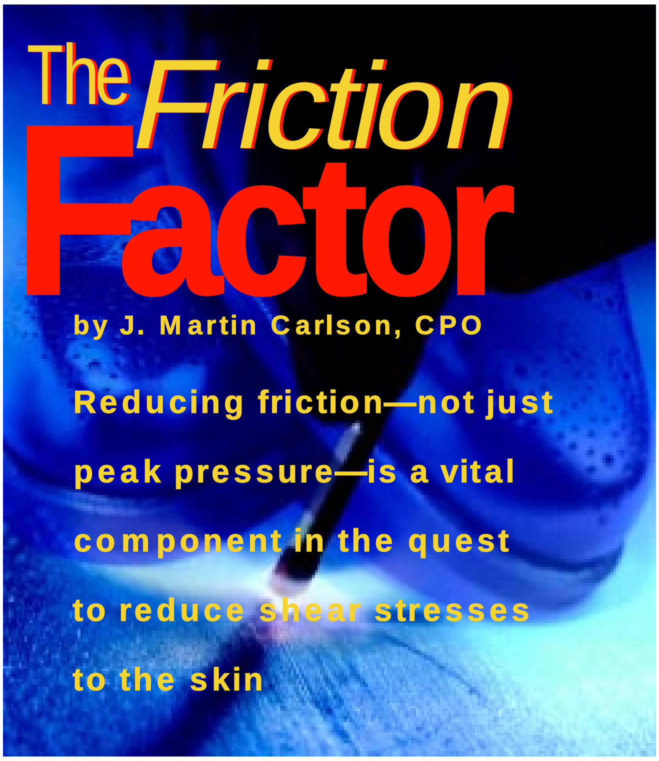

The Friction Factor

by J. Martin Carlson, CPO

Reducing friction—not just peak pressure—is a vital component in the quest to reduce shear stresses to the skin

It seems natural to associate blisters, ulcers, calluses, and reddened skin with excessive pressure. This cause-effect reasoning is widely taught. It appeals intuitively and is reinforced every time we successfully intervene by padding and/ or contouring to reduce peak pressure on the troubled spot.

Researchers have happily focused on investigating and reporting every measurable aspect of the peak pressure vs foot health relationship.

This focus on peak pressure has ignored knowledge about repetitive-loading skin trauma. Repetitive loading is what happens to the various areas of our feet as we walk, march, or run. The angle of incidence of such loadings on our skin varies from area to area, and from one part of the gait cycle to the next.

For any given area at any specific moment, the loading combines a perpendicular (to the skin surface) component and a friction (parallel to the skin surface) component. The perpendicular component is measured by pressure sensors/maps. The friction component is also referred to as a shear component because of the type of stress it imparts on the skin. The friction component is much harder to measure and we do not yet have friction distribution sensing/mapping instrumentation.

New Look at Old Knowledge

The long-ignored knowledge about repetitive-loading skin trauma was discovered and first published in the 1950s and 1960s. Straightforward experiments by P.F.D. Naylor in the early 1950’s[1,2] demonstrated that the perpendicular load component *by itself* is relatively harmless. Those experiments established that the magnitude of repeated pressure peaks are significant because of how they enable and relate to peak friction loads.

Friction loads will not occur without forceful contact. In fact, friction loads can rise only to a certain maximum value directly dependent on the magnitude of the perpendicular loading. To be precise, friction loads can rise to a maximum value equal to the perpendicular (pressure) load multiplied by the coefficient of friction (COF). At that point, a bit of slipping will occur between skin and sock, or between sock and insole, depending on which interface has the lowest COF.

Microdissection work done by Sulzberger, Cortese, Fishman, and Wiley[3] in the 1960s established that repetitive friction load damage does not begin on the outermost skin surface layer. The friction forces create shear stresses within the skin. If those stresses exceed a certain magnitude, micro tears begin to form within the third layer (stratum spinosum) of the epidermis. With each load repetition, more micro tears appear and existing ones grow.

How much of that skin damage occurs with each load cycle depends directly on the peak friction/shear load magnitude. If the loading repetitions persist long enough, those little tears in the stratum spinosum coalesce to form a cleft within the spinosum parallel to the skin surface. We typically call these water blisters because the cleft quickly bulges with serous fluid.

Repetitive friction loading has another consequence—it stimulates the stratum basal, the deepest epidermal layer, to increase its production of new epidermal cells. The result is callus formation. The process of cell generation and the migration of cells through the spinosum, granulosum, and corneum strata to exfoliation takes about 28 days.

Once exuberant callus production has been established, it is not clear exactly what is required to bring basal cell generation back to a normal level. Conversations with John Bowker, DPM, and Nancy Elftman, both experienced in diabetic foot care, indicate that an established callus persists for at least 2 months beyond effective removal of the friction stimulus. Callus production on the periphery of a wound will remain active indefinitely. Obviously, callus management requires patience, but those who care for diabetic feet know the importance of callus control.

It is no surprise that research proves peak contact pressure is important. We routinely approach an assortment of problems by reducing contact pressure in the specific area showing redness, blistering, or ulceration.

However, we have largely failed to realize that the COF is equally important. If you took physics, you may remember the equation: friction/shear load is less than or equal to perpendicular load multiplied by COF. The equation suggests that localized reduction of COF (friction management) in problem areas will be as effective as reducing peak pressures in those areas (pressure management).

Although we have largely (not totally) ignored the friction factor, we do have some products and practices that reduce the COF: 1) Keeping the feet and socks drier by any method reduces the COF of skin-sock and sock-insole interfaces in addition to the benefits to skin toughness; 2) Double socks, especially when the inner sock is a thin nylon (or similar) sheath, creates a sock-sock interface with a lower COF than skin-sock and sock- insole interfaces (when there are multiple parallel interfaces like that, the one with the lowest COF controls the friction level); 3) Some special sock brands combine low COF fiber for all or a portion of the sock construction.

We seem to have happened on these practices and products with little awareness of the background science regarding friction and shear. For example, have you ever known insole material manufacturers to provide COF information relative to their product? How many sock manufacturers have included COF information in their literature? I know of none.

Determining the COF for a pair of dry surface materials does not require expensive equipment. My colleagues and I measured the COF for a typical cotton sock material loaded against a variety of materials commonly used for insoles and orthoses. A low friction interface patch material marketed for friction management had the lowest average COF.

Since the COF usually increases when some moisture is present, we attempted our measurements under both dry and wet conditions. Our wet data cannot be considered as valid as our dry data because the COF for some materials is sensitive to the amount of moisture. Moreover, moisture above a certain level will create a hydraulic lubrication condition. We know of no testing standard defining in-shoe moisture conditions. The cotton-polymerized tetraflouroethylene (PTFE) film interface showed no sensitivity to moisture.

Why friction management technology and practices have not been developed more fully at this point almost 50 years after Naylor's research is an interesting question. I think the reason is that friction and shear phenomena are much less intuitive than, for instance, pressure, compression, and tension.

Exactly how friction functions involves several subtleties. Also, we have images, experiences, and misconceptions regarding such things as slipping, sliding, skidding, rubbing, and abrasions.

One typical mistake is to associate friction exclusively with sliding. Friction is the force which resists an effort to slide one surface across another. If we make a small effort (horizontal push) to slide a 100-lb box across the floor and it does not budge, is friction the cause? Of course, it exactly matched our small force effort and prevented movement. If we push with greater force, the friction will grow.

Depending on the materials in the bottom of the box and the surface of the floor, that interface will have a certain COF. When our horizontal force against the box reaches a certain magnitude (weight of the box multiplied by COF), the box will suddenly begin to slide along the floor. Let us assume, for illustration, that the cardboard-floor interface in this case has a COF of 0.6. That would mean that the 100-lb box would begin to slide when our horizontal push reached 60 pounds.

The friction force resisting sliding is equally a shear force acting upon the surface of the floor. We begin now to see some parallels with skin loading. If we waxed the floor, we might reduce the box-floor COF to 0.3. That would mean that as we pushed the box back and forth, the shear loading against the floor and, likewise, the shear loading against the bottom of the box, would repeatedly rise, never peaking higher than 30 lbs (instead of 60 lbs).

Confounding Subtleties

We have all seen the abrasive skin injuries caused by a forceful slide or rub. That may give the impression that preventing slipping or sliding should be our goal.

Here is where the confounding subtleties arise. If we put on a pair of too-large shoes and play a game of racquetball or basketball, our feet will slip and slide around in those shoes rapidly causing pain and blisters. However, we could slide back and forth for an hour in our stocking feet across a polished floor without discomfort or trauma. It is not the sliding any more than it is the pressure. It is the *magnitude* of the associated friction loads that do the damage.

In those two examples, the trauma accumulation rate is different because the COF is different. Our weight is the same and peak pressures are certainly not lower in our stocking feet on a hard floor. The typical COF operating between foot, cotton sock, and athletic insole is in the range of 0.5 to 0.9. The COF between a dry cotton sock and a polished floor is in the neighborhood of 0.2. Keep in mind the physics equation that says peak friction forces can be no higher than peak contact load multiplied by the COF.

These examples illustrate how dramatically helpful COF reduction can be to reduce friction/shear loading. Practically speaking, a low friction interface patch under a metatarsal head will free the skin and sock to glide back and forth a little with each small amount of bone movement in the shoe.

Friction is Not All Bad

Now that we have thoroughly indicted friction, we must confuse the issue by immediately noting that not all friction inside shoes is bad. Friction, especially in the plantar area, helps stabilize the shoe on the foot. That means we do not need such a tight fitting shoe fore and aft, medial and lateral.

If we eliminated friction over the entire foot bed, a comfortable fit for the ends of the toes, the back of the heel, and the sides of our feet would be almost impossible to achieve for an athlete. Instead, we should reduce in-shoe friction to tolerable, subtrauma levels in those specific locations where the skin shows injury or in high risk areas—that is the essence of friction management. It is an exact parallel with how we manage pressure; we do not try to eliminate pressure, just reduce it to a subtrauma level.

Case Study

Figure 2A shows the foot of a 41-year-old, 6-ft, 8-in, 300-lb man with diabetes mellitus, and a charcot ankle. The man had earlier rejected a walker and was using a metal and leather ankle-foot-orthosis (AFO) with an extra-depth shoe. Rubbing against the lateral aspect of the shoe was causing the ulcer shown in figure 2A.

Figure 2A: New ulcer (photo taken July 10, 2001) on a man with diabetes mellitis.

He refused to discontinue wearing the AFO and shoe and refused to curtail his walking. He took the photo of his own foot and then installed a low friction interface patch in that area of his shoe. There was no other intervention. Figure 2B shows the healing ulcer 6 weeks later.

In the real world, the amount of appropriate friction reduction depends, in part, on the patient's activity level. A relatively inactive diabetic with peripheral neuropathy and/or vascular problems may be best served by maximum friction reduction over a large part of the in-shoe surface. Low friction interface patches in the shoes of an athlete should be relatively small.

Figure 2B: Photo of the healing ulcer (taken on August 20, 2001).

Therapeutic or preventive reduction of the COF in certain locations while leaving the COF in other locations unchanged is quite a new concept. Until recently, we had no clinical tools designed for that purpose.

Much credit for bringing friction and shear back into focus should go to Joan Sanders, PhD, a biomechanics researcher at the University of Washington, Seattle. Sanders, Goldstein, and Leotta[4] published a thorough recap of the findings of Naylor, Sulzberger, Akers[5], and many others. Some of the work of Sanders and her associates[6-9], relates to measurement of shear loads between the skin of a residual limb and the prosthetic socket wall in selected, small areas. Unfortunately, such instrumentation is complex and bulky just to get a single discrete shear load value. We have not yet discovered ways to measure and map shear load variations across an area like we can measure and map pressure variations with a thin mat.

Shear load distribution maps are going to someday be interesting, but a thin mat that gives us friction/shear load distribution over the plantar surface is far in the future. However, addressing friction should not wait for those plantar shear distribution maps. The skin is the practitioner's map.

If the skin of the foot is persistently red, blistered, or ulcerated, it is not tolerating the peak friction/shear loads in that location. We can respond to that clear message by reducing peak pressure, reducing the operative COF, or by doing both.

Field trials of the friction management concept have been positive. Friction management is normally used in conjunction with pressure management techniques, so benefit cannot be objectively assigned or apportioned. However, unusual circumstances have sometimes caused friction management to be the single intervention.

The most graphic trial outcomes were cases where friction management solved chronic problems associated with skin grafts and adhered scarring. The skin surface in such areas has virtually no mobility (high shear modulus), so it is vulnerable to friction/shear damage.

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References

1. Naylor PFD. Experimental friction blisters. *British Journal of Dermatology.* 1955;67:327-42.
2. Naylor PFD. The skin surface and friction. *British Journal of Dermatology.* 1955;67:239-248.
3. Sulzberger MB, Cortese TA, Fishman L, Wiley HS. Studies on blisters produced by friction. *Journal of Investigative Dermatology*. 1966;47:456-65.
4. Sanders JE, Goldstein BS, Leotta DF. Skin response to mechanical stress: adaptation rather than breakdown – a review of the literature. *Journal of Rehabilitation Research and Development*. 1955;32:214-226.
5. Akers WA, Sulzberger MB. The friction blister. *Military Medicine.* 1972;137:1-7.
6. Sanders JE, Daly CH, Burgess EM. Clinical measurement of normal and shear stresses on a trans-tibial stump: characteristics of waveform shapes during walking. *Prosthetics and Orthotics International.* 1993;17:38-48.
7. Sanders JE, Lam D, Dralle A, Okumura R. Interface pressures and shear stresses at 13 socket sites on two persons with transtibial amputation. *Journal of Rehabilitation Research and Development.* 1997;34:19-43.
8. Sanders JE, Daly CH, Burgess EM. Interface shear stresses. *Journal of Rehabilitation Research and Development.* 1992;29:1-8.
9. Sanders JE, Daly CH. Normal and shear stresses on a residual limb in a prosthetic socket during ambulation. *Journal of Rehabilitation Research and Development.* 1993;30:191-204.