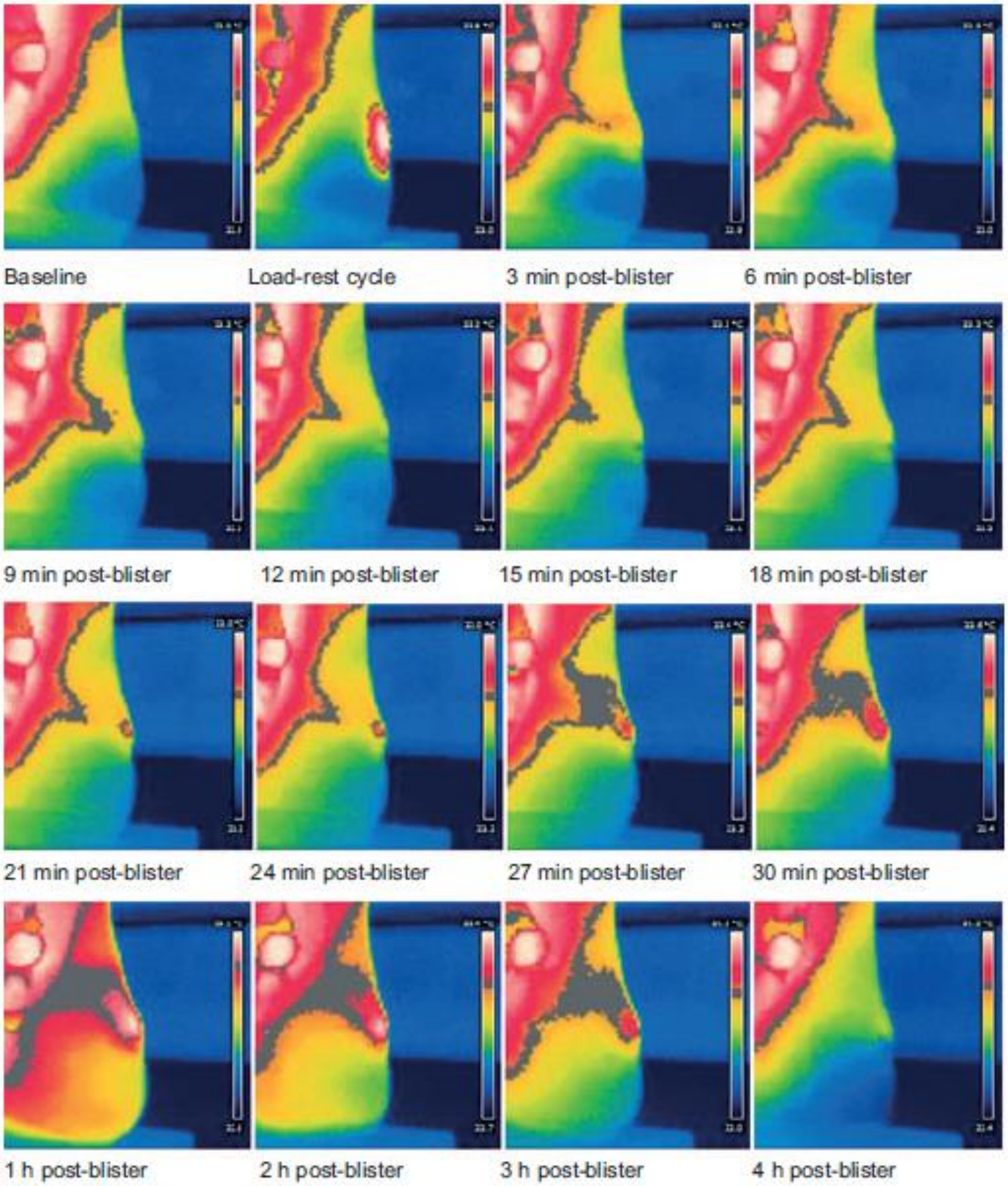


Figure 8: Hashmi et al (2013) demonstrated an increase in temperature for several hours after blister formation indicating the inflammatory response.

SUMMARY

A. The amount of friction, contact force, repetition and skin characteristics are known determinants of blister development.
B. There is conflicting evidence regarding gender, age and fitness as risk factors for blisters.
C. Blisters are not a burn. But heat increases perspiration which increases skin friction and makes blister more likely to form.

PART 2 - BLISTER PREVENTION STRATEGIES

The frustrating reality of blister prevention is it often fails. It can be difficult to find a strategy (or combination of strategies) that works, is long-lasting and is quick and easy to use. Several factors are at play here including the extreme forces encountered by the weightbearing foot and the hot and humid in-shoe microclimate. But also:

- the misunderstandings of what really causes blisters can lead to an unsuitable prevention strategy being chosen
- there are inherent limitations in each strategy that must be understood

Chapters 5-7 will look at all of your blister prevention options. One by one, we'll look at how the strategy works, its pros and cons and what research can tell us about its effectiveness.

WHERE DOES FRICTION EXIST?

But first, there's one concept that's generally missing from the mainstream discussion of blisters. We've touched on it, but if you can understand this, you'll have a better understanding of you blister prevention choices. The concept is that of interfaces.

Friction is present between any two surfaces. We call a pair of surfaces an interface (Carlson, 2006). The in-shoe interfaces are the **skin-sock** (black) interface and the **shoe-sock** (blue) interface. When looking for blister prevention opportunities to do with friction, you need to get **specific** about which interface you're looking at. *It makes a difference!*

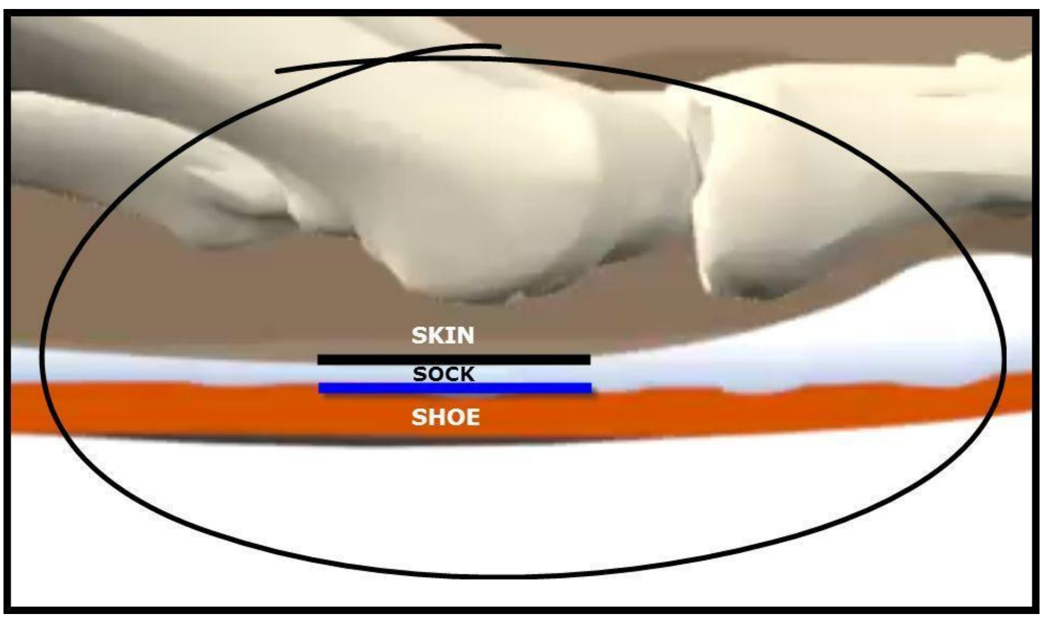


Figure 9: The two interfaces present in most athletic situation when wearing shoes and socks: the skin-sock interface and the shoe-sock interface.

SUMMARY

A. Blister prevention fails when the wrong strategy is chosen for the activity; and when the inherent limitations of the strategy is not understood.

B. Friction exists between any two surfaces (called an interface). Friction may be high or low.

C. There are two interfaces in the shoe that are commonly used to apply blister prevention:
   - Skin-sock interface
   - Shoe-sock interface

CHAPTER 5: BLISTER PREVENTION – YOUR SHOES & SOCKS

1. SHOE-FIT & LACING

Shoe-fit should be your first and most basic blister prevention consideration. Too small and the extra pressure causes shear to become excessive with less repetitions, ~~resulting in blisters sooner~~. Too big and your foot slides around too much in the shoe, increasing the probability of blisters, deroofing of blisters, abrasions, bruises, black toenails, blisters under the toenails and even losing your toenails (Knapik et al, 1995).

Keep these problems to a minimum with a shoe that fits perfectly. Optimal shoe-fit for blister prevention involves length, width and adjustability.

a) Length: The 'rule of thumb' is to have the width of your thumb between the end of your longest toe (usually the 2nd toe – but not always) and the end of the shoe upper. Measure this while you're standing (because your foot will elongate a bit) and make sure your heel is right at the back of the shoe.

b) Width: You don't want the side of your foot overhanging (bulging over) the side of your shoe. By the same token, you don't want too much width and have your foot moving around too much. When you are trying on shoes, if they fit perfectly but the facings (the material the laces go through) are touching one another, the shoe is as tight as you can get it - you've got nowhere to go if your shoe stretches (it's going to get too loose). Again, check this while you're standing.

c) Adjustability: It's not just about the length and width. You could have a perfectly sized shoe but if your laces are too tight or too loose, you've wasted your time. You might as well not have bothered getting the perfect sized shoes! The whole reason we have laces is to optimise shoe-fit at all times. Because it's only when the foot fits snuggly in the shoe that the shoe provides the support it's designed to.

If your shoes are too loose and your foot feels like it's sliding forward or your heel is lifting at the back:

- first make sure you've used the last pair of eyelets – the holes your laces go through
- next try the lace-lock lacing technique
- if that doesn't work, check Ian's Shoelace Site for a lacing technique that suits you

Consider the fact that shoe-fit changes during the course of your activity - foot volume will increase with longer duration walking and running, even in the exceptionally fit athlete. Over-hydration, topical in recent years following the work of **Noakes (2012),** may have the same effect. Be prepared to adjust your laces as you go. And be aware that although shoe-fit has intuitive merit, it is not always enough to ensure blister protection (Dyck, 1993; Cooper in Goldman 2007; Richie, 2010).

SUMMARY

A. Shoe-fit is your first blister prevention consideration.
B. Lacing ensures you can maximise shoe-fit at any time.
C. Optimal shoe-fit may not be enough to ensure protection from blisters.

2. SOCKS

Socks provide relatively high friction to maintain traction for the foot inside the shoe. This is by design. But socks can be used in such a way as to lower friction, namely:

a) Moisture-wicking socks
b) Double-sock systems

a) Moisture-wicking socks – High skin moisture causes high skin friction (Sulzberger et al, 1966; Akers and Sulzberger, 1972; Cua et al, 1990, El-Shimi, 1977; Savescu et al, 2008; Derler et al, 2007; Derler et al, 2009 – which one). The initial goal of a sock is to absorb moisture (perspiration) to keep the skin dry. But because of the sheer volume of moisture encountered, absorption alone won't always be adequate. The absorptive capacity of any sock will be exceeded. Some socks can "move" moisture away from the skin – from the skin side of the sock to the shoe side of a sock in a process is known as wicking. (Van Tiggelen et al, 2009; Richie, 2010A; Richie, 2013). The moisture can then evaporate through the shoe upper. This wicking function is achieved by sock manufacturers by using fibres in a way that sets up a moisture gradient to facilitate moisture movement in this direction.

Socks have many functions and fibres are selected for their construction accordingly. Thermal insulation, cushioning, durability, quick drying and ability to maintain shape: these will demand certain fibre properties. In regard to their interaction with moisture, fibres are chosen according to their hydrophilic (absorbent or water-attracting) or hydrophobic (non-absorbent or water-repelling) nature. The former keeps moisture trapped against the skin while the latter repels it away from the skin. Richie (1997) lists sock fibres from most hydrophilic to most hydrophobic:

Cotton --- Wool --- Acrylic --- Polyester --- Polypropylene

Cotton and wool are natural fibres (yarns). The others are synthetic fibres. Richie (2010A) explains "The most popular synthetic fibers utilised in athletic hosiery are acrylic and polyester. Both acrylic and polyester fibers are hydrophobic and have superior wicking properties and reduced drying time than cotton."

- Cotton: Cotton is the most hydrophilic fibre used in sock construction. It is widely-known that cotton socks have no place in endurance activities where blisters are a common consequence. Moisture is trapped within the sock and against the skin, keeping the skin moist and clammy – just perfect for blister development.
- Wool: On its own, wool is not a great fibre for sock construction because of its hydrophilic nature. But it is a common fibre used in specialist hiking sock construction for its thermal insulation properties. Richie (2010A) explains the premium Merino wool fibre is different. "Compared with traditional wool, Merino wool has a much finer core diameter of each fibre, giving a softer feel and more air space for moisture movement. Merino wool has fewer tendencies for skin itch, which is common with regular wool socks and apparel. The finer fibre and natural airspaces created by Merino wool have lead manufacturers to claim that this fibre is superior to any synthetic fibre for insulation and wicking."
- Acrylic: In 1990, Richie and Herring assessed blister incidence in runners wearing either 100% acrylic socks (with padded construction) or 100% cotton socks. The padded acrylic socks out-

performed cotton in regard to both blister incidence and blister size (acrylic sock wearers experienced half as many blisters and of those blisters that did occur, they were one-third the size of those of cotton socks). However, “one shortcoming of acrylic is its poor insulation. On hot surfaces in summer months, acrylic fiber socks can conduct heat and be undesirable” Richie (2010A).

- Polyester: A common and well-known example of a polyester fibre is **Coolmax**. Van Tiggelen et al (2009) found polyester socks (88% polyester) to significantly reduce the incidence of blisters compared to a double-sock arrangement (45% polyester sock under a thick cotton/wool sock (40% cotton, 40% wool) and compared to a standard military issue sock (70% wool). And “...studies have shown that Coolmax and other polyester fibers have a 15% faster drying time compared to acrylic fibers” (Richie, 2010A).
- Polypropylene: Polypropylene fibres absorb very little moisture.

If you haven’t given much thought to your sock selection, one of the easiest changes you can make to reduce your likelihood of blisters is to make sure there is no cotton fibre content in your socks and instead choose a moisture-wicking sock. “Cotton fiber retains three times the moisture of acrylic and fourteen times the moisture of CoolMax®. When exposed to ambient air, socks composed of cotton retain moisture ten times longer than acrylic” Richie (1997).

Here’s something you may not have given much thought to. In discussing the function of socks, the shoe being worn must be considered as part of the shoe/sock unit (or footwear system as described by Dyck, 1993), particularly in regard to moisture-management. To work adequately, a shoe with a breathable upper is required to allow the evaporation of moisture into the atmosphere (Dyck, 1993; Bogerd et al, 2012A; Van Tiggelen et al, 2009). Water-proofing can prevent this evaporation and not surprisingly, Bogerd et al (2012B) found moisture vapour transmission rates (MVTR) through four different boot uppers to be far below that of sweating rates. On the other hand, the mesh upper of most running shoes will intuitively allow for much better MVTR.

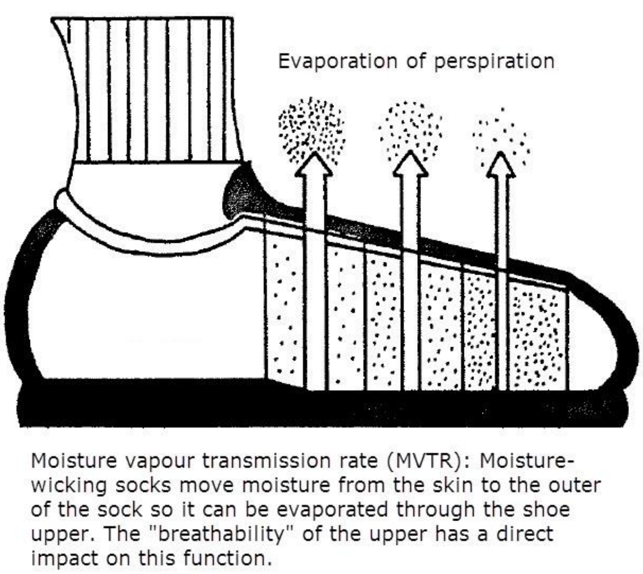


Figure 10: The rate of evaporation of moisture through the shoe upper determines how effective moisture wicking socks can be

b) Double sock systems – Double socks add a new interface into the equation. As well as the standard skin-sock and shoe-sock interface, you now have a **sock-sock** interface.

Double sock systems come in two forms:

- Literally wearing two pairs of socks
- Socks that have two layers at certain locations or throughout the whole sock (double layer socks)

Double-sock systems are all about reducing friction. The idea is to use different materials so that the sock-sock friction coefficient is lower than that of the other two interfaces. And this reduces the need for movement against the skin (rubbing) or within the skin (shear). But double-socks can also provide a moisture-wicking function. By using a hydrophobic material against the skin and a hydrophilic material on the outer, it sets up a moisture gradient (Thompson et al, 1993; Van Tiggelen et al, 2009).

Research has demonstrated an improved blister prevention function with double socks as opposed to single socks (Jagoda et al (1981); Thompson et al, 1993; Knapik et al, 1996). Knapik et al (1996) compared 3 socks systems – a thick, dense outer-sock combined with the thin polyester inner-sock was most effective in reducing the overall incidence of blisters (summarized below).

SOCK CONDITION		BLISTER INCIDENCE	SEVERE BLISTER INCIDENCE
Single sock	Standard military socks (wool-cotton-nylon-Spandex combination)	**69%**	24%
Double sock arrangement 1	Standard military boot sock **plus** a thin polyester inner sock	**77%**	9%
Double sock arrangement 2	Very thick, dense, prototype outer sock (wool-polypropylene combination) **plus** the same thin polyester inner sock as group 2	**40%**	11%

Figure 11: Knapik's research on double socks

In comparing the protective function of moisture-wicking socks to double-socks, Van Tiggelen et al (2009) provide this insight: "On a theoretical base, the inner sock provided the wicking capacity whereas the outer sock absorbs the moisture. On a practical basis, the recruits reported the formation of folds in the inner sock causing unequal pressure zones on the foot. Hence although the properties of this sock system are beneficial to the wearer, the application of the system could counteract its benefit by creating hot spots on the foot." A very close-fitting inner sock is required to prevent this.

Toe-socks can be thought of as double socks for interdigital areas. But this sock-sock interface is actually the same material. The crux of double-sock systems is to use different fibre content to ensure lower sock-sock friction. Alternatively, any benefit may come from the increased cushioning bulk between the toes. Unfortunately, research is totally lacking when it comes to toe-socks.

SUMMARY

A. Moisture-wicking socks aim to minimise friction at the skin-sock interface.
B. Double-socks introduce an additional interface (sock-sock) where friction is theoretically kept lowest.
C. The absorptive capacity of the sock and breathability of the shoe upper determine the success of these measures.

3. CUSHIONED INSOLES

Insoles can reduce blister formation in 2 ways:

a) cushioning reduces peak pressure contemporary
b) cushioning materials absorb shear (shear modulus)

a) Peak Pressure - Compared to other parts of our body, the pressure placed on our feet is unmatched. While mainly the weightbearing surface, there is a high force of contact between the shoe and the heel, toes and other parts of the foot even while standing. Start running, jumping, accelerating, decelerating and changing direction and we're looking at even higher forces. This pressure contributes to blister-causing shear by way of the coefficient of friction. It contributes! Pressure is not *the* cause of blisters, it is a contributing factor (Carlson, 2006). Remember the experiment pressing your fingertip either firmly of lightly into the back of your hand – the degree of shear is depended on having high friction as well.

Cushioning reduces this pressure peak by increasing surface area – by spreading the load over a larger area. Look at the diagram below. Fixed volume gels do this best as the gel is displaced laterally to form a cradle at the edges of the bony prominence.

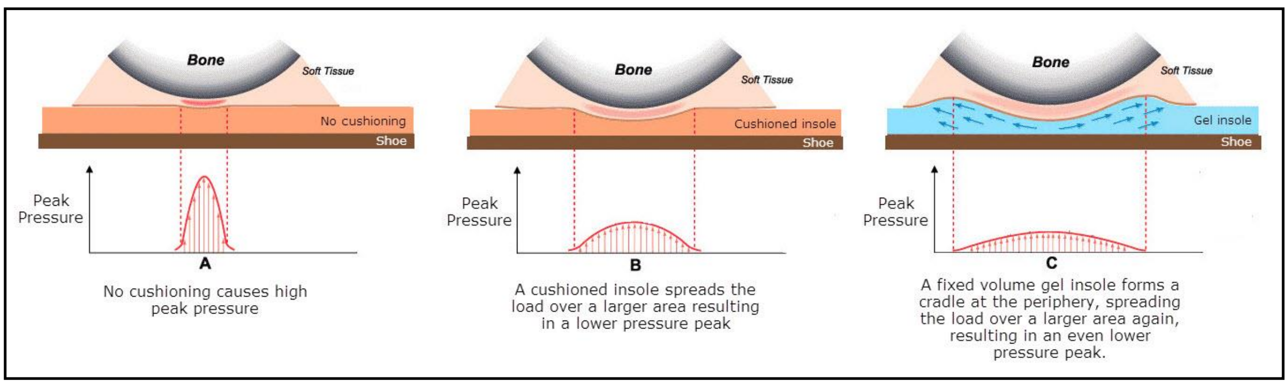


Figure 12: Cushioning spreads load over a larger area thereby reducing the peak of pressure. Fixed volume silicone products have the potential to reduce peak pressure further – from *Carlson 2006.*

b) Shear Modulus - Due to its thickness and cellular composition, a cushioned insole has the ability to absorb shear. When the material itself undergoes shear, it means the skin doesn't have to (or at least, less-so). This is called the material's shear modulus. A low shear modulus indicates the ability of the material to absorb more shear. Silicone gel has a very low shear modulus and has the ability to absorb more shear than standard insole and cushioning materials (Curryer and Lemaire, 2000; Carlson, 2011).

What The Research Shows

Not all insoles have the same ability to reduce peak pressure or absorb shear. Two common insole materials that have been tested in regard to blister prevention include Spenco (a closed-cell neoprene polymer rubber) and Poron (a cellular polyurethane) (Spence and Shields, 1968; Smith et al, 1985). The statistics from the Smith study (reported by Knapik et al, 1995) showed Spenco performed better at reducing blister and callus incidence (table below). However, a further study found an un-named cellular polyurethane foam slightly increased blister incidence (House et al, 2013).

PREVENTATIVE STRATEGY	BLISTER / CALLUS INCIDENCE
No Insole	33%
Poron Insole	17%
Spenco Insole	5%

Figure 13: Results of Smith et al, 1985 reported by Knapik et al, 1995

For cushioning to be effective, its properties must be a good match to the job at hand. If it's too soft, the cushioning material will simply flatten and not reduce the peak pressure at all. And if shear modulus is excessively low, braking and propulsive mechanisms are compromised, reducing the mechanical efficiencies of gait. "Cushioning degrades control and energy efficiency. Ideally, cushioning should be used sparingly ..." (Carlson, 2006). This is one of the limitations of gels used under the sole of the foot.

One thing to be aware of is insole materials like Spenco, Poron and silicone gels tend to exhibit high friction (Sanders et al, 1998; Zhang and Mak, 1999; Carlson, 2001; Payette, 2010) as seen in the graphs below. Any blister protective function is unlikely due to the reduction of friction.

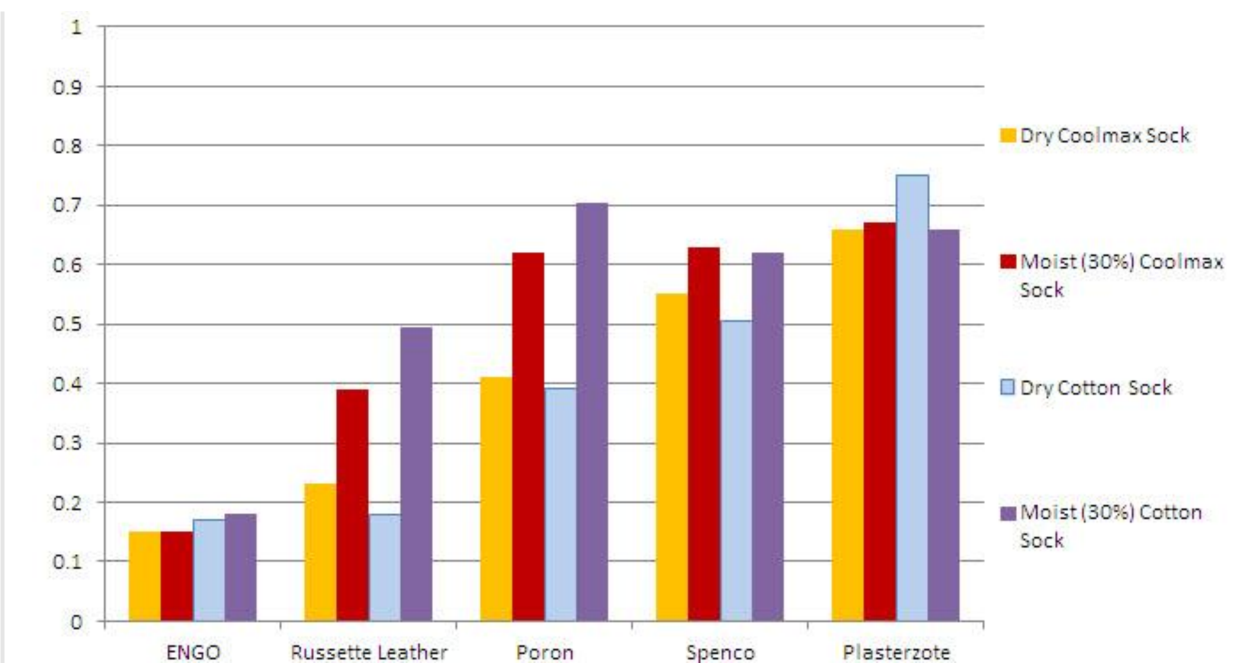


Figure 16: The coefficient of friction of 5 materials against 2 sock type in dry and moist conditions (Payette, 2010)

SUMMARY

A. Cushioning materials reduce peak pressure by spreading load over a larger area.
B. Cushioning materials can also absorb shear via their shear modulus.
C. More cushioning is not always better as it can affect shoe fit and reduce functional efficiency.

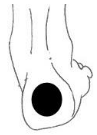
4. ORTHOTICS

Foot orthotics (orthoses) can be used to change the magnitude and timing of vertical and parallel forces on the foot. Therefore, orthotics can be used to prevent blister-causing shear.

Below is a table of ten common sites for foot blisters outlining:

a) an example of biomechanical factors that could contribute to blister-causing shear
b) the potential orthotic prescription variables that can be used to alter the foot's biomechanics
c) a few other salient factors related to footwear

The terminology may be difficult to understand if you are not au fait with foot biomechanics. The purpose is not to use this table to treat your own blisters, as each are singular examples of what is possible and may not apply to your blisters. The purpose of this table is to show you that a podiatrist has a lot of knowledge and tools at their disposal to help you with your blisters.

LOCATION	EXAMPLE OF STRUCTURAL / BIOMECHANICAL ISSUE	CONSEQUENCE	INTERVENTION
Back of Heels 	Tight calf muscle complex (increased ankle joint dorsiflexion stiffness)	Increased tension in Achilles causes the calcaneus to lift sooner	› Gastrocnemius/soleus stretches › Heel lifts / heel height differential › Joint mobilisation to lower tibiofibular joint
Plantar 1^{st} metatarsal head 	A flat pronated foot with a semi-compliant plantarflexed first ray	High medial loading Large forward / backward movement of 1^{st} metatarsal head combined with high peak pressure	› Orthoses with prescription variables to improve windlass mechanism: first ray wipe, forefoot extension 2-5, Cluffy wedge, heel lift, calf stretches › Metatarsal dome or other padding to deflect pressure from 1^{st} metatarsal head
Medioplantar 1^{st} MPJ 	Hallux abductovalgus (bunion) and excess STJ pronation with shoe width not accommodating foot width at forefoot	Poor footwear fit with first metatarsal head bulging over sole of shoe, exacerbated by high medial loading	› Improved footwear fit (sole width) › Minimise subtalar joint pronation forces with orthotic
Plantar hallux interphalangeal joint 	Compliant plantarflexed first ray causing inadequate windlass mechanism function	High peak pressure under interphalangeal joint of hallux	› Orthoses with prescription variables to improve windlass mechanism: first ray wipe, forefoot extension 2-5, Cluffy wedge, heel lift, calf stretches
Plantar 5^{th} metatarsal head 	Stiff anterior cavus	High peak pressure under 5^{th} metatarsal head	› Reduce ankle joint dorsiflexion stiffness with calf stretches or heel lift › Increase orthosis contouring of lateral border of foot
Plantar Metatarsal Heads 2-4 	High ankle joint dorsiflexion stiffness with excess STJ pronation and compliant 1^{st} and 5^{th} rays	Increased forward / backward movement and peak pressure at 2^{nd}-4^{th} metatarsal heads	› Reduce ankle joint dorsiflexion stiffness with calf stretches › Reduce STJ pronation moments and improve windlass mechanism
Toe apices 	Ligamentous laxity with very pronated / flat foot posture	Compensatory toe flexor muscle action causing toes to claw during gait	› Orthoses to reduce STJ pronation › Toeprops

Top of toes 	Fixed digital clawing	Higher peak pressure at dorsum of toes due to toe box too shallow	➢ Shoes with adequate depth in toebox ➢ Adjustability (laces/velcro) to enable firm fitting around midfoot to prevent forward slide ➢ Silicone toe sleeves
Between toes 	Adductovarus deformity of lesser toes	➢ Excess interdigital pressure due to lesser toe deformity ➢ Digital movement during gait	➢ Interdigital wedging/cushioning to reduce peak pressure and relative toe movement
Under medial longitudinal arch with orthosis 	Inadequate management of arch flattening moments	Soft tissue of plantar first ray is subjected to high compression and shear	➢ Modify orthosis prescription variables to facilitate windlass mechanism and reduce STJ pronation moments more

Figure 14: Examples of biomechanical factors for blisters by location

SUMMARY

A. Podiatrists have an advanced understanding of foot biomechanics to help prevent blisters.
B. Foot orthotics alter pressure and friction and therefore have a direct impact on soft tissue shear.

5. POLYTETRAFLUOROETHYLENE SHOE PATCHES (ENGO PATCHES)

Polytetrafluoroethylene (PTFE) is an ultra-low friction material. Teflon® is an example of a PTFE material. ENGO Blister Prevention Patches is another. These adhesive patches are applied to the shoe or insole where high friction is causing blisters. Research shows two things about these patches:

a) a coefficient of friction of around 0.16 which is very low compared to other in-shoe materials.
b) the low coefficient of friction is maintained in the presence of moisture (Carlson, 2001; Payette, 2010; Hendricks and Franklin, 2010).

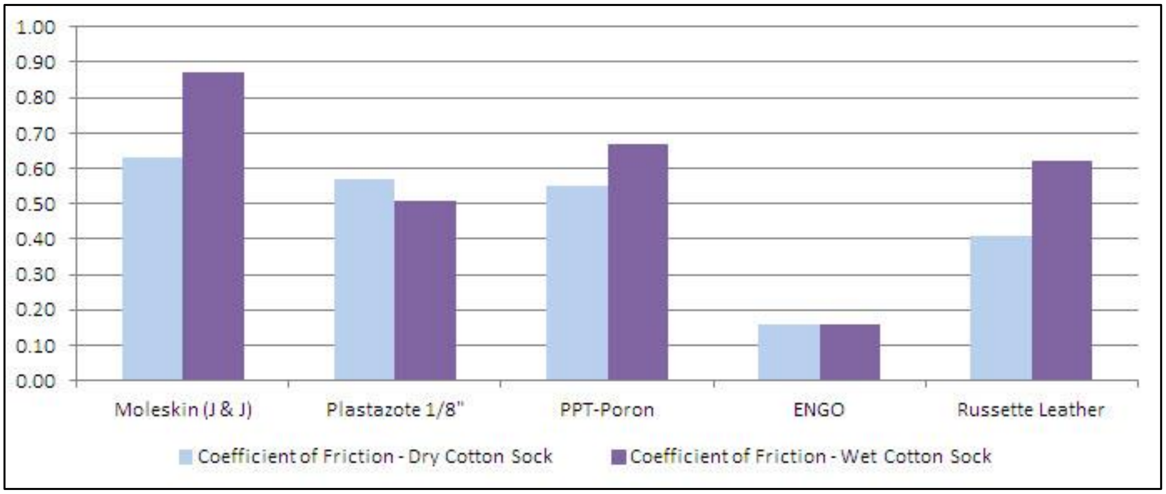


Figure 15: ENGO's low coefficient of friction remains low in the presence of moisture Carlson (2001)

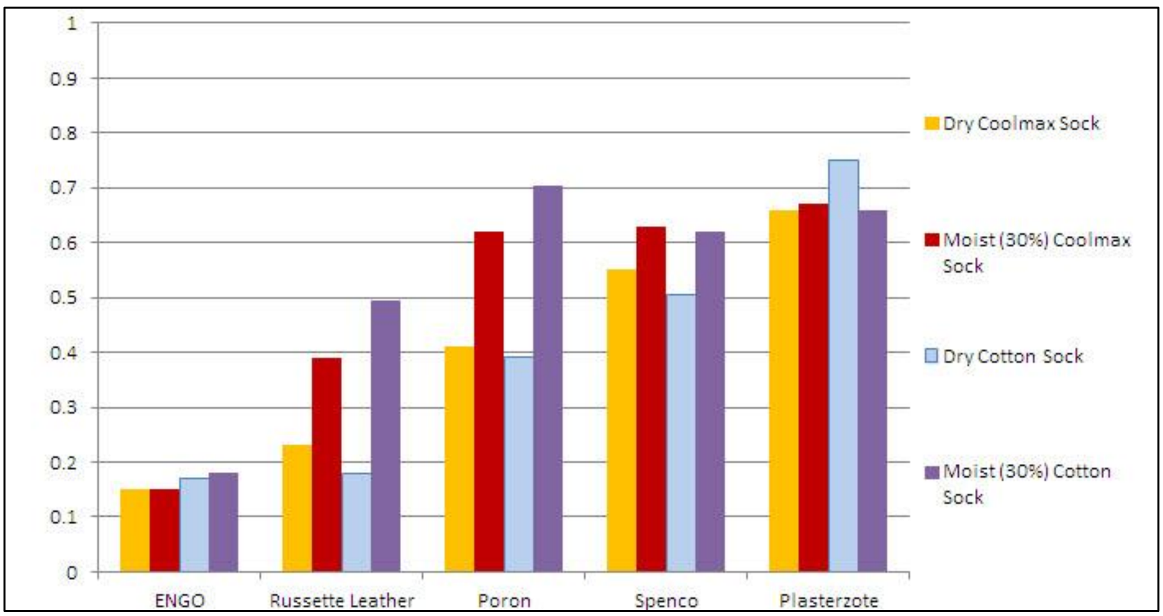


Diagram 16: The coefficient of friction of 5 materials against 2 sock type in dry and moist conditions (from Payette, 2010)

Most attempts at reducing friction are focused on the skin (the skin-sock interface) – powders, antiperspirants, lubricants and moisture-wicking socks. But friction reduction can take place on the other side of the sock (the shoe- sock interface). The advantage is that sweat is not a constant threat to adhesion. So as long as the shoe isn't water-logged, ENGO Patches will stay in place for an extended period. In fact, both the adhesive and the PTFE surface is very hardy, lasting around 500kms of wear.

And ENGO Patches allow the targeted management of friction: they minimise 'bad' friction in discrete areas to avoid blisters whilst maintaining 'good' friction elsewhere to maintain necessary traction - meaning biomechanical function is unchanged and functional efficiency is maintained. This is a considerable benefit.

Figure 17: ENGO heel patches applied to the shoe *Figure 18: ENGO patches applied to the insole/orthotic*

Considering the very low coefficient of friction of 0.16, it is very likely friction will be reduced (more than most other strategies considering the COF values above) to below the blister threshold of most people, regardless of how heavy perspiration is. Informal blister case studies show favourable results in the sports of volleyball, soccer, American football and basketball (Carlson JM 2001; Carlson JM 2006; Carlson JM 2009; and Hanna T and Carlson JM, 2004). And PTFE has been found to reduce the incidence of another shear injury, diabetic foot ulcers (Lavery et al, 2012).

SUMMARY

A. Polytetrafluoroethylene (ENGO) patches reduce friction at the shoe-sock interface.
B. PTFE has very low friction properties that are unaffected by moisture.
C. They allow the targeted management of friction.

CHAPTER 6: BLISTER PREVENTION – YOUR SKIN

1. ADAPTION

One of the most common rookie mistakes leading to blisters is to start a new type of activity without any thought to adapting the skin. By training in the shoes, socks and other gear, and on the terrain, you allow the skin to adapt to the physical demands of the activity. And this provides a protective function. Research has shown that when the skin is subjected to repeated frictional forces below that which causes blistering, epidermal cell turnover is faster, cells are more resistant to frictional forces and the stratum corneum becomes thicker (MacKenzie, 1974A&B; Jagoda et al, 1981; Sanders et al, 1995; Knapik et, 1996B). These adaptive changes within the skin occur sooner than you might think - changes after 7 days are identical to those at 14-35 days (Sanders et al, 1995). And it takes approximately 28 days for skin cells to move from the bottom of the epidermis to the surface (Sanders, 1995).

A level of reduced blister incidence has been reported with:

- having “worn in” footwear (Brennan et al, 2012; Patterson et al, 1994; Gardner and Hill, 2002)
- having previous experience in the activity (Van Tiggelen et al, 2009)
- more miles trained per week for marathon runners (Caselle and Longobardi, 1997)

Gardner and Hill (2002) found hikers that had not preconditioned their footwear were more likely to get blisters (32.1% versus 25.5%) - a mild protective effect. And in testing double sock systems against standard military issue socks, Thompson et al (1993) found reduced blister incidence was most noticeable early on in recruit training, when “recruits are adapting to the rigors of physical training.”

The take home message here is, depending on your blister threshold, although adapting your skin to your activity does not ensure protection from blisters, it will be a step in the right direction and should not be neglected.

You can take this too far - Thickening of the stratum corneum is one of the adaptive response. At its best, this thickening is barely noticeable. At its extreme, it constitutes a callus. Some people believe calluses to be protective. While there is no doubt a thicker corneum will reduce the likelihood of abrasions (just because there is more thickness to wear through before getting to raw skin), blisters are not abrasions. And clinical experience suggests that thick calluses are far from protective. In fact, shear experienced under a thick callus is more likely to be destructive to deeper layers of the skin and make blistering and blood blisters more likely.

Skin toughening **-** is a phrase used to describe the effect of some preparations used in blister prevention, like Compound Benzoin Tincture, alcohol, salt water, black tea (Read, 1990; Vonhof, 2012). These preparations more appropriately fit a ‘skin drying strategy’ providing for a lower frictional force – discussed next.

SUMMARY

A. Skin becomes more resistant to shear when subjected to repeated shear cycles.
B. It helps to train in the gear and on the terrain to benefit from this blister protective function.
C. Calluses are not protective to blisters.

2. SKIN DRYING STRATEGIES

Moist skin has higher friction than very dry or very wet skin (Akers and Sulzberger, 1972, Naylor, 1955A and Sulzberger et al 1966; Highly et al, 1977; El-Shimi, 1977; Nacht et al, 1981; Wolfram, 1983; Knapik, undated; Veijgen et al, 2013B). The theory is simple: keep your skin dry - keeps skin friction low - hopefully below your blister threshold - successful blister prevention is the result.

But keeping your feet dry is a tough ask: surrounded by socks, enclosed in shoes, sweat, varying amounts of evaporation, exercise, environmental conditions! Then consider if you sweat more than average. It's not difficult to see how a "very dry" in-shoe environment might be all but impossible to achieve.

Skin drying strategies include:

a) Antiperspirants
b) Powders
c) Astringent skin treatments (often termed "skin toughening")
d) Moisture-wicking socks (already discussed)

a) Antiperspirants – Antiperspirants are chemical agents that reduce sweating (spray-on, roll-on or powder form). The most popular antiperspirants have aluminium chloride and aluminium chlorohydrate at varying strengths as the active ingredients (Ngan, 2005). Aluminium-based antiperspirants work by blocking the sweat ducts thereby reducing the amount of sweat that reaches the skin's surface. Sweat continues to be produced by the sweat gland but it ~~just~~ isn't able to reach the surface of the skin (Ngan, 2005). Based on this, there may be a risk of an intra-epidermal maceration (weakened skin).

Aluminium-based antiperspirants have been tested in blister research. The table below summarises the effect on blister incidence but at the expense of skin irritation.

RESEARCHER	ANTIPERSPIRANT	METHOD	RESULT	SIDE-EFFECT
Knapik et al (1998)	20% solution of aluminium chloride hexahydrate in anhydrous ethyl alcohol	21-km hike	Blister incidence 21% (antiperspirant group) vs 48% (control group)	Skin irritation
Darrigrand et al (1992)	aluminium chlorohydrate and aluminium zirconium tetrachlorohydrex glycine	1 hour treadmill walking	No significant blister prevention effect	Irritant dermatitis
Reynolds et al (1995)	20% aluminum zirconium tetrachlorohydrex glycine PLUS moisturizing additives	3hr 20min treadmill walk	Skin irritation was negated with the addition of moisturizing additives	But the blister protective effect was lost

Figure 21: The disappointing results of antiperspirants for blister prevention

Another antiperspirant, Prantal Powder, works differently to the aluminium-based antiperspirants. Its active constituent diphemanil methylsulfate effects the parasympathetic nerves that control sweat production to prevent perspiration altogether (Ngan,2005). No research has been performed in relation to blister prevention.

b) Powders – Talcum powder has the ability to absorb moisture and act as a dry lubricant to reduce friction (Comaish and Bottoms, 1971; El-Shimi, 1977). But adding 13-17% hydration (ie: when your feet get a bit sweaty) causes the friction coefficient to increase. “It is self-evident that talcum does not remain dry in such areas as the foot for very long” and “the addition of talc to socks would be expected to increase frictional trauma” (Comaish and Bottoms, 1971). Both Knapik et al (1995) and Richie (2010) cite three British military studies from the 1960s that tested the use of drying powders in British military settings to find either no benefit or an increased blister incidence. If for whatever reason a powder is your blister prevention strategy of choice, reapplying is better than using too much in one application.

c) Skin toughening – Skin toughening is a phrase used to describe the effect of some ‘astringent’ preparations used in blister prevention, like Compound Benzoin Tincture, alcohol, salt water, black tea (Read, 1990; Vonhof, 2012) but of which there is no blister or skin friction research (Knapik et al, 1995; Brennan, 2000; Richie, 2010). An exact ‘skin toughening’ mechanism of action is not clear. Since astringents “precipitate protein, reduce permeability of the cell membrane and reduce transcapillary movement of plasma proteins” (Noxon, 2008), this equates to a drying effect to the stratum corneum. This is not so much ‘skin toughening’ but rather a skin drying strategy. But more explanation is needed and definitely some research to demonstrate a protective effect to blisters.

SUMMARY

A. Moist skin exhibits higher friction than dry skin – so keeping skin dry is a method of blister prevention.
B. The in-shoe microclimate dictates that the skin is usually moist.
C. Neither antiperspirants nor powders have proven to be both safe and effective and there is no data on the use of astringent preparations. Moisture-wicking socks (discussed earlier) have proven to provide a level of blister protection.

3. LUBRICANTS

At the opposite end of the skin moisture spectrum are lubricants. Vaseline (petrolatum) is a well-known one, you apply to your skin and friction definitely reduces. El-Shimi (1977) and Highly (1977) explain that viscous lubricants like this work by forming a film on the skin which keeps your sock and skin apart. Interestingly, the frictional properties have nothing to do with the skin-sock interface but rather, the hydrodynamic properties of the lubricant. Even more interestingly, over time, the lubricant disperses and friction actually increases. The lubricant disperses for two reasons:

- As the lubricant film becomes thinner, the contact increases between the surfaces and the observed friction level is less about the hydrodynamic properties of the lubricant
- The lubricant absorbs into the skin, increasing skin hydration and therefore skin friction

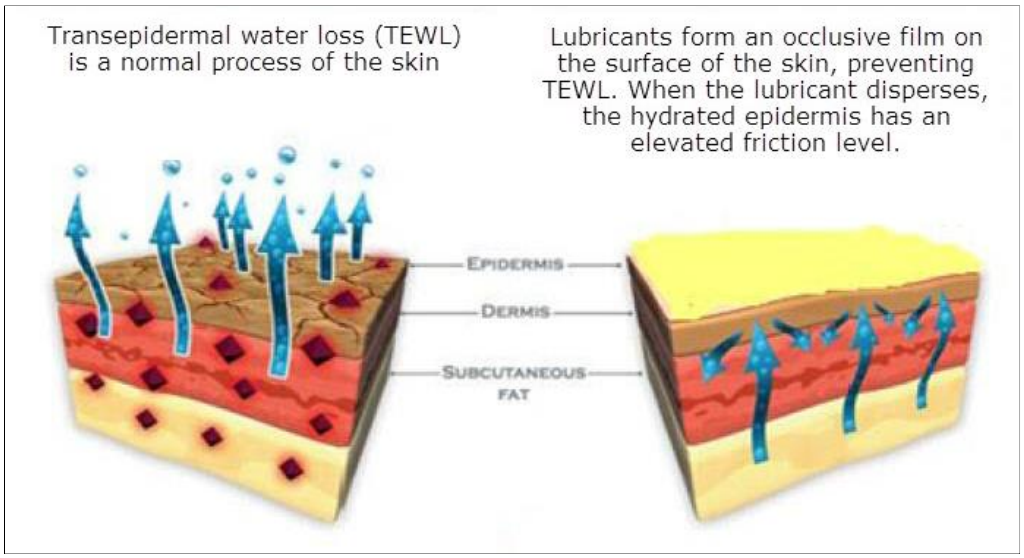


Figure 20: A lubricant forms a film on the epidermis such that frictional properties have nothing to do with the skin but rather the properties of the lubricant. But the occlusive film traps moisture within the skin and once the lubricant disperses, skin friction levels are increased. And the skin can become macerated.

Landmark research by Nacht et al in 1981 measured skin friction for 6 hours after using moisturisers graded according to their perceived “greasiness”. The level of greasiness determined whether friction increased or decreased, as outlined in the graph below. Only the very greasy “lubricants” (petrolatum, heavy mineral oil and glycerine) reduced friction, and only for 60-90 minutes. Highly et al (1977) produced similar results with viscous lubricants and Sivamani et al (2003B) found similar trends for increased skin friction with water and slightly/moderately greasy moisturizers. It should also be noted that the two surfaces used in these studies were a hard-surface probe against the skin. Comaish and Bottoms (1971) suggest this reduction of friction will be even more short-lived when the skin is in contact with a fabric (as opposed to the flat non-fabric testing probe used in the Nacht study).

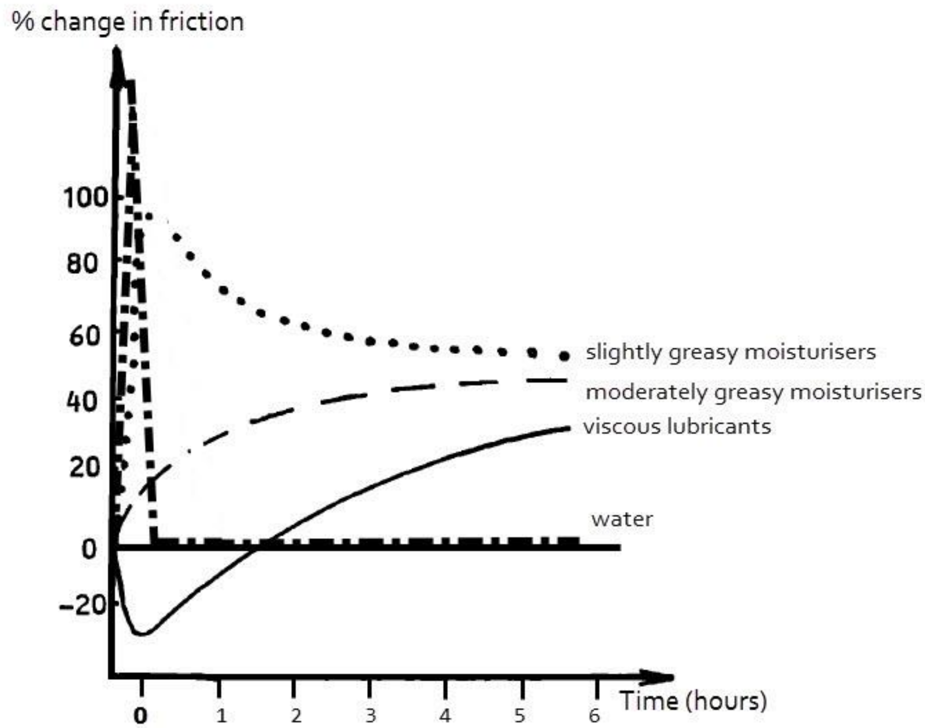


Figure 21: Change in friction after application of different moisturizing / lubricants to the skin (Nacht et al, 1981)

The increase in friction found by these researchers is what Richie (2010) alludes to when he states "Physicians, coaches and athletic trainers continue to advocate the use of petrolatum jelly and skin powders to prevent blisters while the scientific literature suggests these measures may actually increase the chance of blistering on the feet." To explain this fully, the potential limitations to lubricants use include:

1. **Initial lack of traction -** Lubricating large areas of the feet, particularly the weightbearing sole of the foot may not be a good idea. In preventing blisters, it is not the aim to reduce friction indiscriminately. A targeted approach is the ideal approach so that traction and functional efficiency are maintained.
2. **Later friction increase –** This won't be a problem with short duration exercise but for longer duration efforts, you would need to reapply the lubricant to maintain any benefit. If not, not only has your blister protection gone, you're actually at more risk of blistering.
3. **It weakens the skin -** Lubricants have an occlusive effect that traps moisture within the skin. By reducing transepidermal moisture loss, skin hydration is excessive and prolonged. In other words, the skin becomes water-logged. And water-logged skin is weaker and less able to resist trauma. It's a bit like how your skin goes when you're in the bath for too long.
4. **Attracting grit & messy -** The common lubricant Vaseline (petrolatum jelly) can be a poor choice, particularly on off-road surfaces as it has a tendency to attract grit. And its potential carcinogenic properties have become a concern in recent times as it is a product of petroleum. Viscous lubricants like Vaseline are messy too.

SUMMARY

A. Lubricants affect friction at the skin-sock interface.
B. Moisturisers increase friction.
C. Viscous lubricants initially reduce friction. As the lubricant absorbs and dissipates, friction increases.

4. TAPING

Sports tape applied to blister susceptible areas is a common prevention strategy. Leukoplast, Fixomul, KinesioTex Tape and RockTape are popular choices. And blister dressings like Compeed are also popular. These products are adhered to the skin.

By admission from athletes, sports medicine professionals and manufacturers themselves, taping provides protection from rubbing. Rubbing removes skin cells from the skin surface to progressively deeper and deeper layers causing abrasions. But this is not blister prevention - because you don't need rubbing to cause blisters (Comaish, 1973; Zhang and Mak, 1999; Carlson, 2006; Carlson, 2011). This describes *abrasion prevention*. So how does taping prevent blisters? Surprisingly, there is a lack of evidence (Knapik et al, 1995; Brennan, 2000; Richie, 2010). And a proposed mechanism of action has not attracted significant discussion in the literature either (other than is stops rubbing – which misses the crux of blister causation). Actually, rubbing will cause some shear, but not as much as when there is no rubbing (Comaish and Bottoms, 1971; Akers, 1985, Carlson, 2011).

So, tapes may help reduce blister formation, if the tape's surface provides lower friction than skin friction. Understanding this, Polliack and Scheinberg (2006) gathered a number of blister dressings and tested their friction properties (table below). The over-riding impression from the Polliack and Scheinberg's research is that most of these coefficient of friction values are very high, when compared to the values shown in the graphs from Carlson (2001) and Payette (2010) in Chapter 5.

DRESSING	MANUFACTURER	COF	THICKNESS (mm)
Bursatek bandage	Advanced Wound Systems, Newport, OR	0.57	6mm
Dr Scholl's Moleskin Plus	Schering-Plough Corp, Kenilworth, NJ	0.69	31mm
Moleskin	PPR Inc, Brooklyn, NY	0.94	26mm
Band-Aid	Johnson & Johnson, New Brunswick, NJ	1.01	22mm
Band-Aid Plastic	Johnson & Johnson	1.03	18mm
2nd Skin Blister Pads	Spenco Medical Corp, Waco, TX	1.04	35mm
New-Skin	Medtech, Jackson, WY	1.05	9mm
Nexcare Comfort	3M Health Care, St Paul, MN	1.08	35mm
Dr Scholl's Blister Treatment	Schering-Plough Corp	1.20	32mm
Blister Block (Compeed)	Johnson & Johnson	1.37	40mm
Tegaderm	3M Health Care	1.54	1.5mm

Figure 22: CoF measurements of blister dressings (using 237g normal applied load to end probe - plastic): Adapted from Polliack and Sheinberg (2006)

Unfortunately, there is no such coefficient of friction data for tape, neither from research nor their manufacturers. So, we don't know whether individual tapes reduce friction or not! Knapik et al (1995) confirms plain adhesive tape can be used to prevent rubbing (ie: abrasions) "and may be effective if it reduces the coefficient of friction (ie: if it is 'slick')." Of taping, Richie (2010) states "There are no published studies to show these measures actually work. Few things applied to the feet will stay intact for more than one hour of vigorous activity." highlighting the effect of perspiration and the extreme in-shoe conditions that are constant threats to adhesion.

An alternative mechanism of action – Although not described in the literature, it is plausible that tapes reduce shear at discrete locations due to the fact that they're adhered to the skin (Carlson, 2013: personal communication). Just as cushioning spreads the vertical load over a larger area to reduce peak pressure, because tape is adhered to the skin, does tape spread the 'pull' of the horizontal load over a larger area to reduce peak shear distortion per unit area of skin? In other words, by spreading the shear load, shear per unit area of skin will be less.

Taping technique – Whatever the mechanism of action, the success of taping relies on keeping the tape well-adhered to the skin. Much effort is put into perfecting both the choice of tape and the application technique. Yet there is little consensus on either.

John Vonhof (2012) is arguably one of the most accomplished practitioners of taping for the most extreme ultramarathon conditions. He favours the kinesiology tape called StrengthTape in wet conditions. Other advice from Vonhof to maximise adhesion include:

a) Compound Benzoin Tincture applied to the skin before taping in order to maximize adhesion.
b) Apply tape at least one hour before use (if not the night before) which allows the tape's adhesive time to bond with the skin.
c) Rub the tape for 20-30 seconds after applying it to the skin – it warms the adhesive to make it more tacky.
d) When using kinesiology tapes, lay the tape on the skin and if you have to stretch the tape around a heel or toe, only apply a slight stretch. The more stretch you apply, the more likely the tape is to come loose, especially in wet conditions.
e) It takes as long as it takes – a precision tape job can take more than 30 minutes. Practice makes perfect and an adequate application technique can take time.

Figure 23: Taping technique. Image from *http://www.fixingyourfeet.com/blog/2013/08/high-quality-feet-pre-taping)*

Anna Beethem for Oxfam Trailwalker in Melbourne uses Fixomul and explains her application technique in this video: http://youtu.be/dIHILzTQ8ek. And Trent Salkovich prefers Leukoplast and uses the following technique: http://youtu.be/hHxLjumvd0M.

SUMMARY

A. There has been very little research on how taping prevents blisters.
B. Tapes and dressings prevent abrasions.
C. Perspiration compromises the adhesion of tapes and dressings.

CHAPTER 7: BLISTER PREVENTION – YOUR ACTIVITY

Friction is a very necessary force that helps us move with speed and efficiency. And the bones within our feet must move back and forth with every step and in all directions as part of normal function. As such, shear is a normal and unavoidable consequence of movement.

> "The foot approaches the ground at a tangential angle (not a purely vertical angle) and then pushes off in a similar tangential direction. The foot [*bones*] must skid to a stop and then push into the ground to propel forward. The skidding will occur in both an anterior-posterior and medial-lateral direction, depending on the activity and demands of the sport" Richie (2010B).

Most blister prevention studies focus on the friction component of this equation. And quite rightly because there is a huge potential for reducing friction alone to prevent blisters. However, you can also expect some sort of blister prevention by minimising bone movement relative to the skin surface.

MODIFY YOUR FORM

Changing the way you walk and run (commonly referred to as form) can reduce the magnitude of shear distortions per step. Here's an example:

The underside of the heel is not a common blister site. Hikers covering steep downhill terrain are most susceptible to these debilitating blisters. You hit the ground with your heel. The heel bone slides forward relative to the stationary skin, which causes a lot of shear to the tissues under the heel bone. Compared to walking over a flat surface, there is a delay in the forefoot contacting the ground – so shear under the heel bone is prolonged. Not to mention the higher magnitude of shear; the braking forces are much higher due to the slope and forward/downhill momentum of your body weight.

Changing your form to a foot-flat strike, or even if you remain heel striking but your heel strikes closer to you, you can minimise these shear distortions. You'll achieve this by taking smaller steps and/or by bending your hip and knee more. Runners can do the same.

If this change in your form is enough to bring the shear distortions under your blister threshold, you'll avoid these nasty blisters.

MODIFY THE ACTIVITY

Tennis is a sport where blisters are very common and the shear distortions result from aggressive side-to-side movements, particularly under the ball of the foot and on the toes. Netball is another. Features of these court sports are sudden accelerations, decelerations and changes in direction. Have a look at this video: http://youtu.be/wDBV_iBiR4k. Tennis players, netballers and other court sport players sustain a lot of this side-to-side shear. The video barely does these sports justice but you can image the magnitude of these shear distortions when playing competitively!

Keeping this in mind from Knapik et al (1995): “The magnitude of frictional forces and the number of times that an object cycles across the skin determine the probability of blister development…”

If you’re just playing socially, you could ease up a bit, or sub off. If you’re a runner, you could forget about your times and just not push yourself as hard, or cut back on your distance. And for the example of our downhill hiker, taking a different route to minimise the slope could be an option. These modifications revolve around:

- Reducing the intensity
- Reducing the duration
- Reducing the frequency

In reality, these options may just not be practical – neither possible nor desired!

SUMMARY

A. Aspects of form and technique may contribute to blister-causing shear.
B. The duration, intensity and frequency of an activity can be altered to prevent blisters.
C. Alterations to form and activity are often impractical and undesirable.

CHAPTER 8: PROS & CONS

The following table represents a summary of the pros and cons of the blister prevention strategies discussed. The star-rating, with 3-stars being the best score, is based on the following criteria:

a) quick and easy to use
b) a lack of harmful effects
c) maintenance of normal function and efficiency
d) demonstrated preventative effect and research evidence

THE PROS & CONS OF BLISTER PREVENTION STRATEGIES			
	PROS	**CONS**	**STAR RATING**
SHOE-FIT & LACING	Your first and foremost blister prevention strategy	May not ensure blister protection	★★★
INSOLES	Proprietary insole can easily be replaced if necessary	More is not always better	★★
ORTHOTICS	Can be relevant to some blister locations. Often neglected.	Not relevant to all blisters	★★★
ENGO PATCHES	Extremely low COF Long-lasting (500kms) Unaffected by moisture Targeted friction management	Avoid water-logging Can't be used for blisters between toes	★★★
MOISTURE-WICKING SOCKS	You need socks anyway so why not choose socks with advanced moisture management properties	Absorptive capacity of sock can be exceeded	★★★
DOUBLE-SOCKS	Thin inner sock will not adversely affect shoe fit	Optimal combination will take trial and error Absorptive capacity of sock can be exceeded	★★
ADAPTION	Can be achieved in one week	Requires preparation – training in gear and on terrain before event	★★★
ANTI-PERSPIRANTS	Easy to apply	Usually ineffective or only short term effect Stronger preparations can cause skin irritation	★
POWDERS	Readily available	Messy Short term effect	★
ASTRINGENTS	Popular	No research exists Theoretically only has a short term effect	★
LUBRICANTS	Popular	Messy Friction reduction lasts for 60-90 mins, then friction increases above baseline	★
TAPING & DRESSINGS	Very popular Good abrasion strategy	Very little research May not reduce friction Time consuming Sweat compromises adhesion	★★
FORM ALTERATION	Can help if running form is at fault	Changing technique may have adverse effect elsewhere	★★
ACTIVITY MODIFICATION	Theoretically easy to institute	Rarely possible or acceptable	★

Figure 24: The pros and cons of blister prevention strategies

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