The Case for Friction Management

Here's an innovative idea to consider for preventing foot ulcerations.

BY PAUL SCHERER, DPM

Editor's Note: *This article originally appeared in the September 2012 issue of PM; we are reprinting it here because of its uniqueness in the podiatric literature and as a testament to the late Dr. Scherer's impressive legacy of accomplishments.*

We have all been working on an assumption that higher plantar foot pressures impose a higher risk for ulcers mainly because of Dr. Bolton's' work in 1983, which identified dynamic vertical foot pressures as a diagnostic and predictive aid. Later articles by Drs. Frykberg and Lavery as well as others reinforced this concept by calling the pressures "loads" and "vertical forces." It became apparent to the clinician that vertical forces caused plantar ulcers, a concept that continues today as an unsubstantiated but logical conclusion.

We as a profession got so comfortable with this concept—that vertical forces in neuropathic feet cause plantar ulcers—we never questioned what else could be contributing to these wounds. We, unfortunately, became distracted from other causes and directed 100% of our attention to "off loading" the potential ulcer area to reduce the vertical load.

Recently Armstrong and Lavery questioned how valid this concept was, that increased foot pressures were responsible for ulceration. Their research found that the increased pressures were not as specific in producing ulcers as we had thought. Since we had already accepted that pressures were the cause, which was very intuitive, we never really looked to see if ulcers really only occurred in areas of high peak pressures. They don't!

Ledoux in 2005 showed in his research that patients could ulcerate in areas of normal pressure and further may not ulcerate in areas of increased pressures. How could this be and what good is off-loading these areas if increased pressures are not the cause? Bolton's team in 1992 showed that ulcers appeared at high-pressure peaks only 38% of the time! Were we using the wrong tool to determine or predict ulcer location? Did we even want to look for another reason ulcers occurred in specific areas? Since we became so comfortable with our intuition that only high pressure created ulcers in insensate feet we didn't look further.

The reason we didn't look further was both our reluctance to go beyond our comfort zone as well as our technical limitation that we could only measure vertical force. Similarly, at the turn of the century, most illnesses were thought to be caused by bacteria because we could see the increase in their numbers in certain infections.

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We were mostly right but we did not consider the virus's influences, simply because we could not see them. Researchers in ulcer formation were stuck with using only vertical forces data and as a result, considerations for other forces, like shear or horizontal forces, were not made.

What Else Can Cause Skin Damage?

We were very comfortable, intellectually, to simplify the etiology of foot ulcers and only consider pressure. A 1983 paper by Pollard hypothesized that it may be shear, not pressure, that precipitates ulcer formation. We know from some elegant and straightforward experiments by Naylor way back in 1955 that both repetitive skin loading trauma as well as higher friction levels could produce blisters in normal skin. Sulzbeger in the 1960's corroborated these findings and confirmed friction as a

Continued on page 100

Friction *(from page 99)*

significant culprit in skin physiologic damage.

We should digress slightly here and define some terms. Simply put, friction is rubbing. To be a little more sophisticated, there are perpendicular loads we call pressure and there are parallel or horizontal loads we call friction. Naylor found that the higher the perpendicular load, combined with the higher the friction load, the quicker the damage to the skin. Even at the same perpendicular load but with a higher friction load, the quicker the blister is formed. Friction may be the missing link in producing the variable distribution we see in ulcer formation. Increased friction can make a small vertical load very destructive to skin.

Another thing that was interesting: Naylor and Sulzberger found that when they lowered the peak friction loads by applying talc or oil to the skin but keeping the pressure the same, it consistently took a longer time to produce skin damage. Naylor discovers that a 30% reduction in the COF (coefficient of friction) would triple the number of cycles before the skin would react to the trauma.

What Is Friction?

A very brief description of friction is necessary to fully understand how we can manipulate or manage this damaging force. Friction is actually the force that resists sliding. If we pull some object sitting on a surface with less force than its inertia, it doesn't move. If we pull some object with more force, we exceed what's called the limiting friction load (LFL) and it moves (Figure 2). Same-weight objects move easier on a surface than others with the same pull because their coefficient of friction (COF) is different. This can be represented by a number. Picture a block of 1 kg on a board and slowly lifting one end of the board. At 10 degrees the block does not move but at 45 degrees, the limiting friction load is exceeded and it slides downhill. This would represent a COF of 1.0. If it had slid at 30 degrees because we put the block in a cotton sock, this would be a COF of 0.50. In other words the easier an object (foot) moves across a surface (shoe, floor, orthotic, insole) the lower the COF.

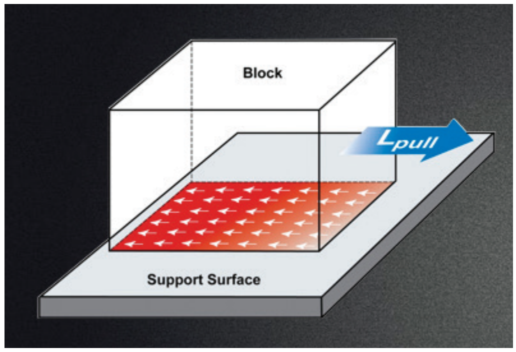

Figure 2

Here is the important part—the lower the COF, the less the rubbing, the less the horizontal load in a particular area of the skin. If you can't change the perpendicular load, as in pressure peaks, you may be able to change the parallel load and thus decrease the skin damage area in a very unique way. Maybe, just maybe, we can reduce both vertical load and parallel load with an orthotic device and prevent skin damage.

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What Can Be Done to Reduce Horizontal Load?

Let's talk about materials that have a lower COF than most. The bar graph in Figure 3 shows the different materials we use in shoes and orthoses. Typical foams and top covers are in the COF 0.5 to 0.6 ranges. A material called PTFE (polytetrafluoroethylene) has a COF of about 0.16. That is incredibly low for any material. Ironically we normally use the higher COF materials mainly because they are soft and we think they are better for the foot.

PTFE is a new material that is also used for vascular and nerve sutures as well as for artery grafts. It allows the suture material or blood components to move through the vessel with little friction, therefore limiting the trauma of the suture or blood flow (Figure 4).

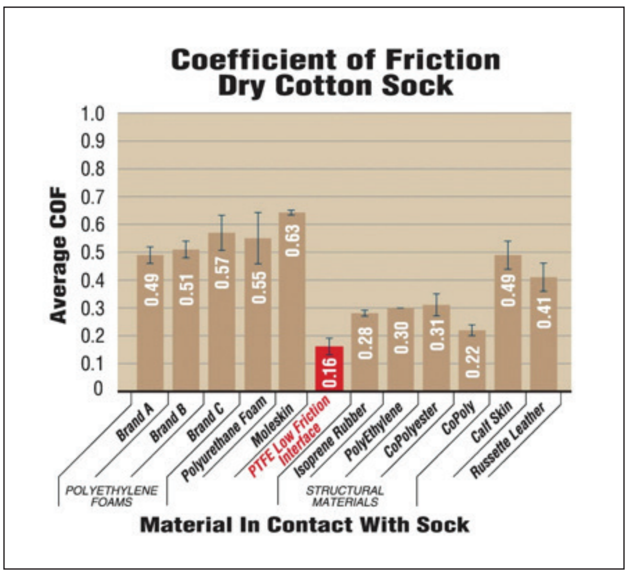

Figure 3

Environment also plays a role in COF. The majority of insole or orthotic material that we use not only has a higher COF but the COF gets greater with moisture (Figure 5). If we wet a cotton sock, EVA or plastazote (think sweat on the skin), we increase the COF and that increases the horizontal load, which increases the trauma. Interestingly if we wet a material like PTFE the COF does not increase.

Continued on page 102

Friction *(from page 100)*

We have to also consider that friction is not altogether categorically bad for feet. It is only bad in areas where inflamed skin or hot spots show that there is high peak friction as well as high vertical load, strong enough to damage the skin. In all other areas friction performs a valuable function by adding stability and control. Otherwise we would slip out of our shoes or off of our orthoses.

How Does Friction Contribute to Skin Damage, Blisters or Callus?

Let's talk about skin trauma and the origins of blisters and ulcers. Callus or skin inflammation usually precedes ulceration. These signs can be perceived as early warning signs but should really be more importantly considered increased horizontal load and the first signs of irreversible skin failure.

Any material, especially the skin, can fail, either because of:

- too much vertical load (pressure)
- or because of too much horizontal load (friction)
- or too many cycles (steps)
- or all of the above

Essentially the loads are introducing more energy than the skin tissue can tolerate or recover from. Our intervention, until now, only addressed the vertical load or the number of cycles.

M. Yavus, Ph.D. at the Cleveland Clinic eloquently exposed the complexity of skin response to trauma. We still don't know for sure if the callus response absolutely always precedes a blister and a blister precedes the ulcer physiologically, but it does seem that there is a ratio of shear force, vertical force and duration that plays an interconnected role of skin failure. If we reduce both the vertical force and the shear force but increase the cycles we may get the same skin damage result. Our attention must be directed to all three as much as possible.

A brief review of skin anatomy and physiology is now necessary. Hopefully we remember the outer layer is the epidermis, under that the granulosum, next the spinosum and deepest the basal layer (Figure 6). Epidermal cells are produced by the most inner layer, the basal. The transition from the birth of new skin cell to the flake off on the sock or in the shoe is just 28 days.

Figure 4: PTFE is now used in sutures to reduce friction of arteries and nerves and also used to create grafts that have limited friction to blood parts.

Sulzberger's' group performed biopsy of the skin during repetitive trauma and found that first micro tears appear in the spinosum. As the load repetitions continue the tears coalesce and a cleft is formed parallel to the surface with the corneum and granulosum layers on top or as a roof. The cleft fills with serous fluid and the roof is ultimately abraded away. A slower process causes dead cells to build up on the epidermis.

If the rate of trauma is low, say with multiple interruptions, the basal layer accelerates cellular generation resulting in epidermal thickening (callus). Interruptions in this process are usually caused by pain, which unfortunately does not occur in patients with a sensory deficit. The basal layer ultimately exhausts itself and cell production cannot keep up with cell destruction and the skin fails.

Healed plantar skin (after an ulcer) has even less mobility and is subject to even higher friction load.

Can We Prevent Plantar Ulcerations?

Now, given that we now know something about ulcer formation not necessarily occurring in high vertical load areas and the physiology of skin failure, can we rethink how we prevent ulcerations from occurring or reoccurring by considering the horizontal load?

Vertical forces can only be reduced by a weight loss program, softer shoes or by shorter steps, which unfortunately produce more cycles. They can also be redistributed by greater surface area contact such as in total contact casts or custom molded orthotics. The vertical force can also be attenuated for a short time by shock absorbing materials. Now we

Continued on page 104

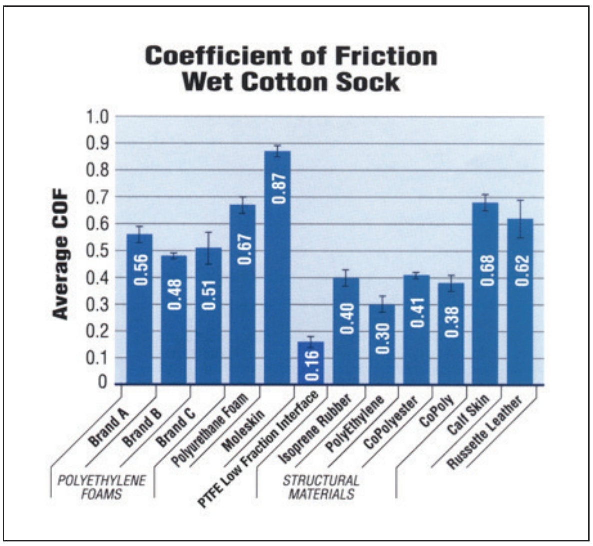

Figure 5

Friction *(from page 102)*

can reduce the horizontal load with PTFE, which reduces friction on the skin. Another term for this strategy is called "friction management."

Cushioning materials, like plastazote, absorb very little shear motion because they work by creating contours to hold an object in place—increasing, not decreasing the limiting friction load. To make things worse plantar skin has less mobility than dorsal skin and healed plantar skin (after an ulcer) has even less mobility and is subject to even higher friction load.

Lavery recently attempted to reduce horizontal load by adding PTFE to an orthosis in diabetics with decreased sensation in a NIH project. This simple blinded, randomized trial of 299 subjects consisted of two patient groups who had no significant differences in patient characteristics but were all sensory-deficient. One group received the PTFE forefoot devices, the other a similar device without PTFE on the forefoot. The group with the shear-reducing PTFE devices had significantly fewer ulcers after 18 months. There were 10 ulcers in the control group, and only 3 in the PTFE group, representing a 70% reduction in ulcer morbidity.

Figure 6: An extra-depth diabetic shoe with an insole fitted with a PTFE patch to reduce the coefficient of friction (COF) under the second, third, and fourth metatarsal heads, a common site of foot ulcerations in insensate patients. *Photo courtesy of Strategic Medical Friction Management, Inc.*

Other Factors

Repetitive loading (steps) is the last factor in skin failure that ultimately produces ulceration. We know from several studies that reducing stride length reduces vertical forces on the forefoot but it takes more steps to cover the same distance. We know that full contact casts reduce pressure peaks and we know that cast boots reduce forefoot pressures and limit walking, therefore reducing repetitive loads.

PTFE appears to be a logical solution to reducing horizontal loads that produce shear and ultimately plantar skin failure.

These modalities are directed and are more successful at an active ulceration site than ulcer prevention or re-occurrence and are usually not practical in the non-ulcerated patient. The shear-reducing qualities of PTFE cannot reduce repetitive load but as Naylor found, there is an inverse relationship between shear and repetitive load. The less shear, the more cycles were necessary to produce skin failure, or (this is important) the further a patient can walk before building up too much damaging skin forces.

It's not like we were barking up the wrong tree when we used off loading to prevent ulcers, we were just incomplete with our thinking. We must still address vertical forces by using impact-reducing materials and create custom shapes that spread out the pressure over a larger contact area. We should now also reduce the horizontal loads that, when combined with the vertical forces, produce skin failure, especially in previously damaged skin.

PTFE appears to be a logical solution to reducing horizontal loads that produce shear and ultimately plantar skin failure. The previous research of Naylor in the fifties, which seems to have been temporarily forgotten, confirms that skin shear is directly related to skin failure. Recent research seems to demonstrate that shear-reducing materials prevent skin failure. Future research will probably confirm the value of PTFE on a diabetic orthosis (Figure 6). **PM**

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For over 40 years **Dr. Scherer** made significant contributions to the podiatric community, most notably in podiatric education. In addition to teaching foot and ankle biomechanics in the classroom, he lectured nationally and internationally, authored numerous scientific articles and the popular text *Recent Advances in Orthotic Therapy*. Dr. Scherer held several academic positions at the California College of Podiatric Medicine and was Clinical Professor at the College of Podiatric Medicine, Western University of Health Sciences. In 1989, Dr. Scherer co-founded ProLab Orthotics. He passed away unexpectedly in 2018, leaving a legacy of accomplishments and high standards of education for future generations of podiatrists.