Highlights from the International Forum on Deep Tissue Injury Evolution: A Research-based Scientific Collaborative

After 2 years of research and months of planning, the International Forum on Deep Tissue Injury Evolution: A Research-based Scientific Collaborative met at host site Staten Island University Hospital (SIUH), Staten Island, NY on October 15, 2013. The event was coordinated by Karen J. Farid, DNP, CWON/CNS, and moderated by Dr. Farid and Amit Gefen, PhD. More than seven researchers and a panel of five representatives from the New York State Department of Health (NYS DOH) and the Staten Island nursing community attended (see Table 1). The overarching intent of the Forum was to collate the animal, experimental, forensic, and nursing research with human studies and move toward one large body of evidence to increase current understanding of pressure-related deep tissue injury (DTI). The collaborative Forum centered on five specific goals:

1) To validate the concept that DTI — ie, a demarcated skin lesion that has an unrelenting prognosis of a necrotic eschar which, when debrided, has an end result of a Stage III or Stage IV ulceration — is consistent in development over time since death of the tissue to the time when it presents visibly on the skin;

2) To differentiate between the presentation of outside-in tissue injury, also known as crushing or ligature (forensic) injury to the skin, and true shear DTI that originates in the skeletal muscle at the level of the bone;

3) To demonstrate ways in which these two types of local injuries to the skin and deep tissue reflect forensic findings in decedents regarding features of dead tissue decay;

4) To align and compare features of deep tissue myocutaneous injuries with other local tissue death— eg, myocutaneous flap failure, frostbite, and burns;

5) To bridge the gap between DTI research and practice in the community.

To achieve these goals, participants presented research that addressed the relevance to and implications of their study to enhancing understanding and treatment of DTI.

Temperature and Pressure in Pressure Ulcer Formation

Iaizzo discussed his focal cooling study, one of a series of studies performed on healthy (ie, capable of rapid healing), 30-kg to 40-kg swine. Twelve (12) discs, 51 mm in diameter and 10 mm thick, randomized in terms of temperatures and pressures, were applied to each animal and heated to between 25˚ C and 53˚ C. Each disc was weighted with pressures ranging from 10 to 50 mm Hg and from 100 to 150 mm Hg for varying lengths of time. Perpendicular disc placement minimized shearing. Serial histological assessments at various depths of tissue (through muscle and down to the bone) were performed to determine and verify the literature that the optimum time for damage assessments would be ~7 days. Subsequently, serial biopsies of all the sites were performed at 7 days and healing processes described for up to 1 month.

Greater epidermal necrotic damage occurred at higher temperatures (eg, 50˚ C, while applying 10 mm Hg for 5 hours) with some spread into the dermal tissues; whereas, if 100 mm Hg of pressure was applied for 5 hours at 35˚ C, no major damage was noted to the epidermal or dermal layers and little in the subcutaneous fat. However, severe necrotic development occurred within the muscle lying below. In contrast, applying pressure of any weight for 5 hours at 45˚ induced a broad spectrum of damage to all layers of tissue. Cooling these pressure application sites minimized lesions: when 100 mm Hg of pressure was applied for up to 10 hours, then discs were cooled to 25˚ C, damage in all tissue layers was minimized.

Even at what is considered normal occurrence of pressure (50 mm Hg at 35˚ C for 5 hours), necrotic changes occurred in muscle primarily versus other tissue layers. Some regions were damaged well beyond 7 cm of transection and beyond what was apparent on visual inspection. This also occurred at even lower application pressures of 50 mm Hg. Thus, underlying muscle is at the highest risk for ischemic injury or damage.

Application of pressure involving near-normal body temperatures showed most lesions and damage came from the inside outward, with progressive changes from the muscle as it progressed to the subcutaneous layers into the dermal layers. However, as the temperature applications above the normal body temperature were increased at the same pressures for the same durations, damage was noted through the epidermal layers all the way into the deep muscle layers.

From these collected results, various computational models were created from which predictive assessments and further extrapolations could be generated as to this matrix of temperature/pressure ranges. From a clinical point of view, this study represented the best-case scenario — ie, ideal temperatures to resolve these injuries and temperatures in the tissue layers that were near the core temperature (on the trunk) versus what might be in the lower extremity.
Summary statement/clinical implications: Temperature can contribute to DTI development on areas with compromised blood flow from pressure. In practice, using cooling modalities locally to high-risk tissues can preserve the tissue integrity. Cooling in addition to pressure-relief measures may prevent pressure ulcers.

Falx Lunatica and Myocutaneous Flap Ischemia

Harder et al.² addressed the concept that falx lunatica (a reference to its crescent-like half-moon shape) is part of the zone of demarcation process (see Figures 1 and 2) but not interchangeable with the demarcation process as a whole. The area of demarcation of a critically perfused flap is located between vital tissues proximally and respective nonperfused necrotic tissues distally. In analogy to ischemic strokes or burns, this zone of transition appears in fasciocutaneous and myocutaneous flaps and is unpredictable. If left untreated, the zone of demarcation will extend toward the proximal zone of the flap necrosis and eventually die; if provided timely, adequate treatment, it may be rescued.

Studies³–⁵ have shown a relationship between frostbite and ischemia. Temperatures, whether cold or hot, can lead to tissue necrosis; the zone of demarcation develops similarly in each of these tissue injuries, independent of the initial mechanism of harm. Burns and freeze injuries — according to the temperature and the contact time administered to the skin — will initially induce tissue injury that can progress due to direct thermal injury and persistent ischemia. Clinical experience and animal studies have shown necrosis in frostbite demarcates in a much slower
and unpredictable timeframe compared to burn injuries or deep tissue ischemia-induced necrosis (predictable in ~7 days), a fact of clinical relevance because debridement — if needed — has to be scheduled differently.6

Discoloration. DTI is manifested by the sudden appearance of a bluish-purple discoloration, believed to be a combination of oxygen consumption and stagnant blood in disrupted microvessels. On the one hand, the critically perfused tissue requiring oxygen tries to extract every possible molecule of oxygen to prevent anaerobic metabolism and acidosis.
On the other hand, injury to the tissue leads to disruption of the microvessels and erythrocytes, resulting in dermal bleeding. These byproducts turn the tissue increasingly purple.7

In terms of myocutaneous flap tissue damage, the more acute the ischemic injury, the quicker the tissue will die (ie, necrosis will appear, particularly in tissues that have short ischemic time —eg, muscle compared to skin). If tissue does not have time to adapt to a critical condition such as an ischemic situation, cell apoptosis will occur more quickly and the necrosis will be more extensive. In addition, the tissue that stiffens due to edema formation increases in consistency and volume. If pressure is applied over existing ischemia, the necrosis will increase at a faster rate.6

Summary statement/clinical implication: Understanding the development of the falx lunatica in acute tissue death from ischemia incentivizes the clinician to utilize every opportunity to “optimize” fluids, transfusions, oxygen delivery, and management of sepsis to keep pressure ulcer development to a minimum in order to salvage as much of what is salvageable. In addition, assessment of pressure ulcers is enhanced by this information by enabling the clinician to determine when the pressure ulcer tissue death actually occurred — ie, counting back 7 days from the first appearance of the demarcated DTI. Staff doing skin assessments should be encouraged to document pressure ulcers with photographs, especially those with intact skin (early manifestations). The medical record is not just a record of the patients’ historical health events; it also can provide the clinicians with knowledge and a historical perspective and appreciation of disease presentations.

Lower Extremity Flap Failures

Culliford et al’s8 15-year retrospective study (N = 500+) examined the timing of interventions regarding lower extremity flap failures. Some flaps failed immediately after surgery (primary flap failure) and others had started to heal and then failed. Flap success was entirely due to the integrity of the microvascular circulation and not related to pressure on the effective limb. Typically, the free flap on the lower extremity must heal over tibial fixation screws, and the injured extremity is elevated and held off a bed, hanging from a trapeze...
or elevated on pillows; pressure is not a contributing etiologic force in success or failure. Other factors related to flap success are the skill of the (micro)surgeon and the timing of flap failure. The failure rate is highest in the subacute phase. In Culliford et al’s study, if the lower extremity wound was covered with a free flap within the first 72 hours to 4 days, the success rate was much higher than if the flap was created in the following 10 to 14 days.

Similarities can be observed between tissue death from pressure and the partial or complete death of a myocutaneous flap. Pressure-induced tissue death has a strong tissue ischemia component, resulting in a DTI, ultimately related to an ischemic component that also demarcates visibly along a line on the skin that defines the border between the viable and dead tissue. When axial flaps, which are primarily perfused by one solid blood vessel, become ischemic at the distal end, they have an intermediate zone that could possibly be saved if the right approach is known and instituted. Recent plastic surgery literature discusses what is referred to as angiosome theory. Angiosomes are subset units of vascularity, starting with a main artery and several “zones” as the arteries/arterioles divide into smaller and smaller vessels. Beyond a certain number of zones, 15% cannot survive, because the area from the main artery at the beginning of the angiosome unit to the smallest divide (the classic design) is too big. The angiosomes included in the flap will not support the final 10 zones/arteriolar divisions (15%).

The New York State Panel of Pressure Ulcer Experts defined skin failure as a rapid development of multiple pressure-related intact discolored areas of skin both blanchable and nonblanchable appearing within minutes; hyperemia noted in the process of patient repositioning and/or persistent hyperemia or Stage 1 lasting hours or days; and DTIs. Using the Braden Scale for pressure ulcer risk, skin failure cut-off was 15 or below, the 3-month average Braden Score for the study facility’s critical care areas. The risk factors identified that occurred before or simultaneously with the skin failure were 1) hypotension and/or on vasoactive drugs, with or without generalized edema, 2) fever, 3) coagulopathy – bleeding or clotting, 4) unintentional weight loss >10 lb in 1 month and/or NPO >7 days, 5) respiratory or metabolic acidosis. Culliford et al’s study also found these conditions frequently accompany lower extremity flap failure, with the exception of acidosis, which did not contribute to skin failure as much hypotension and fever. The top three clinical reasons for failure in microsurgery are venous thrombosis, arterial thrombosis, and infection.

Summary statement/clinical implications: Myocutaneous sections of tissue, whether DTI or myocutaneous flaps, have similar problems with ischemia and shearing — eg, flaps over fixating screws and plates exhibit similar surface (skin changes and discoloration) and physiological changes from ischemia with similar negative outcomes (infection, eschars requiring debridement resulting in full-thickness wounds).

Recognizing these similarities, the clinician can predict DTI outcomes, understanding the wound is not “getting worse” or “looking awful” but following the pattern of dead tissue decay as it changes appearance from purple to black to wet grayish-yellow slough.

Ultrasound as a Diagnostic Tool

For the Forum, Scheiner provided ultrasound (US) slides of persons participating in a DTI study (see Figures 3 through 7). At the time of admission in the emergency department, patients who consented to the study had US of bony prominences where no evidence of tissue injury was visible at the time of scanning. The participants were followed-up on day 3 or 4 and then again on day 7. According to preliminary observations, DTIs seen on US appear on the skin 6 to 7 days after admission.

Every admitted patient recruited via the emergency department in Scheiner’s facility is provided radiology scan, performed under the supervision of a licensed US technician. The scan includes the sacrum, upper and lower buttocks, both hips, both heels, both lateral ankles, and both lateral foot areas to ascertain graphic base deep tissue abnormalities — ie, abnormality arising from deep tissue and extending up superficially, not the other way around. On sonography, subcutaneous fat is echogenic; it reflects sound waves. Therefore, it forms a good intrinsic sonographic image of soft tissues that contrast with other heavy tissues (fat and muscle). Fascia is very echogenic and shows up as smooth white horizontal lines (normal). Bone does not reflect at all; it is echocoic. The first visible layer starting at the bottom is muscle. A DTI arising out of the muscle will break through the fascia, appearing as an interruption in the white line (see pink lines on figures 3 through 7, indicating DTI lesions). Scheiner and Bajaj determined that once DTI is identified on US, the tissue is permanently damaged/dead.

Moving forward, to determine whether injury can be noted sooner, additional elastography sonograms will be performed on study patients. Elastography recognizes and records differences in the “stiffness” of tissues or hemorrhages within the tissues. This technique is already being used to detect tumors, especially in the breast and liver; theoretically, it should be able to detect areas of reversible ischemia.

Moghimi et al describe pressure lesions, specifically DTIs, experimentally created on the hipbones of guinea pigs. The lesions can be followed on US, arising at the level of the bone and moving upward. At the same time, US had detected a smooth, white fascial line below the skin that appeared after the injury and remained intact until the day 7 when the DTI broke through the structure. The authors theorize this interruption of the fascia signifies the devascularization of the subcutaneous layer and the skin that is occurring on day 7; on day 8, the white linear structure (presumably representing the edematous collagen fascial interface between the subcutaneous tissues and the dermis)
is re-established through revascularization. Although the Moghimi et al\textsuperscript{28} study does not record visible skin changes, the break in the white, hyperechoic (highly reflective) linear structure most likely marks the arrival and visible appearance of the DTI on the skin (day 7). The appearance of the DTI is sudden, not gradual — ie, a 1-day window.

**Summary statement/clinical implications:** The addition of highly advanced US technology to the clinical assessment of DTI has expanded the knowledge base to include accurate visual evidence of the DTI dimensions and progression/resolution that clinicians heretofore have only suspected. This tool has not only revealed how DTI tracks to the surface, but it also has enabled clinicians to track which lesions progress and which lesions resolve before reaching the skin.

**“Time Since Death” Forensics**

Moghimi et al\textsuperscript{28} US study supports the original timeline for “time since death” of DTIs that Farid originally proposed in her forensic publication\textsuperscript{29} and in her thesis using skin temperatures to predict DTI.\textsuperscript{30} In these endeavors, Farid et al\textsuperscript{29,30} studied the differential between pressure-related, blanching and nonblanching, intact discolored areas of skin (PRIDAS) and the surrounding adjacent skin. Farid’s hypothesis, supported by the findings, was that PRIDAS that were cooler than the surrounding area would deteriorate to DTI. Specificity was extremely high: 100% of the warm PRIDAS when combined with positive blanching did not deteriorate to DTI, and 20% of the “cool” blanching PRIDAS went on to DTI, also reflecting the behavior of lividity seen in decedents that becomes fixed (nonblanching) within about 24 hours after death (this phenomenon, seen in DTI development, is illustrated in Figure 8a-c). This study was based on the forensic principle that a dead body loses temperature until ambient temperature is reached. Farid’s study\textsuperscript{29} also represents a school of forensic thought known as “time since death.” The PRIDAS sites were followed for 1 week; Farid et al discovered the DTI would appear between days 6 and 7. The older PRIDAS were most likely the lesions that deteriorated to DTI on day 6.

Another possibility for purple discoloration involves the denaturing of the heme molecule. Bass and Jefferson\textsuperscript{31} wrote that on day 7, a decedent left at room temperature displayed an abdomen bloated with intestinal gases generated by the overgrowth of intestinal bacteria, and the superficial veins under the abdominal skin became enlarged, rope-like, and purple. They speculated this was the reaction of the blood becoming putrefied by the invasion of the intestinal bacteria. This also might be the mechanism of the DTI when it breaks through the collagen layer beneath the skin (Moghimi et al\textsuperscript{28}) and with “outside in” pressure (ie, ligature marks) in forensic pathology. The purple imprint of the offending object appears around day 2 (see Figure 9), logical in light of breaks (ie, points of entry) in the damaged skin.

**Summary statement/clinical implications:** Forensic physical science school of thought on “time since death” can provide important information concerning the behavior of dead tissue in its early stages of decay. This process has been appreciated both before and after the appearance of DTI and reveals commonalities in both timing and discoloration comparable to decaying tissue on decedents at room temperature, chronicled by forensic scientists.

**Friction/Shear**

In a real world scenario, the effects of shearing on the outer competence of the skin can never be separated from the deformation and compression...
of the deep tissues at the level of the bone. A study by Linder-Ganz et al using computer engineering modeling that can separate out the shearing loads and the muscular vascular collapse indicates the difference is theoretical. In reality, the reaction cannot be controlled. As soon as pressure is exerted, a combination of friction, compression, and shearing occurs, as shown by Iaizzo’s swine model.

Summary statement/clinical implications: The negative impact of moisture (increases friction), such as accompanies incontinence and causes the skin to lose elasticity and edema that stretches the skin to paper thinness, not only elevate the potential for tearing at the surface, as well as subsequent deep pressure.

Additional Concerns Addressed by the Forum

Health literacy. The World Health Organization has identified health literacy as a top world health issue, stating that improving people’s access to health information in a capacity to use it effectively is critical to empowerment. Thus, clinicians should provide face-to-face basic physiologic explanations to enable patients to identify directly with what’s happening within their own bodies. The clinician can describe to the patient the cause of their lesions and how to heal them by removing the cause and prevent new lesions from forming.

Positioning during surgery. Pressure is dependent on positioning during surgery; post-op patients often develop DTIs on post-op day 2 or 3 during rounds. To prevent DTI from occurring during surgery, there must be pressure relief, but ensuring pressure relief during surgery is challenging because the patient is asleep and immobile. A great deal depends on maintaining a steady systolic pressure and planning the procedure so the patient is in and out in the shortest time and ambulated as quickly as possible. In addition, some clinicians use pillows that provide focal cooling to high-pressure areas, probably based on the studies discussed here. Early data show the application of specialty foam dressings over the sacrum during surgery also can protect against DTI.

Ultrasound accessibility. In the future, sonographic equipment may be brought to the bedside for nurses to use for early detection of DTI and muscle necrosis; currently,
Figure 9. A female patient with advanced pulmonary fibrosis cared for at home. Before admission to the hospital, she was found unresponsive in bed with slowed respiratory rate and a pulse of 35. Forty-eight hours after admission, these apparent imprints of the bedding she was lying on at home appeared as these purple marks (outside-in pressure); 7 days from the first visit, a single large purple, demarcated deep tissue injury encompassing the sacrum and both buttocks, including the markings above) became visible (not shown), which evolved into a large black eschar (22 cm x 24.5 cm) by day 14, 1 day before the patient’s demise.

Portable US needs to be improved. Many hospital ICUs use US for quick diagnosis of colitis and kidney problems. Machines are getting better and smaller; perhaps in the future they thermography and color will be added to improve insight into the layers of tissue damage.

Ultrasound effectiveness. Approximately 75% of the larger DTIs detected on US are visible on the surface 6 to 7 days later. But until all the data are in, it is not known which lesions do or do not appear on the skin and the possible reasons. Scheiner detected a number of smaller pressure injuries of the foot in the subcutaneous tissue layer, demonstrating US sensitivity. These injuries don’t seem progress, possibly because of better vascularization or because they are nearer to the cooler surface of the skin, or both.

Cooler temperatures. Focal cooling could have some benefits. For example, some prototype wheelchairs have focal cooling in the cushion so individuals doing prolonged sitting can minimize any occurrence of deep tissue damage.

Mechanism of spread. US studies have shown DTI gradually extends from the area by the bone and then upward to the skin. But not all the DTIs make it to the skin and some eventually resolve, regardless of size. In Farid’s US study, one patient had retraction of the skin (a large dimple) over the site of a DTI that never reached the surface; the skin remained normal, but the scarring underneath shortened and pulled the skin down. DTI advancing toward the skin seems to convert viable tissue in its path to dead tissue. The progress and spread of the injury is likely due to a combination of apoptosis of cells adjacent to the necrotic tissue and local pathological changes in tissue stiffness that excessively deforms not-yet-damaged tissues.

Iaizzo noted muscle is the tissue layer mostly likely to have damage in all pressure/elevated temperature scenarios, whereas the skin and subcutaneous layers can recover. Therefore, the amount of cell apoptosis would influence whether the DTI eventually reaches the skin.

A role for bacteria? In a post-forum sidebar, Farid and Gefen discussed a potential role of bacteria in DTI. Farid proposed regardless of type of bacteria, the metabolism starts with the affected tissues with high lactic acid production, continues with the anaerobic metabolism by bacteria that are present and gradually increasing, and results in the denaturing of the heme molecule. Gefen countered bacteria can only penetrate the wound if the skin breaks down and offers a portal for entry. Otherwise, while the skin is still intact, no reason exists for bacterial infection. Farid maintained bacterial invasion would be implicated as the DTI penetrates the subdermal and dermal layers and in the outside-in types of full-thickness injuries. In those cases, an object is pressed into the skin by pressure (eg, the sheet imprints on Figure 9), inflicting direct injury to the skin. This also would explain why the outside-in pressure ulcers appear purple so quickly — ie, within a couple of days. Thus, outside-in pressure ulcers are not classic DTIs in that they do not originate in the muscle layer and usually ultimately do not result in a Stage IV (exposed bone) ulcer unless the skin lies directly over bone. Of note: it takes an additional 7 days for the eschar to form on the larger, deeper outside-in pressure ulcers.

Summary

The same consistent timeframe from DTI formation at the bone to appearance on the skin was validated by both human and animal studies discussed, and presentations jived with previous findings. Forum participants were able to describe how their research findings were reflected in their direct patient observations and experiences. Discussion of the mechanism of the purple skin color change with DTI highlighted differences between the appearance of a DTI and the mechanism of surface changes in color from outside-in pressure damage (ligature marks). Temperature changes of early reddened areas (PRIDAS) and the relationship of skin temperature to the prediction of DTI or survival of the skin fostered an appreciation of the commonalities of dead human tissues, regardless of whether the tissue death is local or on a decedent (a corpse). Research into the phenomenon of DTI is ongoing and continually enlightening.

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References