WCHM

WOUND CARE AND HYPERBARIC MEDICINE

VOLUME 7, ISSUE 4 — WINTER 2016

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Wound Care and Hyperbaric Medicine is published quarterly by Best Publishing Co.

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NOTE FROM THE EDITOR

As 2016 ends, we thank all of our sponsors, contributors, and readers for making *WCHM* the only magazine to cover all topics under pressure: wound care, diving, and hyperbaric medicine. *WCHM* started as a paid subscription for a print publication, but as our online audience grew over the years, we offered the magazine exclusively online, compliments of Best Publishing Company and the amazing group of *WCHM* Elite and VIP Sponsors.

In the hyperbaric medicine section of *WCHM*, UHMS and US Wound Registry offer free advice on Medicare reimbursement. Enjoy an excerpt from a chapter of the soon-to-be-released, much-anticipated 4th edition of *Hyperbaric Medicine Practice* by Dr. Harry Whelan et al. The chapter, "Fracture Healing and Roles of Hyperbaric Oxygen," is coauthored by Dr. Michael Straus, Lientra Lu, and Anna Tan. The Clinic in Focus section highlights the hyperbaric oxygen unit at Mather Hospital in Long Island, NY. Finally, read about the Brazilian Society of Hyperbaric Medicine becoming an affiliate of UHMS.

In the wound care section of *WCHM*, the third of five articles in the popular series "Prevention of New and Recurrent Foot Wounds" by Dr. Michael Strauss, Lientra Lu, and Anna Tan discusses the evaluation and management of foot skin and toenails. Heather Hettrick concludes her three-part series on lymphedema by discussing the complications resulting from the disease.

Dr. Jayesh Shah provides an excerpt from the upcoming *Textbook of Chronic Wound Care: An Evidence-Based Approach to Diagnosis and Treatment* by Drs. Jayesh Shah, Paul Sheffield and Caroline Fife.

If you've ever wanted to get an article you've authored published to an audience of thousands of wound care and hyperbaric medicine practitioners, 2017 is the year for you to make this happen. Please submit your articles to info@bestpub.com or call 561-776-6066. We also invite you to join our elite group of *WCHM* advertisers and reach your target audience.

Happy New Year! We look forward to hearing from you.

Lorraine Fico-White
Managing Editor, *WCHM*

UHMS and US Wound Registry Offer Free Advice on Medicare Reimbursement

By Renée Duncan, Communications Coordinator,
Undersea and Hyperbaric Medical Society

The Hyperbaric Oxygen Therapy Registry (HBOTR) has released an important paper detailing its work in Medicare reimbursement issues.

The paper, "Rapid analysis of hyperbaric oxygen therapy registry data for reimbursement purposes: Technical communication," by Caroline E. Fife, Helen Gelly, David Walker and Kristen Allison Eckert, is available as an epub-ahead-of-print download to the public.

Jointly sponsored by the UHMS and the US Wound Registry (USWR), the HBOTR recently provided national data quickly to the American Medical Association's Specialty Society Relative Value Scale Update Committee (RUC) on thousands of patients who underwent HBO_2. The aim was to help establish a fair analysis of the physician work of hyperbaric chamber supervision.

Medicare reimbursement rates for all physician services are established via a complex methodology utilizing data provided by the RUC, which values the "relative work" and practice expense of CPT codes and makes recommendations regarding valuations to the Centers for Medicare and Medicaid Services (CMS).

The authors note: "It is vital that hyperbaric practitioners engage in registry submission if they are to survive the titanic shift in healthcare payment reform under MACRA (Medicare Access and Chip Reauthorization Act of 2015)."

Participation in a Qualified Clinical Data Registry (QCDR) can satisfy the requirement for specialty registry participation under "Meaningful Use" of an Electronic Health Record and counts as 15% of the provider's total score in MACRA's Merit-Based Incentive Payment System (MIPS). Hyperbaric practitioners who report quality measures through the HBOTR can earn bonus points for the Quality Reporting portion of MIPS (50% of the total score), particularly if they report safety, appropriate use, or outcome quality measures.

While no such hyperbaric measures are available in the Physician Quality Reporting System, the UHMS developed hyperbaric safety, outcome, and appropriate use measures in partnership with the USWR, which can be reported through that QCDR and whose data become part of the HBOTR.

To read the paper, click on https://www.uhms.org/publications/uhm-journal/uhm-journal-ahead-of-print-public.html or go to the Undersea and Hyperbaric Medical Society (UHMS) website at www.uhms.org, toggle over the "Publications" tab, and use the pull-down menu to find "UHM Journal Ahead of Print – Public."

Fracture Healing and Roles of Hyperbaric Oxygen

(Chapter excerpt from Hyperbaric Medicine Practice, *4th edition, edited by Dr. Harry Whelan et al. (Best Publishing Company, 2017)*

By Michael B Strauss, MD, Anna M. Tan, DPM, and Lientra Q. Lu, BS

Hyperbaric oxygen (HBO) treatments for fracture healing is not an approved indication according to the guidelines formulated in the 13th edition of the *Undersea and Hyperbaric Medical Society Hyperbaric Oxygen Therapy Indications*.[1] Use of HBO for fracture healing is, therefore, considered an "off-label" therapy for this modality. Consequently, the Centers for Medicare and Medicaid Services, as well as most other third-party payers, do not reimburse for using HBO as an adjunct to fracture healing. Since it is estimated that 300,000 (4.7%) of the 6.3 million fractures that occur in the USA yearly are slow to heal or do not heal, other modalities need to be considered to improve these statistics.[2,3] Hyperbaric oxygen is one of them.

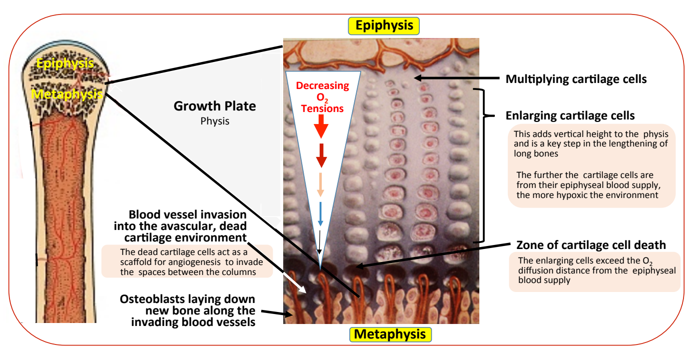
Bone is a remarkable tissue. It has multiple functions, including support and protection of the soft tissues of the body, a framework for muscles to act through joints, a fundamental component of calcium homeostasis, a site for generation of hematopoietic elements of the bloodstream and a reservoir for red blood cells. These functions of bone continue to occur while the fracture is healing or even in the presence of delayed or nonhealing of a fracture. Bone can also heal without leaving a scar, a trait it shares with the liver as the only body tissues that have the ability to do such.

Three requirements are essential for fractures to heal: adequate perfusion, appropriate stabilization and an environment for progenitor cells to be induced to form bone. When one or more of these elements is deficient, delayed or nonhealing of the fracture is likely to occur, as in the 4.7% of fractures in the USA that become nonunions. Hyperbaric oxygen has mechanisms to mitigate two of the three reasons fractures become nonunions. These are augmentation of perfusion-oxygenation and enhancement of the environment for fracture healing. This chapter describes the physiology of fracture healing, reports on the laboratory studies that support the use of HBO for bone healing and reviews the limited clinical experiences where HBO was used as an adjunct for fracture healing. From this information, a "new look" is warranted for using HBO in a select complement of fractures.

Physiology of Bone Growth and Fracture Healing

In the developing individual, two types of bone growth occur: enchondral and intramembranous. Enchondral bone formation occurs in the growth plates of long bones. It starts with a cartilaginous anlage. As the cartilage cells enlarge, they calcify and then outstrip their blood supply (Figure 1). Invasion of blood vessels bring in bone formation cell precursors, which line the calcified cartilage and lay down new bone along the cartilage anlage. The dead cartilage cells are reabsorbed by osteoclasts/chondroclasts. Intramembranous bone formation occurs under the periosteum of flat bones such as the clavicle. Bone formation occurs in situ under the periosteum and is incorporated into the outer surface of the cortical bone.

FIGURE 1. Bone formation at the growth plate



Legend: Oxygen availability is highly regulated in the growth plate. Cartilage multiplies in an oxygenated environment adjacent to epiphyseal blood vessels, but enlarges to lengthen the physis and eventually exceeds the diffusion distance of O_2. The cartilage cells die from hypoxia; this initiates blood vessel invasion between the columns of cartilage. Osteoblasts generate new bone along the blood vessels

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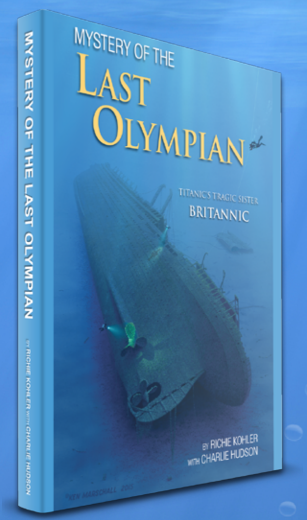

MYSTERY OF THE LAST OLYMPIAN: *Titanic*'s Tragic Sister *Britannic*

by Richie Kohler with Charlie Hudson

For 100 years the mystery surrounding the sinking of *Titanic*'s tragic sister *Britannic* was a riddle waiting to be solved. This book gives you a firsthand account as Richie Kohler takes readers on the intriguing journey from the rise of the magnificent Olympians to the ship's fateful sinking in 1916. He then moves forward in time through multiple expeditions, beginning with the great Jacques Cousteau, who located the wreck of the ocean liner in 1975. Each successive team of divers who risked their lives uncovered new clues, but it was not until 2009 that Kohler and his dive partner definitively pinpointed the secret that had eluded everyone before then.

Join Kohler, host of the History Channel's *Deep Sea Detectives* and featured in the bestselling book *Shadow Divers,* as he solves the *Mystery of the Last Olympian*.

"In Richie Kohler's new book, the same drive for adventure that captivated my father comes alive as Kohler rediscovers the mysteries surrounding the ship's fateful demise. Their journey spans across past and present, honoring the legacy of an unsinkable ship and the determination of those who risked, or even lost, their lives in the search to uncover its secrets."

~ Jean-Michel Cousteau, explorer, environmentalist, educator, and producer

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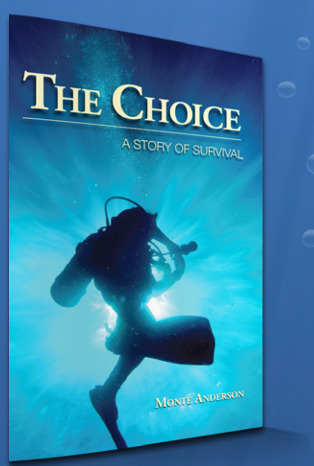
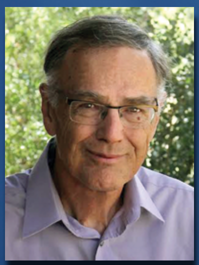


THE CHOICE: *A Story of Survival*

by Monte Anderson

As three friends drove across the Navajo Reservation in northern Arizona after backcountry skiing in Colorado, they talked about their lives. Then one said, "I really shouldn't be alive today."

David Scalia's astounding story occurred in 1982, when a scuba equipment failure caused a devastating accident, but he had a scrapbook documenting everything that happened. He suffered incalculable damage to his body for more than 12 grueling hours. Days later, he was given a profound choice — to live or to die. Almost unbelievable, this is his true story — and it involves some friends and colleagues you may know, including Dr. Gregory Adkisson, Dr. Tom Neuman, and Dr. Paul Phillips.



About the Author: Monte Anderson completed a medical residency at Creighton University and continued his studies with subspecialty training in gastroenterology and hepatology as an army officer at Fort Sam Houston in San Antonio, Texas. After his discharge from the military, most of his career was happily devoted to the Mayo Clinic in Arizona. Feeling that true tales tend to be more compelling than fiction, he has always preferred reading nonfiction, especially since something is always learned in the process. *The Choice: A Story of Survival*, his first effort outside of scientific writing, is nonfiction.

"Dr. Monte Anderson makes his debut in nonmedical writing with The Choice: A Story of Survival and does so with a splash. The nonfiction book relates the fascinating story of his friend's 1982 diving accident near a remote island in Mexico. Dr. Anderson's recounting of the details reflects his tremendous investigative ability, as well as the diver's will to survive."

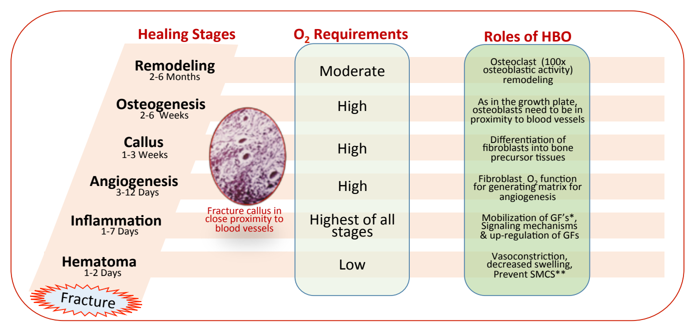
~ Neil B. Hampson, MD, author of *Cherry Red*

Available on Amazon and www.bestpub.com.
$11.99 paperback, $6.99 ebook

Fracture healing incorporates features of both types of bone formation with highly regulated oxygen tensions in the healing environment. Intramembranous bone formation is visualized on x-ray as periosteal new bone. Fracture healing has many analogies to soft tissue wound healing (Figure 2). The stages include injury, hematoma formation, inflammatory response, formation of granulation tissue, mitogenesis to soft callus, maturation to hard callus/new bone formation and remodeling. Two factors are essential for each stage to progress to the next. First, there must be adequate perfusion-oxygenation to the fracture site so that the cells in each stage of fracture healing can express themselves with their oxygen-dependent functions. Second, the environment of the bone surrounding the fracture must act as an inducer for the pluripotential cells of the granulation tissue phase to transform to osteogenesis precursors rather than continue to form collagen that would heal the soft tissue wound.

Three cell types are associated with bones: osteocytes, osteoblasts and osteoclasts. Osteocytes are the cells embedded in the bone matrix. They are anything but "resting" bone cells, being very metabolically active in directing osteoblastic and osteoclastic activity as well as in the calcium phosphorus regulation in the bone

FIGURE 2. Fracture healing, O_2 tensions and roles of hyperbaric oxygen



Legend: Oxygen availability and regulation, as in the growth plate, is required throughout the fracture healing process. This occurs without problems in the 95.3% of fractures that heal normally. In the other 300,000 fractures that go onto nonunion in the USA each year, identifiable factors and especially ischemia-hypoxia are the cause. Hyperbaric oxygen can mitigate the ischemia-hypoxia cause

Key: * = Growth factors, ** = Skeletal muscle-compartment syndrome

Dr. Bassett in the late 1960s demonstrated fracture cell precursors when compressed in a hypoxic environment formed cartilage and in the hyperoxic environment formed bone (Figure 3).[4] This model conforms to what is observed in nonunions where avascular cartilage and fibrous tissue bridge the bone ends.

Another consideration is that healthy, "raw" bone edges at the fracture site contribute to the induction effect. Death of bone cells immediately adjacent to the fracture is postulated to occur with all but the simplest fracture patterns. This dead bone is removed by the osteoclast, a very oxygen-dependent cell.

tissue. Osteoclasts are multinucleate giant cells from the macrophage linage that are induced to form alkaline and acid phosphatases to remove calcified tissues. They are very metabolically active and have 100 times the oxygen requirements as the osteoblast.[5] Osteoblasts are the bone-building cells. Their ability to build bone is about one one-hundredth that of the osteoclast's ability to remove bone.[5] Consequently, stabilization (as well as alignment during the remodeling stage) as stated above, is an important component of fracture healing. Without it, bone is subject to deformities and, subsequently, pathological fractures, abnormal mechanics leading to arthritis, and wound development at the apex of the deformity.

> Bones are in a continual state of remodeling. Structural unsound bone is removed by the osteoclast, while osteoblasts form new bone along lines of stress. When osteoclast function is inhibited by bisphosphonates, an anti-osteoporosis medication, bone remodeling is impaired. Although the bone may appear structurally sound (i.e., thick cortical margins) on x-ray, the failure to remove and rebuild bone along the lines of stress make it subject to pathological fractures, as seen in femurs of longtime bisphosphate drug users.

Laboratory Studies with Oxygen and Fracture Healing

Many articles have been published about the effects of different oxygen tensions on fracture healing in animal models. Online libraries such as PubMed, Rubicon, Elsevier, Google Scholar, and VA Medical Library have been searched to obtain the most relevant studies on this subject; most of them are prospective, case-control experiments and are reviewed in this section.

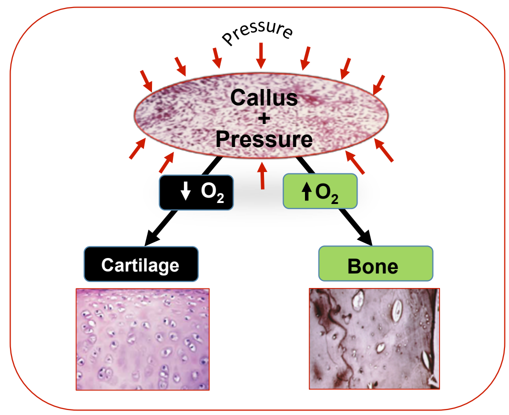
In 1932, Ham et al. observed that osteogenic cells have a "dull potentiality" — being able to form bone or cartilage in response to the degree of perfusion-oxygenation in the area in which it differentiates.[6] If oxygenation was compromised, fracture healing was disrupted and cartilage formed as is so often observed at a fracture nonunion site. Several earlier fracture-healing animal studies demonstrated that increased vascularity at the fracture site was needed before fracture healing occurred (Table 1).[7-12] Degree of perfusion and rate of angiogenesis at the fracture site correlated highly with the speed of callus resorption and bone union. Cavadias and Trueta reported that periosteal and endosteal vessels invaded the undifferentiated mesenchyme at the fracture site.[12] This confirmed that perfusion and oxygen delivery is an integral part of bone formation. Kolodny's findings also supported the perfusion-oxygenation hypothesis when he created fractures on canine tibia and disrupted the nutrient artery sites to the bone.[7] Nonunions uniformly occurred. Gothman observed that for a fracture to heal in a nonunion fracture model, angiogenesis/revascularization must occur within 14 days after the injury and the blood supply to the site needed to increase by a four- to fivefold factor; otherwise, nonunion would continue.[9] From their study on the vascular pattern of canine's undisplaced closed fractures, Rhinelander and Baragry found that increased blood flow associated with fracture healing stimulated long bone overgrowth.[11]

TABLE 1. Animal studies where vascularity was investigated in fractures

Reference	Animal	Treatment	Results
Kolodny	Dog radius	Fracture & disruption of nutrient artery separating bone & soft tissue	Nonunion resulted; decreased to total absence of callus formation vs. control limb
Trueta	Rabbit	Kuntscher (clover-leaf) type of intramedullary nailing of fracture model	At 7-10 days, new bone layer appears along the diaphysis → gradually becomes denser. Periosteal callus appears earlier and more robust in rodded side & reflected periosteo perfusion
Gothman	Monkey tibia	Intramedullary nailing vs. plating vs. external fixation	In nailed fractures, there was initially an 85.6 % reduction in blood flow, but after 90 days, they had significantly greater blood flow than externally fixed and plate fixed fractures
Wray	Immature rat	Tibial fracture without immobilization	↑ Fractured femur length (i.e. overgrowth secondary to increased perfusion,; ↑ vascular bed observed at fracture site
Rhinelander	Dog	Undisplaced closed fractures vascular pattern vs. normal	Vasodilatation of existing arterial tree, ↑ medullary (predominantly) and periosteal (auxiliary) circulations
Cavadias	Rabbit	Permeable barriers implanted in fractures	Periosteal & endosteal blood vessels invade the implant bed

Reports in animal models demonstrate the harmful effects of hypoxia on bone precursors in fractures (Table 2). When Bassett subjected undifferentiated bone precursors of chick embryonic tissue to a hypoxic environment and pressure, cartilage formed (Figure 3).[4] With induced hypoxia of varying degrees in rats, Vaes and Nichols noted that more lactate accumulated in bones with low oxygen tensions

FIGURE 3. Effects of pressure and oxygen tensions on undifferentiated mesenchyme



Legend: Dr. Bassett's findings (Reference 4) confirmed that undifferentiated pluripotential cells form bone when subjected to compressive forces in an enriched oxygen environment and form cartilage in a hypoxic environment. Cartilage is typically found in the nonunion site.

and there was a decrease in synthesis of new bone matrix.[14] In canine tibial fractures exposed to hypoxia, Heppenstall reported that there was a decreased rate of bone union.[24]

With 85% oxygen and 5% carbon-dioxide partial pressures, Sledge and Dingle observed increased rate of cartilage degradation and bone formation in the dog model.[15] With rats subjected to hyperbaric oxygen exposures several hours a day for 14 to 20 days, both Coulson et al. and Wray and Rogers noted an increase in callus formation and decrease in break strength.[16,17] This latter finding was consistent with HBO augmentation of osteoclast activity. This resulted in temporary weakening of bone during the bone remodeling process. Yablon and Cruess demonstrated increased healing of fractures with twice-a-day HBO exposures in rats.[18] Laurnen and Kelly using radioisotopes (strontium-85 washout) showed a sixfold increase in blood flow in dog tibial fractures, while oxygen consumption, carbon-dioxide production and blood calcium and pH changes remained the same as in the opposite control limb.[19] These findings confirm that increased metabolism occurs with the concomitant need for oxygen in fracture healing.

Niinikoski et al. and Penttinen et al. studied biochemical changes in rat tibial fractures.[20,21] They found that increased oxygen tensions stimulated precursors of fracture healing and mineral productions such as Ca, Mg, Zn, etc. This led to increased callus formation at the fracture sites. According to Brighton and Krebs's study on the rat epiphyseal growth plate utilizing mega vitamin A doses and high oxygen tensions, the pretreatment low oxygen tension promoted calcium release from the blood stream to the growth plate.[22] Subsequently, the high oxygen tensions resulted in hydroxylation of proline, an essential amino acid bone formation precursor generated by the undifferentiated fibroblast. The study also revealed a progressive decrease in oxygen tensions from the epiphysis to the metaphysis of the growth plate (Figure 1). In an experiment on murine calvaria fractures exposed to two atmospheres absolute pressures continuously for 24 hours, Gray et al. found an increase in collagen deposition and a decrease in bone formation and resorption.[23]

TABLE 2. Animal studies demonstrating the effects of varying oxygen tensions on fracture healing

Reference	Animal	Exposure	Results
Bassett	Chick embryo	Compression plus high (35 % O_2) and low O_2 tensions	Bone formation with high O_2 tensions; cartilage formation with low O_2 tensions
Vaes	Rat	Hypoxia of varying degrees	If bone O_2 tensions remained low, lactate accumulated,; ↓ synthesis of new matrix
Sledge	Chick embryo	85 % O_2, 5 % CO_2	Degradation of cartilage septa, conversion of cartilage to bone
Coulson	Rat	3 ATA, 2 hr. daily; 14 days	↑ Breaking strength of fractures
Wray	Rat	2 ATA, 6 hr. daily; 20 days	↑ callus, decreased strength
Yablon	Rat	3 ATA, 1 hr. BID; 4-40 days	Improved healing with BID HBO
Laurnen	Dog	Strontium-85 clearance after 10 minutes in tibiae 12 weeks after fracture	No difference in fx side & control side pO_2, pCO_2, pH. O_2 consumption & CO_2 production increased, reflecting blood flow has stabilized.
Niinikoski	Rat	2.5 ATA, 2 hr. BID; 5-21 days	↑ callus; ↑ precursors
Penttinen	Rat	2.5 ATA, 2 hr; BID	Callus 19-42 % ↑, nitrogen 15-60 % ↑, minerals (e.g. Ca, Mg, Zn, etc.) 20-63 % ↑; strengths unchanged
Brighton	Rat	Low O_2 initially in the cartilage anlage of the growth plate	Low O_2 → Calcium release; O_2 requirement for proline → OH-proline
Gray	Mice calvaria	2 ATA, 24 hr. continuous exposure	↑ collagen; ↓ bone formation & bone resorption
Heppenstall	Dog	Hypoxia (50 %)	Delay fracture healing

As the animal review shows, in the 1960s and 1970s there was much interest in studying the roles of oxygen and blood flow in general and HBO in particular on fracture healing in animal studies. Unfortunately, this interest waned after this time probably because of improved orthopaedic fracture fixation techniques, application of callotaxis principles (Ilizarov), new and improved bone grafting alternatives, pulsed electrical stimulation of bone and use of inducers such as bone morphogenetic protein. Consistent findings associated with HBO exposures included increased and speedier callus formation and faster bony union. The fracture strength, however, was initially weaker than compared to the control limbs. These observations substantiate the mechanisms that HBO exhibit in fracture healing. In fracture healing, the oxygenated environment is essential for the pluripotential cells in the precallus to generate bone. In contrast, the physis (growth plate) accounts for the longitudinal growth of long bones in children. In this situation, the cells in the cartilage columns enlarge to the point that they exceed the oxygen diffusion gradient from the epiphyseal arteries and die (Figure 1). This stimulates angiogenesis from the metaphyseal blood vessels, which, in turn, provides a sufficiently oxygenated environment for the osteoblast to lay down new bone along the dead cartilage cell anlage.

In summary, the increased oxygen tensions in the fracture-healing environment accelerate callus formation and osteogenesis. In addition, the activity of the highly oxygen dependent osteoclast is also stimulated. This results in faster bone resorption for the remodeling and ultimate strengthening process of the fracture. In the interim, because of the speeded-up remodeling process, the bone exposed to HBO is temporarily weaker. By the ends of the observation periods, bone strengths were usually equal in both the HBO and control limbs.

These observations are consistent with the first authors' experiences that in about 20% of the cases where HBO was used for fracture healing and/or arrest of refractory osteomyelitis, delayed onset stress fractures occurred after there was x-ray evidence of bone union.

A final observation from the animal studies is that "pulses" of HBO, that is intermittent exposures, are sufficient to achieve the bone healing effects. In contrast, the study of a continuous HBO exposure was detrimental to bone healing, which is consistent with oxygen toxicity (probable generation of free radicals) from the single, prolonged HBO exposure.[22]

Clinical Review of Hyperbaric Oxygen in Fracture Healing

While there have been numerous articles exploring the effects of HBO and fracture healing in animal models, little comparative clinical evidence of effectiveness exists. Extensive literature search via Pub Med, Ovid, Cochrane Library, and Google Scholar revealed a dearth of information, with search results consisting primarily of case reports and prospective series. These studies and most recent literature will be summarized in the following section.

Lindstrom et al. reported on 20 subjects requiring intramedullary nailing for closed tibial fractures who received HBO as an adjunct therapy. They measured transcutaneous oxygen tensions in the lower leg, limb temperature and distal arterial flow via Doppler. The trial, however, did not report any clinical outcomes in relation to fracture healing.[25] Porcellini et al. reviewed patients with serious vascular injures in addition to fractures. Hyperbaric oxygen therapy was utilized in 7 out of 34 patients to control bacterial contamination and improve wound healing. Outcomes regarding HBO and its effect on fracture healing, however, were not explicitly reviewed.[26]

Braune et al. detailed the case of a patient with 17-year-old posttraumatic pseudarthrosis of the dens axis following conservative treatment of unstable Anderson's type II odontoid fracture. Following surgical intervention and revisions, x-rays revealed an unstable posttraumatic Blauth's type III odontoid nonunion in association with wound dehiscence, exposed autograft and internal fixation hardware. Hyperbaric oxygen treatments were used as a therapeutic option in conjunction with a surgical salvage procedure. Complete wound healing was observed after 25 days. In addition, radiographs showed bone fusion with incorporation of the autologous bone graft and solid atlantoaxial fusion.[27]

In a 2005 Cochrane review study, the authors were unable to find any articles to meet its inclusion criteria for justifying HBO for fracture healing.[29] Thus, the conclusion was that there was insufficient evidence to support or refute HBO in use for delayed bony healing and nonunion of fractures. There is one randomized double blinded control trial, however, in which the authors studied fracture healing in crush injuries.[28] Bouachour et al. reported complete healing in 94% of the HBO group versus 33% in the control limb, while need for repeat surgery (after initial debridement and stabilization) was 6% in the HBO group compared to 33% in the patients who did not receive HBO. Both observations were statistically significant ($p < 0.05$). All patients had crush injuries (Gustilo grade 2-B open fractures) where vascular compromise and threatened flaps were an integral part of the pathophysiology of the injury.

The most recent studies regarding HBO and fracture healing are from China. Chen observed the effect of intramedullary nail fixation combined with HBO in the treatment of long bone fractures in children. The authors concluded that those in the HBO group had lower levels of pain and swelling with earlier ambulation and shorter healing times.[30] In another study from China, Yu found that HBO significantly improved the formation of callus in 44 patients with delayed union of tibial fractures.[31] In his randomized controlled study, the 22 patients in the test group who received HBO had a "total effective rate" of 95%. The author concluded that HBO promoted the healing of fractures and reduced the incidence of delayed union and nonunion.

In summary, only meager clinical evidence from the literature supports the use of HBO for fracture healing and especially nonunions. Further studies including prospective series and randomized control trials are needed to advance HBO as an adjunct to fracture healing, prevention of delayed union, and healing of nonunion fractures. Nonetheless, the current knowledge of fracture healing mechanisms and the animal studies reported above are consistent with specialized roles for HBO in fracture management.

Personal Experiences with Hyperbaric Oxygen in Fracture Healing

Through the years, the first author (MBS) has had a number of patients for which hyperbaric oxygen has influenced healing of fractures. This group needs to be differentiated from the multitude of cases where HBO has been used as an adjunct to manage open fractures and crush injuries as described in the Bouachour study previously cited as well as in cases of chronic refractory osteomyelitis.[28,32] The subset of patients in questions had delayed or nonunions of their lower-extremity fractures, or fracture healing was likely to be impaired due to the severity of the injury. The first experiences occurred with three active-duty US Navy personnel who had nonunions of their tibia fractures after motorcycle accidents. After nonhealing of the fracture was ascertained, each underwent a segmental (about 5 cm in length) fibula ostectomy and Sarmiento patellar tendon cast bracing. The rationale for the fibular osteotomy was to allow compressive forces to increase across the fracture site with weight bearing. Without subsequent evidence of healing, arrangements were made for the patients to receive three US Navy Treatment Table 5 HBO exposures a week for four weeks at the Naval Special Warfare recompression chamber at the US Naval Amphibious Base in Coronado, California. All three fractures became stable, allowing the discontinuation of cast bracing. X-rays indicated the stability was attributed to periosteal new bone formation.

Subsequently, the first author used HBO for a small number of "last-resort" fracture situations referred to him at Long Beach Memorial Medical Center in Long Beach, California. The following are five anecdotal cases in which HBO appeared to change favorably the patients' outcomes:

One of the earliest cases was a middle-aged male who had bilateral nonunions of his distal femurs after Rush rodding and bone grafting. During the course of 20 hyperbaric treatments, the rods were removed, and then the femoral fractures stabilized with external fixation. The fractures healed after another 10 HBO treatments and subsequent removal of the external fixators 12 weeks after applications.

A second case involved a nonunion of the proximal femoral shaft in a male in his 20s. After cast immobilization failed, an external fixator was applied, but there was hardware failure with breakage of the fixator. With HBO treatments while remaining nonweight bearing on the extremity, the fracture healed.

A third case was that of male smoker in his 40s who after a motorcycle accident sustained a severe proximal tibial fracture that was managed with medial and lateral platings. The proximal 20% of the skin over the anterior aspect of the tibia sloughed, exposing both plates and the necrotic anterior tibial fragment (Figure 4). The patient was referred for HBO treatments as alternative to an above-knee amputation. With staged surgeries while receiving ongoing HBO treatments, the wound was debrided, hardware removed and the fracture stabilized with external fixation spanning from the distal femur to the middle tibia. After granulation tissue covered the cavity, autologous bone grafting was used to fill the defect, and a rotational gastrocnemius muscle flap used to provide soft-tissue coverage. Twenty-five years later, the patient continues to be a community ambulator with moderate loss of knee flexion.

FIGURE 4. Major skin slough and devitalized proximal tibia bone

Legend: Severe proximal tibial injury after motorcycle accident referred for HBO treatments as adjunct to orthopaedic and plastic surgery interventions to prevent an above knee amputation

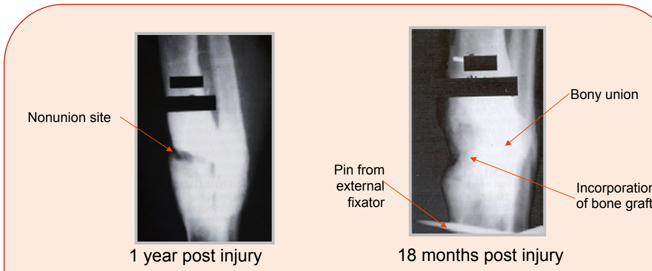
The fourth case was that of a male in his 20s who developed an infected tibial nonunion after plating of a closed shaft fracture and more than 15 subsequent surgeries. Eighteen months after the injury without evidence of healing or control of the infection, he had made the decision to undergo a below-knee amputation (Figure 5). His wife, a nurse at our medical center, convinced him to try HBO as an alternative to an amputation. After two weeks of HBO treatments, the nonunion site was debrided and the fracture site stabilized with an external fixator. A week later, when the nonunion site was covered with healthy granulation tissue, autologous bone grafting (Papineau technique) was done. Hyperbaric oxygen treatments were continued for two additional weeks. Blood vessels grew into the open bone graft, and gradually the graft epithelialized over a three-month period. At that time, the fixator was removed, and bony union was confirmed by clinical exam and x-rays.

A fifth case concerned a male also in his 20s who sustained a severely comminuted open distal tibia and fibula fractures with a 5-cm gap due to loss of bone after the initial debridement. A spanning external fixator with single half pins in the calcaneus and proximal to the fracture were used to temporarily maintain alignment until plastic surgeons could perform a microvascular ipsilateral fibular graft to span the defect. Unfortunately, the fixator did not maintain the length, and at the time of the fibular grafting, the gap had shortened 4 cm. The plastic surgeons where stymied as to what to do: Accept the shortening and use 1 cm of the 5-cm fibular graft to span the remaining gap, discard the fibula graft, or seek an immediate second orthopaedic surgeon's opinion. The latter option was chosen. The vascularized fibular graft was morcellized into fine fragments and packed into the gap. A rigid external fixator was applied with transfixing pins placed in the foot and above the fracture. Hyperbaric oxygen treatments were started to manage swelling and the threatened flaps after the four-and-a-half-hour surgery. Two weeks later, the patient was returned to the operating room (OR) where the morcellized fibular graft was stretched out by readjusting the fixator. This maneuver nearly regained the full tibia length. At four weeks, the axial and rotatory alignments were "fine-tuned" in the OR to achieve an essentially normal-appearing extremity, and HBO treatments (40 in total) were stopped at that time. At 12 weeks, the fixator was removed and the leg casted for another six weeks, at which time x-rays showed consolidation and full incorporation of the bone graft. The patient resumed walking with a normal gait.

A final case was of a male in his late teens whose leg got caught in a rotating drum water extractor for drying rags while working at a car wash. An open fracture with 20 or more comminuted bone fragments resulted (Figure 6). The patient refused an amputation and was transferred to our medical center for HBO treatments. Stabilization was achieved with an external fixator. At three months, the fractures had developed callus and the fixator replaced with a walking cast. At six months, bony union was achieved.

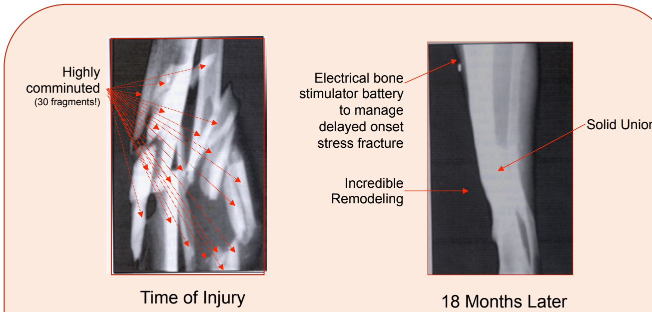
Several conclusions can be drawn from these favorable outcomes using HBO as an adjunct for fracture healing. First, HBO was used in conjunction with "state-of-the-art" orthopaedic management. It should always be used as an

FIGURE 5. Infected nonunion with multiple surgical attempts to resolve problem



Legend: Infected tibial nonunion after motorcycle accident and over 20 previous surgeries. HBO used as an adjunct to debridement and external fixation followed by staged bone grafting

FIGURE 6. Limb threatening open fracture with recommendation for a below-knee amputation



Legend: Extremely comminuted, open mid-shaft tibial fracture secondary to twisting injury. Early wound infection. Patient referred for HBO treatments when he refused a leg amputation. Remarkable remodeling (osteoclast effect), but delayed stress fracture shown healed at 18 months.

adjunct to orthopaedic management and not a substitute for it. Hyperbaric oxygen treatments alone would not have achieved the same results. Second, a course of HBO treatments before definitive orthopaedic interventions appeared to help the fracture site respond to the final, definitive orthopaedic intervention. Staged surgeries using HBO before surgery to generate a favorable environment at the nonunion site for bone grafting and after surgery to promote bony union is logical, based on the mechanisms of HBO.[33] Third, HBO favored bone formation of the undifferentiated mesenchyme that invaded the fracture site in the fracture milieu. In this capacity, it may have acted as an inducer of osteoblastic and osteoclastic activity as well as providing an oxygen environment sufficient for these cells to function. Fourth, HBO supported angiogenesis (i.e., vascular ingrowth of the avascular bone graft scaffold) in those cases were bone grafting was used in the management. Fifth, early utilization of HBO in the course of healing of fractures that are highly predictable of complications (e.g., the first author's cases 3, 5, and 6 described above) is supported by the above observations. Finally, HBO promotes bone remodeling by the osteoclast, which is the most metabolically active of the three bone cell types. This was apparent in cases 5 and 6 above where extensive remodeling occurred. It is also seen as a minor complication with delayed-onset stress fractures after resuming ambulation. This has been observed in about one-fifth of our patients treated for crush injuries, osteomyelitis and nonunions of long bones.

Discussion

There is much supporting information that perfusion-oxygenation is a key factor in bone formation and growth. This is observed in limb length overgrowth of children's lower-extremity fractures and is attributed to the increased flow associated with fracture healing. For similar reasons, bone overgrowth and hypertrophy are associated with arteriovenous fistulas. The propensity for excessive bone formation is seen after muscle injury (i.e., heterotopic ossification) and after brain and spinal cord injuries. Increased perfusion associates with both the inflammatory reaction in myositis and disruption of sympathetic nervous system vasoconstriction with the neurological conditions. Although acromegaly is attributed to pituitary tumors and increased elaboration of growth hormone, there appear to be concomitant changes in blood flow from the hormone.[34] This may be the reason that increased bone mass is associated with this condition. Finally, the formation of bone spurs is possibly due to an inflammatory response increasing blood flow to bone from repetitive trauma to the site either from traction effects (spurs pointing away from the metaphyses) or over underlying bony deformities.

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Additional information showing the importance of blood flow and oxygen availability for bone viability is observed in those situations in which blood supply is lost. Examples include: 1) osteonecrosis of the femoral head associated with fractures, steroids, alcoholism, and dysbarism; 2) osteoradionecrosis of the mandible due to sclerosis of blood vessels from radiation; 3) jaw-bone necrosis from bisphosphonates with failure of bone remodeling (from the osteoclast) to maintain channels for blood vessels to perfuse the mandible; 4) osteonecrosis in conjunction with osteopetrosis for similar mechanisms attributed to jaw-bone necrosis; and 5) bone death in purpura fulminans and frostbite from sludging and obstruction. Bone viability can be confirmed with the technetium nuclear medicine scan.

The approximately one in 25 fractures (4.7 %) in the USA in which healing is delayed is usually predictable. Soft tissue damage, energy exchange, comminution, displacement, contamination, interruption of vascular supply and inadequate management are obvious causes. A multicenter review of more than 300,000 fractures reported that the highest nonunion rates were in the metatarsals (15.5%), scaphoids (15.3%), tibia and fibula (14%) and femur (9%).[3] For all open fractures, the nonunion rate was 10.9% and ranged from 4.4% in those patients with a single fracture to 24% in patients with 7 fractures. Odds ratios were the highest for patients on a combination of nonsteroidal anti-inflammatory drugs and opioids (1.84), management requiring surgery (1.78), open fracture (1.66), concomitant anticoagulation (1.49), high-energy injury (1.38), osteoporosis (1.24), insulin requirement (1.21) and smoking (1.20). Other factors had odds ratios less than 1.20 and included such items as use of antibiotics, use of bisphosphonates for osteoporosis, vitamin D deficiency, use of diuretics and renal insufficiency, in that order. Surprisingly age in 10-year increments from 18 to 63 did not show significant differences in rates of nonunions (range from 4.5 to 5.5%). A surprising omission of the study was absence of information on perfusion to the fracture site. Nonetheless, the five risk factors of multiple fractures, NSAIDs plus opioid use, open fractures, anticoagulation and osteoarthritis plus rheumatoid arthritis increased the risk of nonunion by 50%.[3]

Can information of this sort provide justification for using HBO as an adjunct for prevention of nonunions and achieve fracture healing? The answer is a qualified yes if tools currently available are utilized to justify the decision to use HBO. The first step, of course, is the clinical evaluation and assessment of perfusion directly and oxygenation indirectly. Palpation and Doppler detection of pulses provide a direct assessment of perfusion. Skin (and wound base) coloration, skin temperature and capillary refill provide indirect evidence of perfusion and oxygenation. Finally, juxta-wound transcutaneous oxygen measurements provide objective information as to tissue oxygenation.[35]

Two user-friendly clinical tools can supplement the fracture evaluation information and help justify decision-making regarding salvage or amputation of the lower limb nonunion. These tools are the Wellness and Goal Scores that are also found in our osteomyelitis foot wound chapter in the fourth edition of *Hyperbaric Medicine Practice* (Tables 3 and 4). Each is a 0-to-10 score based on five assessments graded with objective findings from 2 points (best) to 0 points (worst). Scores on these two tools when each is 5 points or greater support the decision to do everything possible to heal the nonunion. If ischemia-hypoxia is associated with the nonunion, and the factors having the highest odds ratios for nonunion (i.e., NSAIDS plus opioid use, operating room treatment, open fracture, anticoagulation and high-energy injury) are present, we feel there is substantial justification for using HBO as an adjunct to other orthopaedic interventions. Even if orthopaedic interventions were used before and failed to resolve the nonunion, repeat bone grafting, callotaxis, use of bone morphogenetic protein, electrical stimulation and/or microvascular bone transplants should be utilized in conjunction with HBO treatments when the indications from the Wellness and Goal Score tools support the decision to heal the nonunion.

Unfortunately, there is minimal clinical information to support the use of HBO for fracture healing (Boauchour et al., Chen ,Yu and the first author's anecdotal observations).[28,30,31] Mitigation of hypoxia was the design for most of the animal studies dealing with fracture healing. Impairment of oxygenation on a perfusion basis in tibial nonunions has been documented with transcutaneous oxygen measurements.[36] Information such as this supports the use of HBO since hyperoxygenation of plasma and tissue fluids is a primary mechanism of HBO.[33] When a score we devised titled Rational Indications for Using HBO is applied to fracture healing, only modest justification (i.e., 4 points out of 10 possible points) is summated (Table 5). Obviously, new animal studies using perturbations from the clinical literature associated with nonunions and randomized controlled clinical trials are needed before HBO can be unequivocally recommended for this problem.

Conclusions

While hyperbaric oxygen is not an approved use for nonunions, its mechanisms support its use when ischemia-hypoxia is contributing to the failure of bone union. Identifiable clinical factors, juxta-wound oxygenation measurements and imaging studies can confirm whether

TABLE 3. Wellness score

Assessment	2 Points	1 Point	0 Points
ADLs (Ability to do activities of daily living)	Full	Some	None
Ambulation	Community	Household	None
Comorbidities (Except neuro; include obesity)	Normal	Impaired	Decompensated
Tobacco/Steroid Use	None	Past	Current
Neuro Function	Normal	Impaired	Decompensated

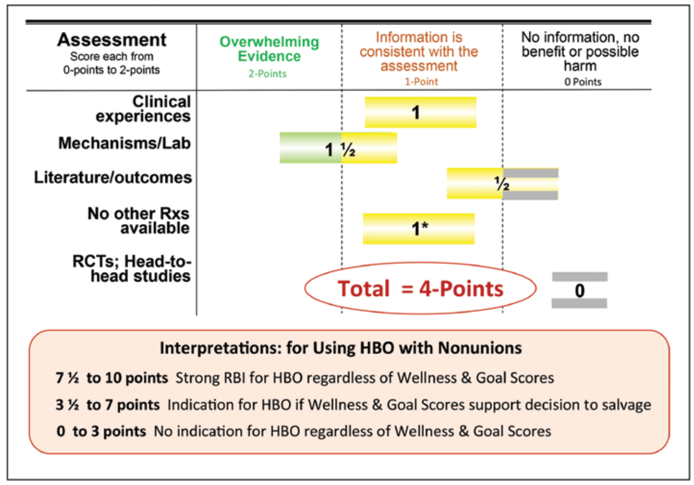
Note: The "Wellness Score" is a quick to obtain evaluation tool to assess how functional a patient is . If scores are 5-points or more, the patient's overall health status as measured by these five easy to ascertain assessments justifies limb salvage

TABLE 4. Goal score

Assessment	Full 2 Points	Some 1 Point	None 0 Points
	Use half points if mixed or intermediate between 2 grades		
Comprehension			
Motivation			
Compliance			
Support (Family, caregiver, institutional)			
Insight			

Note: The "Goal Score" is another useful tool to determine how successful and how intent the patient and the family are in avoiding a major amputation. Goal Scores greater than 4 ½ points supports the decision to avoid lower limb amputation and do everything possible for salvage of the nonunion. This score coupled with the Wellness Score (Table 3) provides objectivity for decision making regarding limb threatening nonunions.

TABLE 5. Rational based indications (RBI) for using HBO with nonunions



or not perfusion-oxygenation is adequate to the bone at the nonunion site. User-friendly tools such as the Wellness and Goal Scores support decisions to salvage or amputate the nonunion. Although there is only sparse clinical information to support the use of HBO as an adjunct to fracture healing, the laboratory studies consistently validate the need for oxygen in fracture healing in general and the nonunion in particular. Even though only one in 25 fractures (300,000) of the 6.3 million fractures that occur in the USA each year go onto nonunions, they present major treatment and financial challenges. When "tried-and-true" orthopaedic interventions such as bone grafting, optimal stabilization, bone morphogenetic protein, callotaxis and pulsatile electrical on sonographic bone stimulation have not resolved the nonunion and there is justification to avoid a lower limb amputation, then HBO should be utilized in the management as an adjunct to one or more of the above orthopaedic techniques. There is no information, study, or observation where bone perfusion-oxygen is not a primary consideration in fracture healing. ■

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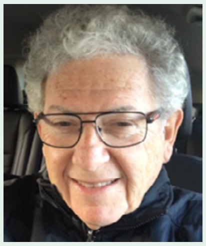
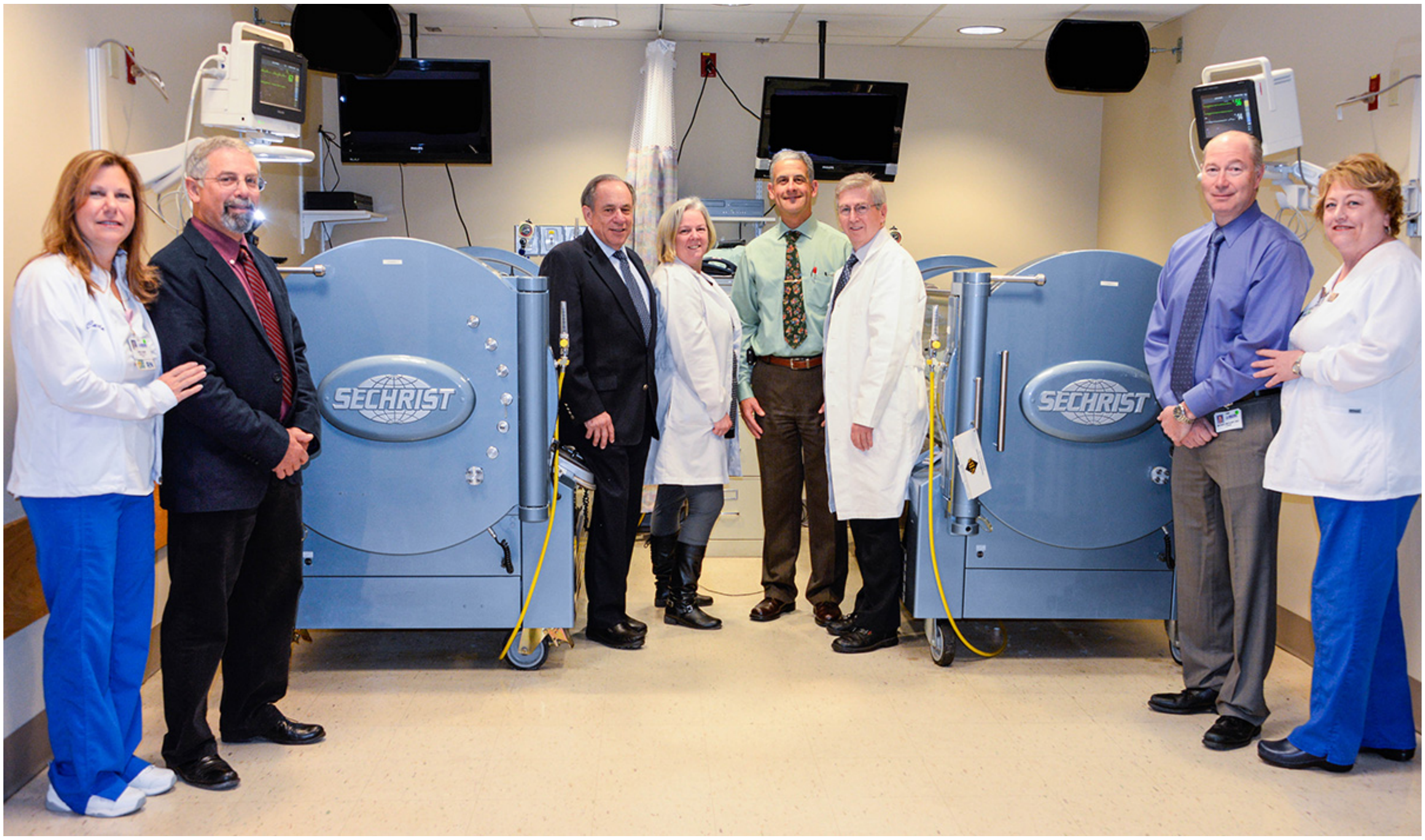
About the Authors



MICHAEL STRAUSS, M.D., has been a regular contributor to *WCHM* with almost 30 articles and citations to date. He is appreciative of Dr. Whelan's (the editor of the 4th edition of *Hyperbaric Medicine Practice*) approval to share with the readers of *WCHM* at this time the fracture-healing chapter from this soon-to-be-published text. As an orthopaedic surgeon, Dr. Strauss is understandably well versed in fracture healing. Even during his orthopaedic residency, Dr. Strauss was able to use his background in hyperbaric and undersea medicine to arrange treatments for several tibial fracture nonunions (see text). His integration of hyperbaric oxygen therapy to the subject of fracture healing is a singular contribution to the hyperbaric medicine literature.

ANNA M. TAN, DPM, is the chief resident at the Long Beach Memorial Medical Center podiatric medicine and surgery program. She has been collaborating with Dr. Strauss on the five-part *WCHM* series "The Prevention of New and Recurrent Foot Wounds." Dr. Tan will be the first author in the upcoming fourth part of the series with her article titled "Protective Footwear." In addition to contributing to this fracture-healing chapter for the 4th edition of *Hyperbaric Medicine Practice*, she has also coauthored with Dr. Strauss the chapter "Hyperbaric Oxygen in the Evaluation and Management of Diabetic Foot and Other Wounds." She has a special interest working with patients with challenging foot and ankle problems, and in her spare time enjoys cooking, traveling and Bikram yoga.

LIENTRA LU is a research coordinator at the VA Medical Center in Long Beach, California, under the guidance of Dr. Ian Gordon, a vascular surgeon, and Dr. Michael Strauss, the first author of this paper. She is also working with Dr. Strauss and Dr. Tan on the series of five articles, "The Prevention of New and Recurrent Foot Wounds." Miss Lu is the first author of the third paper, titled "Evaluation and Management of Foot Skin and Toenails," also in this publication. Additionally, she has coauthored with Dr. Strauss five chapters for the 4th edition of *Hyperbaric Medicine Practice*, including mechanisms of hyperbaric oxygen therapy, chronic refractory osteomyelitis, diabetic foot ulcers, and crush injuries in addition to the nonhealing fracture chapter, which they were given permission to use in this edition of *WCHM*. Miss Lu is helping with diabetic foot and venous leg ulcer studies at the VA Medical Center while also serving as an assistant in patient care at the PAVE (Prevention-Amputation, Veterans Everywhere) Clinic there. In addition, Miss Lu is helping with Dr. Strauss's Long Beach Wound Score Research Project. She also works with the American Red Cross in disaster preparedness.



CLINIC IN FOCUS

Hyperbaric Oxygen Therapy Unit at Mather Hospital

How long have you been in business?

John T. Mather Hospital began as a vision of a local shipbuilder from Port Jefferson, NY, and in 1929 it became the first general medical hospital in the Town of Brookhaven. In the spirit of its visionary seafaring founder, Mather Hospital added hyperbaric medicine by opening the first hyperbaric unit on Long Island in 1994.

Our staff consists of board-certified physicians in hyperbaric medicine, family medicine, emergency medicine, pulmonary medicine, internal medicine, and cardiology. Our nursing staff consists of critical-care nurses, a critical-care nurse practitioner, as well as a hyperbaric certified nurse and certified safety director.

What are the most common indications treated at your clinic?

Patients come from all over Long Island for nonemergent hyperbaric cases, including common radiation-induced injuries and wound-care issues. We also still treat the emergent cases of carbon monoxide poisoning, decompression illnesses, failing flaps, acute sensorineural hearing loss, acute retinal artery occlusion, gas gangrene and necrotizing fasciitis.

What is the most memorable treatment success story that has come out of your clinic?

The one that stands out most occurred a number of years ago. Since we are still a 24/7 operation, we have undertaken some dramatic situations. A patient had developed an extensive necrotizing infection and was near death. She was in a hospital ICU, intubated and on multiple medications. We were asked to take on her care. Some hospitals and surgeons may have been reticent to both transport and accept this type of transfer, but one of our surgeons agreed, and she was brought from another county to us. She went for extensive surgery, which included an incision from her buttock area up to her thoracic region. We began hyperbaric oxygen therapy in conjunction with multiple surgeries and antibiotics. The patient woke up in two days, was extubated in approximately five days and went on to full healing and discharge.

If you had to pick one thing to attribute your clinic's success to, what would it be?

Staff dedication. Without the support of a dedicated staff and the commitment to excellence, the program would not be in existence. Since we are 24/7, our staff of three nurses and a nurse practitioner are on call regularly, often for a week at a time. Their dedication to return after hours is amazing.

Also, the caring and comradery that they develop with the patients over prolonged courses of treatment is invaluable. Often patients are happy to complete their therapy but sad to leave the friendship and relationships they have developed.

What is one marketing recommendation that you can make to help clinics increase their patient load?

Constantly remain in contact with the community of providers that treat potential hyperbaric cases.

Is there are any additional question you'd like to answer, or any other information about your clinic you'd like to showcase?

We have provided support for the diving operations during the TWA Flight 800 incident as well as local diving operations such as the Air National Guard and have been involved in research projects associated with Stony Brook University and the U.S. Navy. ■

CLINIC DETAILS

Clinic Name: Hyperbaric Oxygen Therapy Unit at Mather Hospital

Location: John T Mather Memorial Hospital, 75 North Country Road, Port Jefferson, NY 11777

Website: http://www.matherhospital.org/hyperbaric-oxygen-therapy-unit.php

Phone: 631-474-2768

How many chambers: 3

Chamber types: monoplace

Medical director: Joseph C. White, MD

How many physicians/nurses/CHTs: 6 physicians, 1 NP, 3 nurses

Do you work with a management company? If so, which one? No

UHMS Welcomes the Brazilian Society for Hyperbaric Medicine as an Affiliate

By Renée Duncan, UHMS Communications Coordinator, with reports from Dr. Iriano da Silva Alves

The Sociedade Brasileira de Medicina Hiperbárica (SBMH) recently became an Affiliate of the Undersea and Hyperbaric Medical Society (UHMS), joining a number of like-minded organizations in support of undersea and hyperbaric medicine. The SBMH application was granted unanimous approval at the November 12, 2016, meeting of the UHMS Board of Directors.

"We joined with UHMS during the preparation period for our biannual 7th Quality, Safety and Ethics Forum, which was held in São Paulo, this past October," noted Dr. Iriano da Silva Alves of Rio de Janeiro. Alves, former SBMH president, is the spokesman for the organization. Dr. Fabrício Rech of Sao Paulo is the current president.

The SBMH promotes a biannual forum, regularly held in São Paulo, as well as a biannual congress in different cities. The next biannual congress, the 8th Brazilian Congress on Hyperbaric Medicine, is set for October 26-28, 2017, in Florianópolis in the state of Santa Catarina. For more information on this event, contact diretoria@sbmh.com.br.

"It will be a great pleasure for the Brazilian hyperbaric community to be part of this very distinguished scientific institution," Alves said.

Hyperbaric oxygen (HBO_2) therapy has a long history in Brazil, beginning in 1934 with Professor Alvaro Ozório de Almeida (1882-1952), who published several papers in European medical journals on the use of HBO_2 in treating leprosy, syphilis and gas gangrene. Brazilian Navy and civilian doctors founded the SBMH in February 1983 in Rio de Janeiro. After the installation of the first hyperbaric chamber in the main Brazilian Navy Hospital in Rio de Janeiro, the organization grew substantially. "Now we have around 180 clinical facilities in Brazil, and the SBMH has around 250 members," Alves said.

As with U.S. chapters, UHMS affiliates have no application fee, and in line with the maxim of "think globally, act locally," both share in the commitment to undersea and hyperbaric medicine in their respective locales.

"I am very excited to welcome the Sociedade Brasileira de Medicina Hiperbárica to our ranks," UHMS president Dr. Enoch Huang said, "and I look forward to jointly promoting the highest standards of patient care and safety for hyperbaric patients in Brazil."

"I'm delighted to learn that you have been appointed as a UHMS Affiliate," UHMS vice president Dr. Gerardo Bosco wrote to the SBMH. "Your society has just the right qualities and experience to support HBO_2, with high standards in clinical practice, science and education. Welcome to the UHMS."

Each affiliate is an independently run international society. There are some requirements that should be met to ensure that the affiliate has similar values and is of a certain size with respect to concurrent UHMS membership numbers.

All approved affiliate society members receive a 50% discount on UHMS dues while retaining full privileges within the society. Reciprocal discounts are not required of affiliates, but some societies may wish to extend similar benefits to UHMS members. Bosco is the board of directors representative for the affiliates.

The SBMH joins these distinguished organizations as a UHMS Affiliate:

- European Underwater and Baromedical Society (EUBS, http://www.eubs.org
- South Pacific Underwater Medicine Society (SPUMS), http://www.spums.org.au
- Canadian Undersea and Hyperbaric Medical Association (CUHMA), https://cuhma.ca

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About the UHMS

The Undersea and Hyperbaric Medical Society is a 501(c)(3) nonprofit association of medical professionals dedicated to the practice of undersea and hyperbaric medicine. Its mission includes the following:

- to provide a forum for professional scientific communication in basic and applied research and patient treatment in hyperbaric medicine and undersea diving
- to promote cooperation between the life sciences and other disciplines with undersea diving activities and hyperbaric oxygen therapy
- to provide a source of information and support in the clinical practice of hyperbaric medicine and stay abreast of legislative, legal and regulatory changes
- to develop and promote educational activities, symposia and workshops that improve the scientific knowledge of matters related to undersea exposures and hyperbaric oxygen therapy
- to raise the quality of care across the spectrum of hyperbaric medicine by promoting high standards of patient care and operational safety through clinical hyperbaric facility accreditation

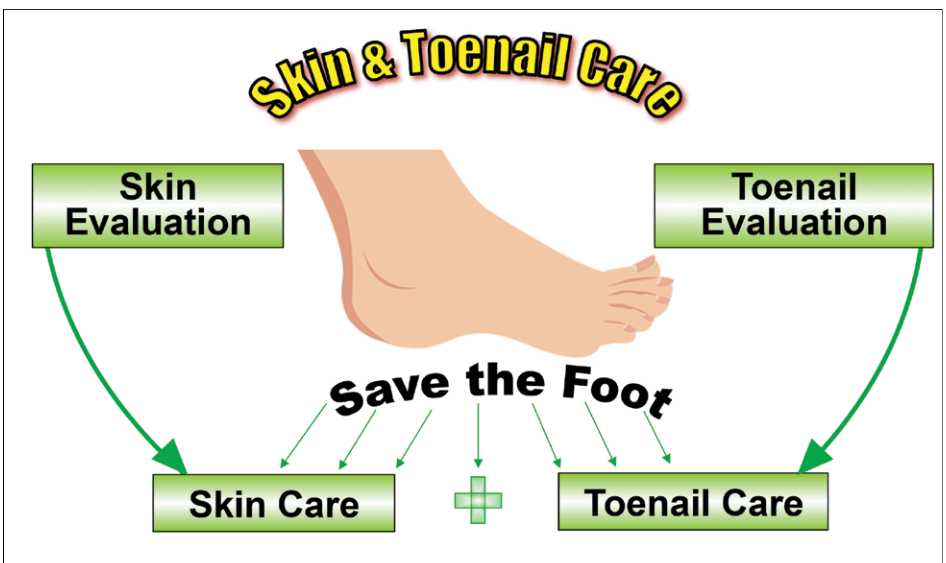
For more information see www.uhms.org or write to uhms@uhms.org. ■

Evaluation and Management of Foot Skin and Toenails

By Lientra Q. Lu, BS; Michael B. Strauss, MD; and Anna M. Tan, DPM

Not only is the skin and its appendages, including nails and hair, the largest organ system in the body, it is the one that has the most contact with the external environment. Consequently, this organ system is the first line of defense in protecting the body from agents in the external environment that could possibly damage the internal contents of the body (Figure 1).[1] In addition, this organ system is a window to disease states within its contents, as will be discussed in the next section. Many predispositions cause problems that make the skin and toenails vulnerable to injury and disease. These predispositions include neuropathies, deformities, ischemia, infections, metabolic problems, and congenital disorders. After patients and their caregivers are instructed in skin and toenail care in the lower extremities, inspection of these areas provide objective evidence as to patient compliance. This information can be used as criteria for determining the compliance assessment of the Goal Score (Table 1) and help gauge the frequency of return visits to the health-care provider caring for the patient's foot conditions.

FIGURE 1. Skin and toenail management are the first line of defense against developing new or recurrent foot wounds.



Legend: Foot wounds and other wounds usually start when the skin and its appendages are no longer able to maintain their protective functions. Skin care and toenail care are the body's first lines of defense for maintaining these protective functions.

Anatomy, Histology and Physiology of the Skin and Toenail

The skin is a part of the integumentary system, an organ system also consisting of hair, nails, and exocrine glands. The skin is only a few millimeters thick but is the largest organ in the body. The average person's skin comprises 10%–12% of the body mass and has a surface area of about 2 square meters, or 20 square feet. Skin forms the body's outer covering and forms a barrier to protect the body from chemicals, disease, UV light, and physical damage.

Epidermal layer — The epidermis is the superficial layer of the skin and protects the deeper and thicker dermis layer (Figure 2). The epidermis is made of 40 to 50 rows of stacked squamous epithelial cells (Table 2). The cells are held together along their lateral surfaces by extracellular connections that act as barriers and are called tight junctions. Tight junctions enable the epidermis to function as a selective barrier that prevents most substances in the external environment from entering the body through the skin. Conversely, it provides an envelope to contain the body fluid, which comprises 70% of the body weight. The epidermis does not contain any blood or blood vessels — that is, it is avascular — and epidermal cells receive all of their nutrition via diffusion of fluids from the dermis.

Dermal layer — The dermis is the deep layer of the skin found under the epidermis. The dermis is mostly made of dense irregular connective tissue along with nervous tissue, tissue fluid, and blood vessels. The dermis is much thicker than the epidermis and gives the skin its strength and elasticity. There are two distinct regions within the dermis: the papillary layer and the reticular layer. Both layers provide nutrients and oxygen for the cells of the epidermis. The nerves of the dermal papillae are used to feel touch, pain, and temperature, while the nerves of the reticular layer sense pressure and pain through the cells of the epidermis.

Subcutaneous layer — Deep to the dermis is a layer of loose connective tissues known as the hypodermis or subcutaneous tissue. The hypodermis acts as the flexible connection between the skin and the underlying muscles and bones and a fat storage area (adipose tissue). Adipose also helps to insulate the body by trapping body heat produced by the underlying muscles.

Toenails — Nails are accessory organs of the skin made of plates of keratinized epithelial cells, which are vestigial claws (Figure 3). Fingernails and toenails reinforce and protect the end of the digits and are used for scraping and manipulating small objects. There are three main parts of a nail: the root, body, and free edge. The nail root is the portion of the nail found under the surface of the skin. The nail body is the visible external portion of the nail. The free edge is the distal end portion of the nail that has grown beyond the end of the finger or toe.

Nails grow from a deep layer of epidermal tissue known as the nail matrix, which surrounds the nail root. The cells of the nail root and nail body are pushed toward the distal end of the finger or toe by new cells being formed in the nail matrix. Under the nail body is a layer of epidermis and dermis known as the nail bed. The nail bed is pink in color because of the presence of

TABLE 1. Goal Score

Assessment	Full 2 Points	Some 1 Point	None 0 Points
	Use half points if mixed or intermediate between 2 grades		
Comprehension			
Motivation			
Compliance			
Support Family, caregiver, institutional			
Insight			

Note: The "Goal Score" is another useful tool to determine how successful and how intent the patient and the family are in avoiding a major amputation. Goal Scores greater than 4 ½ points supports the decision to avoid lower limb amputation and do everything possible for salvage of the nonunion.

FIGURE 2. Assessment of skin hygiene and lubrication using a 2-point (best) to 9-point (worst) grading system

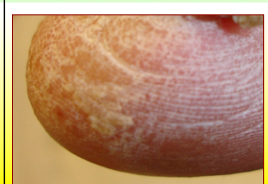
Grade If mixed findings or intermediate between two findings, use half points	Example	Findings	Management
2 Optimal, normal		Soft, pliable well-moisturized, clean skin Free of scaling and plaques	Compliment patient and/or caregivers Continue the same management as before
1 Sub-optimal, marginally satisfactory		Dry, scaly skin Skin in need of cleansing and lubrication	Instruct and demonstrate to patients and/or caregivers skin care measures (see text)
0 Unsatisfactory, in need of immediate attention		Crusts, plaques, eschars, scaling, desquamated skin, debris and/or maceration	Debride in-office or clinic Skin moisturizing and cleansing Skin lubrication

TABLE 2. Specialized cells of the epidermis

Type	Percentage	Function	Comments
Keratinocyte	90	Produces and stores the protein keratin, which makes these cells hard, crusty and water-resistant.	Originates from stem cells at base of the dermis
Melanocyte	8	Produces the pigment melanin to protect the skin from ultraviolet radiation and sunburn.	The number of melanocytes people possess defines their skin color and whether they burn or tan under the sun
Langerhans cell	> 1	Detects and fights pathogens that attempt to enter the body through the skin.	An important component in the first line of defense against skin infections
Merkel cell	< 1	Gives rise to the sensations of touch, movement, vibration, and pressure.	Mechanoreceptors. They form a disk along the deepest edge of the epidermis

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Or Visit Our Website at: www.OurWorldUnderwater.Com capillaries that support the cells of the nail body. The proximal end of the nail near the root forms a whitish crescent shape known as the lunula, where a small amount of nail matrix is visible through the nail body. Around the proximal and lateral edges of the nail is the eponychium, a layer of epithelium that overlaps and covers the edge of the nail body. The eponychium helps to seal the edges of the nail to prevent infection of the underlying tissues.

Skin and toenail wound challenges — The skin and toenails present challenges with respect to the development of wounds that are almost paradoxical. On one hand, these areas are particularly prone to wound problems, especially if one or more of the risk factors for wound development and/or limb amputation, namely: 1) deformity, 2) peripheral artery disease, 3) history of previous foot wound, 4) previous amputation, and/or 5) neuropathy, are present. This is because the skin is always in contact with the external environment, even though covering devices may provide partial barriers, and the skin of the foot transmits the most concentrated forces with standing and walking of any region of the body. Conversely, with simple evaluations and managements, as will be presented in subsequent sections of this article, much can be easily and effectively done to recognize and prevent foot skin and toenail problems.

Predispositions for Skin and Toenail Problems

Comorbidities — Skin and toenail problems are particularly prone to develop in selected patient groups such as those with diabetes mellitus, peripheral artery disease, collagen vascular diseases, vitamin and mineral deficiencies, fluid retention, dehydration and aging. Usually skin and toenail problems secondary to these conditions are associated with the following predispositions.

Hypoxia — This problem is most frequently a consequence of atherosclerosis in the patient population with foot and toenail problems. At rest, noncritical tissues, such as the skin and its underlying tissues, have very low metabolic demands. When these tissues are in a healthy state, the minimal blood supply the atherosclerotic vessels are able to deliver is adequate to meet their metabolic demands. With minimal trauma and the need to repair the injury, however, the blood supply may be inadequate to meet the increased demands for fighting infections and healing of wounds. The consequences are problem, nonhealing wounds. The atherosclerosis process is especially associated with diabetes, but there are many other causes of ischemia and wound hypoxia (Table 3). Collagen vascular diseases with associated Raynaud's phenomena profoundly affect perfusion to the most distal portions of the extremities. Wounds in these areas in patients with collagen vascular diseases are notorious for nonhealing and often result in the need for more proximal amputations. Fluid retention (edema) creates a relative barrier to tissue oxygenation by increasing the diffusion distance from the capillary to the cell. Impaired perfusion from cardiac causes is another cause of tissue hypoxia.

Oxygen requirements — Problems arise when the oxygen demands for fibroblast function, angiogenesis and leukocyte oxidative killing are insufficient to meet

TABLE 3. Ischemia-Related Problems Associated with Wound-Healing Challenges

Problem	Presentations	Management	Comments
Atherosclerotic vascular disease	Localized occlusion, diffuse involvement or combinations	Angioplasty and/or revascularization for localized occlusions Methods to improve wound O_2 such as hyperbaric oxygen therapy and medications	Diffuse vessel disease frequently associated with "problem" wounds
Thrombosis	Abrupt onset of ischemia with a cold, pulseless, pale limb	Thrombectomy and/or thrombolytic therapy	
Venous stasis disease	Hyperpigmentaton, bronzing of skin Venous stasis ulcers	Compression, elevation and vein ligation; most resolve with these measures Challenges occur when venous stasis ulcers are complicated by arterial ischemia	Hyperbaric oxygen, bio-engineered dressings negative pressure wound therapy & skin grafting are useful adjuncts for the most difficult ulcers
Vasculitis	Painful, nonhealing wounds in association with collagen vascular diseases Raynaud's phenomena	Rheumatological interventions including steroids, disease-modifying anti-rheumatic drugs and anti-metabolites to supplement wound care	Healing difficult due to involvement of the microcirculation
Fluid retention	Stasis dermatitis & ulcerations associated with massive peripheral edema	Measures to reduce edema including diuresis, elevation and compression wraps Hyperbaric oxygen and fasciotomy if associated with a compartment syndrome	Oxygen diffusion decreases as capillary to cell distance increases due to edema
Miscellaneous including heart failure, obesity & malnutrition	Findings associated with the primary problem All contribute to wound susceptibility and wound healing challenges	Correction of primary problems in conjunction with wound management When voluntary weight reduction fails, consider bariatric surgery referral as an adjunct for managing morbid obesity.	Once these problems are resolved, the management interventions listed above for the other problems usually effectively resolve the wound problem

FIGURE 3. Komodo dragon and its claws

Legend: The claws of the Komodo dragon, native to Komodo Islands, Indonesia, are the epitome of keratinization of nails.

the skin's and the underlying tissue's demands for repair and controlling infection. The consequences are nonhealing and persistence of infection. Of course, tissues die in the total absence of perfusion, such as after thrombotic occlusion of a blood vessel. If the occlusion is localized to arteries large enough for revascularization, perfusion can be restored. Unfortunately, in the situations previously described, perfusion problems usually are also present at the microcirculation level, so these techniques may have only limited success.

Deformities — These are one of the three findings we label as the "troublesome triad," invariably found in the problem wound.[2] Deformities in weight-bearing areas or other areas subject to contact stresses transfer increased pressures to the skin. If the stresses are acute and localized, a blister forms, as often occurs with walking activity associated with new or ill-fitting footwear. If the pressures are intermittent or subcritical (that is, below a threshold where primary damage occurs to the skin), the skin and underlying tissues react in several ways.[3] First, calluses form over deformities. This is a protective response to the stress manifested by thickening and keratinization of the epithelium. Second, the tissues below the skin over the deformity generate a bursa. With chronic, repetitive stresses, a third response occurs, namely hypertrophy of the bone at the apex of the deformity. This appears on x-rays as periostitis and spurring (eburnations, exostoses, and osteophytes).

Secondary problems from deformities — With continuation of the pressure stresses, secondary problems arise from the reactive processes. If moisture accumulates under the callus, the skin macerates. If the process is not interrupted by debriding the callus and exteriorizing the macerated tissue, erosion of the skin and introduction of bacteria can occur. If the firm callus cracks or develops a fissure, a pathway is provided for bacteria and moisture to accumulate between the callus and the skin. This provides an environment conducive for bacterial multiplication, development of cellulitis, ulceration, and a pathway for deeper infection to occur. The other problem is the generation of a mal perforans ulcer. This problem is an ulceration that arises from inside to outside due to continued pressure stresses the deformity transfers to the overlying skin. A mal perforans ulcer is characterized by a tract from the skin to the soft tissues immediately overlying the bone. If this protective envelope is breached, bacteria have direct access to bone, and osteomyelitis is a possible consequence. The bacteria may multiply, generate an abscess, and then result in the infection dissecting along tissue planes and/or tendon sheaths. The consequences can lead to a progressive necrotizing, limb-threatening soft tissue infection. Interventions need to be initiated immediately to manage deformities where ulceration is a risk due to their presence.

Neuropathy — This problem contributes indirectly to skin and toenail problems. Peripheral neuropathies are especially common in patients with diabetes, but they can be associated with other problems such as spinal cord injury, Parkinsonism, strokes with residual neurological deficits, multiple sclerosis, trauma, and congenital disorders. Peripheral neuropathies have three presentations that are a factor in the genesis of problem wounds.

Neuropathy affecting the autonomic nervous system results in dryness of the skin. Early manifestations are scaling and loss of the normal elasticity of the skin. The debris from scaling may accumulate to form crusts and plaques. Dry skin is less able to tolerate shear and contact pressure stresses than normally moisturized skin, thereby making it subject to breakdown with normal activities. Evaluation and management of skin problems associated with autonomic nerve dysfunction are discussed in the next section.

Impairment of motor function — Motor neuropathies cause imbalances in muscle activities. Initially these cause nonfixed positional deformities of joints. With persistence, the positional deformities become fixed, resulting in contractures (i.e., permanently stiff and/or malaligned joints). Common deformities observed in the feet because of muscle imbalances include clawed toes, hammer toes, mallet toes, hallux valgus/bunions, and equinus contractures. With solitary muscle weakness or dysfunction, other manifestations such as midfoot hyperpronation from posterior tibial muscle-tendon dysfunction and drop foot from peroneal nerve palsy are observed. Peroneal muscle weakness is manifested by foot inversion, resulting in overloading of the lateral bony prominences of the foot such as the fifth metatarsal base and the lateral aspect of the fifth metatarsal head. Contractures with clawing of the toes pulls the fat pads under the metatarsal heads toward the heel so they no longer offer protection for the metatarsal heads. Dorsal subluxation of the proximal phalanges of the toes at the metatarsal phalangeal joints (with proximal retraction of the toes in association with the claw toe deformities) forces the metatarsal heads plantarward. Attention to these problems with protective footwear, orthotics and surgeries will be discussed in a subsequent article.

Loss of sensation — Sensory neuropathy is a third neurological problem that can indirectly contribute to foot and toenail problems. With loss of protective sensation, impending injury to the skin and toenails may

The terms dynamic and static should also be considered when describing abnormal posturing of joints. Dynamic deformities indicate that the contractures are due to muscle activity imbalances such as observed early in the course of disease in patients with cerebral palsy, strokes with residual neurological deficits, multiple sclerosis, etc. The contractures are not fixed. With physical therapy, splinting, medications and tendon surgeries, the deformed joints can be corrected and maintained in nearly normal position.

Static deformities imply that the contractures are fixed, that is not correctible with the measures to manage dynamic contractures. Because of the persistence of the deformities, joint capsules become contracted, muscle-tendon units shortened and joints arthrodesed. To correct fixed/static joint contractures, surgery is invariably required.

If wounds, calluses, or toenail problems are already present, a simplified clinical grading system analogous to the other 0- to 2-point assessments is recommended. A grade of 2 points indicates normal sensation and anesthesia is needed for debridements and all other in-office procedures other than toenail trimming and callus paring. A grade of 1 point indicates patients perceive pain with procedures on wounds and toenails, but the procedures usually can be done with no or only locally applied analgesics. A grade of 0 points indicates a total loss of sensation and in-office procedures can be done on the foot without anesthesia. If findings are mixed or intermediate between two grades, half points may be used to reflect the transition.

TABLE 4. Conditions the May Be Predispositions to Skin and Toenail Problems

Condition	Problems	Comments
Age	Slower metabolism, increased doubling times for fibroblasts, impaired circulation, blunted immunological responses, atrophic changes of the skin, etc.	Age blunts healing responses and ability for the body to mitigate physical stresses
Androgen deficiency	Observed in catabolic states associated with trauma and nutrition problems	Consider androgen supplements when these conditions exists
Anemia	Compromises oxygen delivery to healing and infection fighting tissues	Anemias are associated with other wound healing problems such as chronic infection, kidney diseases and malnutrition
Ehlers-Danlos syndrome	Connective tissue disorder with many presentations Nonhealing wounds and difficult to control infections observed following "clean" surgeries	Problems probably related to defective fibroblast function
Gout (Hyperuricemia)	Uric acid precipitates form crystals (tophi) in tissues vulnerable to trauma, especially over bony prominences	Uric acid level should be checked especially in patients with wounds over bony prominences
Hypercoagulable states	Hypercoagulable conditions include protein C deficiency, anticardiolipin antibodies, Factor V Leiden deficiency, protein S deficiency plasminogen activator inhibitors, homocystein disease, high lipoprotein a, warfarin induced skin necrosis, etc.	Work-ups for these conditions are required when seemingly unexplainable skin sloughs (usually massive & multiple) occur
Hypothyroidism	Slowing of metabolism Dry, pale, cold scaling skin and brittle nails observed	Thyroid function should be assessed in patients on thyroid medications who have wounds
Liver disease	Deficiencies in the formation of protein, growth factors, cytokines and immunological factors Hepatitis a comorbidity in some problem wounds	Blood liver panels and hepatitis studies indicated in patients with chronic wounds
Malnutrition	Inability to form protein and immunological factors needed for wound healing and infection control	It is essential, regardless of the patient's weight, to ascertain nutritional status when "problem" wounds exist
Medications	Medications such as steroids, nonsteroidal anti-inflammatory drugs, immunosuppressors and disease modifying anti-rheumatological drugs interfere with the inflammatory response	These medications coupled with wound healing problems from the underlying diseases (such as collagen vascular diseases) complicate wound healing
Purpura fulminans	Intravascular coagulopathy usually secondary to life threatening infection cause widespread thromboses in the microcirculation often result in massive sloughs and even limb losses	No effective treatment known to manage the stasis in the microcirculation. Hyperbaric oxygen aids in the demarcation of viable and non-viable tissues and in wound healing
Renal insufficiency and end-stage renal disease	Metabolic waste products create an environment adverse to wound healing. Usually other problems such as diabetes, anemias and vascular disease co-exist, which compound wound healing problems	Wound healing is challenging, but possible in many situations with strategic management and special wound healing considerations
Trauma	Acute problems such as nutrition, blood supply and infection interfere with healing Chronic problems such as scar formation, deformities and altered blood supply are precursors to the development of new "problem" wounds	Once wound healing has occurred, proactive measures to prevent new problems including orthotics, special footwear and proactive surgeries may be required

not be appreciated and treatment delayed until more complicated problems develop from the injury. Generally, sensory perception below the "protective sensation" level puts the patient at risk of occult injuries occurring to the skin and toenails without appreciation of pain. Protective sensation is ascertained by testing with a monofilament that bends when approximately five grams of pressure is applied to it. The monofilament is placed on the skin and pressure is applied. If the patient perceives the monofilament touching the skin before it bends, then protective sensation is present. To be valid, the testing should be repeated at the same and different sites. If calluses or other signs of impending wounds or obvious wounds are observed during the exam and the patient walked into the office with no apparent discomfort from the sites, the clinical inference can be made that protective sensation is lacking, regardless of monofilament testing.[4]

Problems associated with metabolism and immunity — These problems, in particular, are associated with diabetes. A number of other metabolic, immune-system and related conditions, however, may be predispositions to skin and toenail wound problems (Table 4). Elevated blood and tissue fluid sugars provide a more favorable environment for bacterial multiplication and wound infection than in patients with normal blood glucose levels. Atrophy of protective fat pads under metatarsal heads is another finding associated with diabetes. Whether this is a consequence of diabetes, ischemia, common neuropathy, or a combination of these is unclear. The result is less protection of the skin over the metatarsal heads and increased susceptibility to ulcer formation.

Hyperglycemia in patients with diabetes cause increased oxidative stress; increased expression of redox-regulated, proinflammatory genes and transcription factors; and changes to the composition of the extracellular matrix and functional deficits of proteins.[5] Some of the changes affect function of mitochondria, suppress cellular immune defense, and alter elasticity of blood vessel walls.[6,7] Consequences include microangiopathy, polyneuropathy, and changes in connective tissue composition.[2] In patients with diabetes, tissues may become less resilient to sheer and compression stresses.[8] This may be due to glycosylation of proteins in soft tissues, which adds to their rigidity. Loss of elasticity in tendons, ligaments, and joint capsules may contribute to joint contractures and deformities as well as tendonitis and tendon ruptures.

Problems associated with connective tissue diseases — Lupus, dermatomyositis, scleroderma, seropositive arthropathies, and mixed connective tissue disorders, although not usually classified as metabolic disorders, have metabolism-related problems and are notorious for being associated with "problem" and "end-stage" wounds. Vasculitis, a common feature in these disorders, occurs at the microcirculation level and can interfere with perfusion enough to arrest healing of even the most minor wounds. Protein complexes and antibodies cause atrophy and fibrotic changes in the skin and subcutaneous tissues as well as other parts of the body, such as the esophagus and the lungs. Calcium deposition in the subcutaneous tissues (calciphylaxis) serves as a nidus for skin ulceration and infection. The etiology for this is not established but may be due to tissue hypoxia, altered acid-base states, abnormal protein complexes or combinations of these. Raynaud's phenomenon with intermittent, severe ischemia of the fingers and toes often precipitated by cold exposure or localized trauma may be mediated by the sympathetic nervous system. Consequences of Raynaud's include soft tissue atrophy, acrosclerosis (ends of the digits become pointed), and nonhealing ulcerations of the fingertips probably after occult trauma. Finally, the use of immunosuppressors (steroids, antimetabolites, nonsteroidal antiinflammatory agents and disease-modifying antirheumatoid drugs) interferes with wound healing and the ability to control infection.

Clinical correlations: A 46-year-old female with a diagnosis of mixed connective tissue disorder on steroids developed a paronychia secondary to an ingrown great toenail. This was managed with surgical decompression and antibiotics. The wound failed to heal, and the distal portion of the toe became necrotic. A partial toe amputation was done. Primary healing appeared to be occurring, but when the sutures were removed, the wound dehisced and developed a necrotic, infected base.

An amputation of the toe at the metatarsal phalangeal joint level was done. Hyperbaric oxygen was given as an adjunct to healing of threatened flaps even though foot pulses were palpable and transcutaneous oxygen measures were normal. This surgical site also failed to heal, and the wound site deteriorated so badly after a couple of months that a more proximal partial first ray amputation became necessary.

When the partial first ray amputation failed, a metatarsal amputation was performed, but gradually dehisced and the wound failed to heal. Subsequently, this led to a below-knee amputation, which healed. Unfortunately a wound developed on the opposed foot, which also eventually ended up in a below-knee amputation on that side.

Comment: This scenario demonstrates the wound-healing difficulties that some patients with collagen vascular diseases may encounter. The distal vasculitis problems in the microcirculation appeared to be so severe that perfusion may only be adequate enough to maintain the steady state but unable to increase enough for wound healing to occur. Palpable pulses and normal transcutaneous oxygen measurements are no guarantee that wound healing will occur in this patient group.

Foot Skin Evaluation and Management

Grading skin condition — Skin assessment is essential for preventing wounds. For those at-risk groups, as previously discussed, checking the skin for precursors of wounds should be done daily by the patient or the caregiver. A simplified, objective grading method based on a 0- to 2-point assessment system (similar to the assessment approach used in generating the Goal Score) is useful for evaluating, documenting, and managing skin hygiene and lubrication (Figure 2). From this grading system, immediate decisions become obvious for appropriate management of the skin. For example, if the skin has a healthy appearance and is moist and pliable (skin assessment = 2 points), the patient and/or their caregivers should be complimented and encouraged to continue the same care they have been doing.

If the skin is dry, scaly, and in need of lubrication (skin assessment = 1 point), the patient (or caregivers) should be instructed in foot and leg skin care measures (Table 5). These include the following four steps (Figure 4):

1. **Moisturizing and cleansing:** This is done by showering, bathing, soaking the feet in a basin or wrapping the feet and legs with a warm, moist towel. Warm, not hot, water should be used. The skin should be gently cleansed of debris using a soft cloth and a mild soap or skin cleanser

during the moisturizing period. Contact with water should be for periods less than 10 minutes to prevent maceration of the skin.

2. **Drying the skin:** This is done with a soft towel or cloth. Additional debris on the skin may be removed while drying the skin. The skin between the toes should be carefully dried and cleansed of debris to prevent fungus infections from moisture remaining in the intertriginous region. If fungus infection is apparent with findings of redness, fissures, dead skin, localized scaling of the skin and/or odor, an over-the-counter fungicidal agent [e.g., tolnaftate (Tinactin®), clotrimazole (Lotrimin®), miconazole (Micatin®), etc.] should be used for application to the affected areas after skin care is completed.
3. **Lubrication and massage:** After the skin is dry, it should be lubricated and massaged with a lubricating agent. The active lubricating agent in most skin lotions is either a petrolatum/glycerin, lanolin or silicon-based product. A multitude of products are available (Figure 5). Usually lubrication and massage only take a couple minutes of time since the moisturized skin tends to readily absorb the lubricating agent. Petrolatum jelly (Vaseline®) is the "ideal" lubricating agent because of its effectiveness and economies. The disadvantages are it requires effort to work it into the skin, and it can leave a greasy residue.
4. **Removal of residuals of the lubricating agent:** This should be done with a soft cloth or towel. Once this step is completed, the skin should feel soft and pliable without a greasiness feeling or visible residuals of the lubricating agent on the skin. Care should be given to removing residuals of the lubricating agents from skin creases and between the toes where moisture accumulation under the agent could lead to maceration and fungus infection.

Zero-point skin grade — If plaques, scales, or hyperkeratinization are present on the skin, skin care should be done in the office or patient's hospital room (Figure 6). Plaques, scales, and hyperkeratinized skin may be debrided with a scalpel. If the skin is in need of cleansing and debridement, a finding frequently noted after cast removal, pulsatile lavage is an effective technique for removing loosely adhering skin

TABLE 5. Types and Components of Skin Lubricating and Cleansing Agents

------------------Categories of Products ------------------	
Lotion	A liquid preparation applied to the skin—usually with dissolved drugs in it
Cream	A thick, oily emulsion with suspended drugs in it
Ointment	A semi-solid preparation that softens, but does not melt when applied to the body with or without added drugs
--------------Lubricants/Moisture Retainers--------------	
Hydrogels (Hydrosols)	A colloid in which the particles are the external or dispersion phase and water is the internal or dispersed phase This is an excellent choice for maintaining a moisturized environment for the healing of a healthy based wound
Petrolatum (Petroleum jelly)	An intermediate product in the distillation of petroleum with excellent skin lubricating properties. Used as a base for many ointments; Prevents evaporation of moisture from the skin Greasy residues after application must be wiped off the skin to prevent moisture retention and bacteria multiplication under the film, especially in regards to the toes
Glycerol (Glycerin)	A fluid obtained by the saponification of fats and vegetable oils. Used as solvent or skin emollient and as a transport vehicle for other agents. Also, prevents evaporation of moisture from the skin
Lanolin	A fatty substance produced from glands in sheep skin that is water insoluble, has barrier properties, blocks contact with water products such as urine and prevents evaporation of skin moisture
Silicones	Polymers of organic silicon oxides which may be liquids, gels or solids depending on the extent of polymerization; can be used as greases or sealing agents
----------------------------Cleansers -------------------------	
Soaps	The sodium or potassium salts of long-chain fatty acids used as an emulsifier for cleansing purposes
Medicinal soft soaps	Soaps made with vegetable oils, potassium hydroxide, oleic acid, glycerin and purified water used as a cleansing agent and stimulant in chronic skin diseases
Hydrogen peroxide	An unstable compound readily broken down to water and oxygen that loosens and cleanses debris and acts as a mild antiseptic
Alcohols	A series of organic chemical compounds used as a cleanser, rubefacient (i.e. causes erythema of the skin), coolant and disinfectant
Solvents	Liquids that hold other substances in solution; organic solvents are cleansing agents useful for removing adhesive residuals, oils, fats, etc., but are harsh to the skin and should only be used on a one-time basis
-------------------------Additives ----------------------------	
Fragrances	Provide pleasant odors, oftentimes helping consumer to identify the product; masks unpleasant odors
Colorants	Enhance visual appeal of the product; camouflages unpleasant appearances of other ingredients
Thickening agents/vehicles	Improve consistency, e.g. corn starch, talc, hydroxyethel cellulose, xanthan gum, essence of oats, etc. Thickening agents bring the product to a specified quantify—i.e. a "filler" such as mineral oil, petrolatum cetyl alcohol and propylene glycol
Keratolytic agents	Useful for removing thickened, hypertrophic, desquamated and callused skin and skin debris; e.g. dimethicone, papain ureas, collagenases, etc.
Antipruritics	Control itching, e.g. diphenhydramine, steroids, zinc oxide, iron oxide, tacrolimus
Anti-inflammatories	Reduce inflammation; helps to control itching, e.g. hydrocortisone, betamethasone, diclofenac
Pain relievers	Reduce pain; e.g. local anesthetics (lidocaine, benzocaine), analgesics (salicylates, menthol, capsaicin, camphor), topical narcotics
Anti-aging agents	Decreases fine skin lines by removing dead skin; e.g. tretinoin, moisturizers, estrogens, Vitamin E ointment
Anti-infectives	Kill bacteria or fungi; e.g. single/double/triple antibiotic products, antifungals (clotrimazole, nystatin, tolnaftate), phenols, menthol, etc.
Moisture barriers	Physically block moisture contact with skin, e.g. zinc oxide ointment, lanolin, petrolatum, etc.
Sun blocks	Prevent ultraviolet rays A and B from skin penetration, e.g. octocrylene, octylmethoxycinnamate, etc.

Comments: Although this list is extensive, it is not all inclusive: Hundreds, perhaps thousands, of additives can be found in skin lubricants and cleansers. These generic categories help the user to understand the roles of the ingredients. Some over-the-counter skin agents have 30 or more ingredients.

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debris. While plaque and callus removal is usually done by the physician, the four-stage foot and leg skin-care measures are usually done by assistants helping the physician. While performing the initial skin care for the patient, the assistants teach the patients how to do the four-step skin-care protocol. How well they follow these instructions becomes apparent at the next return visit, reflects patient compliance, and is a criterion for how often the patient needs to return for follow-up care.

Toenail Evaluation and Management

Toenail evaluation — Toenail care deserves equal consideration to foot and leg skin care as a prevention strategy for wounds. Any patient who has risk factors for wounds (deformity, peripheral vascular disease, history of previous wound, previous amputation and neuropathy) should have his/her toenails inspected each time the feet are examined. Although many conditions cause toenail abnormalities, four findings are most frequently associated with "problem" wounds (Figure 7). Usually two or more findings are present and include the following:

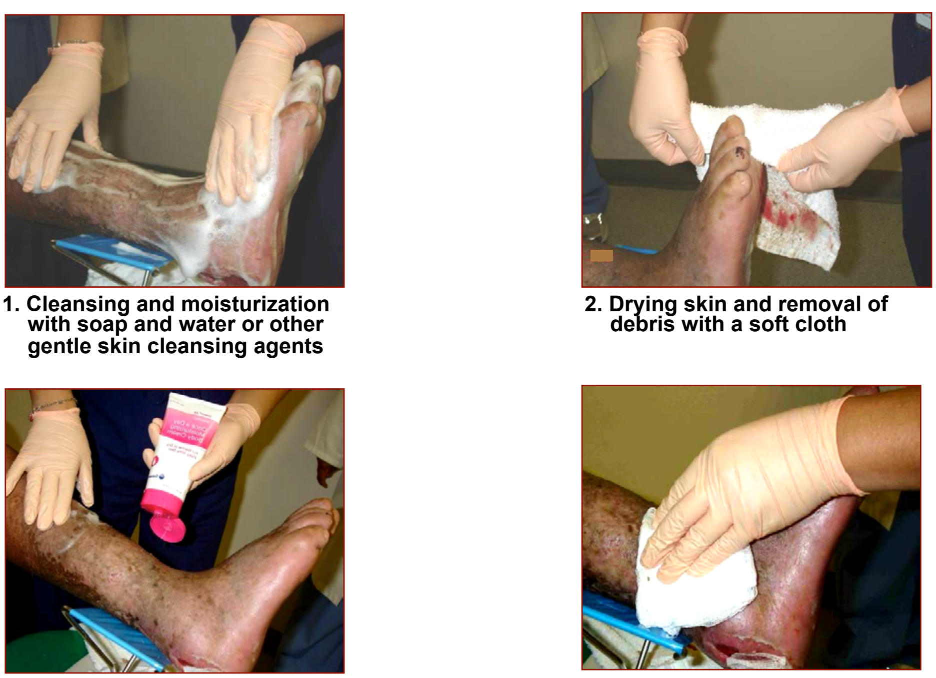
1. **Dysmorphic changes:** This finding indicates that the shape of the toenail is abnormal. The toenail end may be curved like the shape of a spoon, vaulted like a cathedral ceiling or curled like a ram's horn. Usually dysmorphic changes are due to abnormalities in the nail bed from underlying bony deformities or from pressure effects from footwear. When the toenail edges are curved, debris often becomes embedded between the curved toenail edge and the underlying skin.
2. **Dystrophic changes:** These problems are reflected in abnormal growth of the toenail and usually arise from problems in the nail matrix from circulation, disease, trauma, toxic substances or congenital problems. Presentations include thickened, furrowed, discolored, and hypoplastic toenails.
3. **Fungus infected:** Although fungus infection may be a primary problem of toenails, in patients with sensory neuropathy, occult trauma may also be a cause. With occult trauma in these patients, the toenail may be partially avulsed from the nail bed without being recognized. This may allow moisture to accumulate under the toenail and provide an ideal environment for the fungus to grow. Fungus infected toenails become discolored, thickened, friable, honeycombed and/or laminated (layers of infected toenail and debris).
4. **Ingrown:** Direct trauma or contact pressure from shoe and sock wear may force the edge of the toenail into the recess between it and the paronichium. This may introduce bacteria and cause a localized cellulitis or abscess (paronychia) or pyogenic granuloma. Another way bacteria are

For efficiency sake in the office setting, the abbreviations FSC (foot skin care) and TLC (tender loving care) are useful. For example, when it is ascertained that FSC (including the legs, if necessary) needs to be done in the office, the patients are informed that we plan to do TLC for their skin and in the process teach them how to do FSC in the home setting.

Usually when patients hear the words "tender loving care," they feel they are getting special attention. The use of these abbreviations also saves time for documentation of the treatment plan.

Another situation where TLC is effectively used is for cleansing and lubrication of the skin after cast removal. When this is done, the patients feel they are getting an additional "extra measure of care."

FIGURE 4. Four-step skin cleansing and lubrication technique



1. Cleansing and moisturization with soap and water or other gentle skin cleansing agents
2. Drying skin and removal of debris with a soft cloth
3. Lubrication and massage using a skin lotion
4. Wiping off lubricant so no greasy residuals remain on the skin—this is especially important for the skin between the toes

introduced into the skin is when the distal edge breaks off or is trimmed off leaving a hook shape to the edge of the toenail. As the toenail grows outward, the hook end of the toenail grows into the adjacent paronichium.

Grading toenail condition — As in the skin grading system, a simple, quick-to-use 0- to 2-point assessment is recommended for evaluation and management of toenail problems (Figure 7). Management of toenails in patients with risk factors for wounds becomes obvious when the assessment system is used. If the toenails are the proper length and normal in appearance (nail assessment = 2 points), the patients should be complimented and encouraged to continue the same care they have been giving to their toenails. If the toenails are long and/or the ends of the toenails are jagged (nail assessment = 1 point), but otherwise normal in appearance, two options exist. If the patient is agile and his/her vision is OK or the caregivers are conscientious, they may trim the nails straight across. More preferable, especially if sensory neuropathy is present, is to have them use a disposable nail file to keep the nails at the proper lengths with frequent filings. If the patient and/or caregivers are unable to care for the toenails, then they should be trimmed with nail cutters in the office setting by care providers properly trained in toenail care.

If the toenails are dysmorphic, dystrophic, fungus infected or ingrown (nail assessment = 0 points, Figure 8), toenail management should be done by podiatrists, orthopaedic foot surgeons or health-care providers trained in toenail care using sterilized nail instruments specifically designed for these purposes. Embedded material at the nail margins should be debrided. The hooked ends of ingrown toenails should be trimmed proximally to achieve a smooth nail edge. This may require trimming the nail edges along the eponychium to a curved rather than straight-across toenail end (Figure 9). Thickened, fungus infected toenails should be thinned until they are tissue paper thickness (Figure 10).

Toenails that are no longer attached to the underlying nail bed should be debrided proximally until they are attached to the nail bed. This usually eradicates the infected portion of the

> A small rotary craft tool with a cylindrical sanding attachment very effectively debulks and contours thickened toenails.
>
> Personnel who use the tool should be gloved, gowned, caped, and masked to protect themselves from the flying debris that arises from this technique.
>
> A new sanding cylinder needs to be used for each patient. The flying debris generated by the rotatory sander should be simultaneously vacuumed as it is produced.

FIGURE 5. Skin and cleansing lotion choices

Legend: Innumerable skin cleansing and moisturizing agents are available. Choices differ by addition of colors, perfumes, anti-aging agents, sun protection factors, smoothing and firming products, etc.

FIGURE 6. Debridement of skin in the office

A foot presented with crusts, plaques, eschars, scaling, and debris

Debridement in-office or clinic with a scalpel

toenail. In this situation, a sensory neuropathy can be a boon to toenail care since very complete toenail care can be done without requiring local anesthetics or the patient experiencing pain. Once this toenail care is completed, the edges of the toenail and the recesses should be painted with an iodine containing disinfectant for infection prophylaxis.

Zero-point toenail grade — The above approach to complicated toenail problems (nail assessment = 0 points) exemplifies the surgical perspective, that is to aggressively eliminate the problem using appropriate instruments. The time required to achieve this goal is measured in minutes. The other approach when fungus infection of the toenail is present is the medical one using oral fungicidal agents. The more severe the involvement, the less likely fungicidal agents will be effective. At best they cure the infection in 40-70% of the cases.[10]

FIGURE 7. Assessment of toenails using a 2-point (best) to 0-point worst) grading system

Grade If mixed findings or intermediate between two findings, use half points	Example	Findings	Management
2 Optimal, normal		Healthy appearing, appropriate length toenails Note:*Toenail polish should not be used if risk factors for foot wounds exist	Compliment patient and/or caregivers Continue the same management as before
1 Sub-optimal, marginally satisfactory		Long and/or irregular ends of trimmed toenails	Trim toenails with sterilized surgical-quality nail clippers in the office/clinic Instruct patients in trimming techniques including use of a nail file to contour and shape toenail ends
0 Unsatisfactory, in need of immediate attention		Diseased toenails (Figure 8) in need of immediate management	Debride, debulk with sterilized surgical-quality nail clippers File and contour with a nail file or rotating sanding drum Teach patient and/or caregivers toenail filing techniques

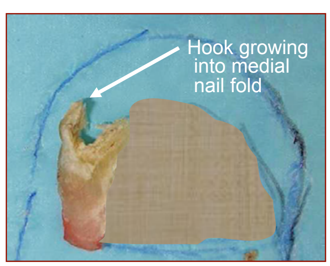
*Risk factors for wound development include: deformity, previous amputation, peripheral artery disease, previous wound and/or neuropathy.

FIGURE 8. Common toenail problems

Dystrophic, fissures, laminated, irregular end

Long, Dysmorphic (dome shaped)

Thickened, fungus infected, embedded debris



Ingrown (hook) of medial nail fold which can lead to a pyogenic granuloma or paronychia

Legend: These examples are among the most frequent toenail problems encountered in a wound healing center. They should be always be documented and managed appropriately.

> In the United States it is estimated that 35 million people are affected with toenail infections. About $1 billion a year is spent on medications trying to eradicate them.[9,10]

In the USA, over a billion dollars is spent each year on oral and topical agents that are used to treat toenail infections.[10] Furthermore, medical management of infected toenails may take takes months or more to cure the problem, if indeed it cures it at all, and monitoring of toxicity from the agent with liver function tests is often required. Once initial debridement of the complicated toenail problem is done, the patient is usually asked to return in a couple of weeks to “fine-tune” the toenail appearance by hand filing and further contouring the toenails.

> Laser treatment of fungus-infected toenails is currently being investigated (not yet approved by the Food and Drug Administration). The treatment with lasers costs $1,000 or more and has reportedly been observed to be effective in 50% to 75% of cases.[11]

“Do’s” and “Don’ts” Pertaining to Skin and Toenail Care

In the previous article, we presented a list of “do’s” and “don’ts” that should be taught to patients with risk factors for foot wounds and/or their caregivers. A number of them are pertinent to skin and toenail care. For this reason, those that apply to foot skin and toenail care are now repeated in tabulated form in this section.

"Do's" with Respect to Preventing Skin and Toenail Problems

- Inspect feet daily (look for area of erythema, attenuation of skin, discharge, or odor).
- Practice good foot hygiene, including skin lubrication (use the 0- to 2-point assessment system to evaluate and determine the appropriate management).
- Perform appropriate toenail care (this may be done by the patient and/or the caregiver with assessment of 2 or 1 point. If the patient's mobility, vision, or both are a concern, however, and/or with assessment of 0 point, the toenail care should be done by properly trained providers).

"Don'ts" to Prevent Skin and Toenail Problems

- Don't walk barefooted (in the presence of neuropathy, patient might not appreciate a punctured wound, which can inoculate the underlying tissue and lead to serious infections).
- Don't use heat on the feet and don't soak the feet in hot water (with impaired sensation, the patient might not appreciate that the water will burn the skin and with poor circulation, the patient has impaired ability to dissipate the heat stress to the skin, thereby resulting in burns).
- Don't use chemicals or sharp objects to trim calluses (same consideration as for not walking barefooted).
- Don't trim corners of toenails (unsterile, over-the-counter toenail clippers may accidentally cut into the eponychium and lead to infections).
- Don't use toenail polish, especially if risk factors for foot wounds exist (toenail polish may trap moisture and provide an environment for the fungus to thrive).

Conclusions

The skin of the feet and the toenails are windows to the interior of the body. Being that they are the furthest distance from the body core, they may be the first to demonstrate circulation problems and the development of neuropathy. Consequently, what you see in these structures can tell you a lot about the patient's wellness. Most patients, their caregivers, and even health-care providers often do not take the time to look into the window, that is, to examine the skin of the legs and feet and inspect the toenails. The other benefit of examination of these structures is to confirm how well these patients follow instructions and are compliant with recommendations. When risk factors for wound

FIGURE 9. Toenail care techniques


Filing and contouring of toenails


Trimming with nail clippers


Debriding with ronguer


Debulking with rotatory sanding cylinder

Legend: Instrument selection for toenail management depends on the severity (assessment grade - Figure 7). Often two instruments are used to optimize outcomes such as a nail clipper for trimming and a disposable nail file for achieving smooth ends and contouring the toenails.

FIGURE 10. Establishment of healthy margins for severely diseased toenails


Before toenail care

After toenail care

Legend: Appropriate toenail care to eradiate fungus disease and ingrown margins may require trimming the nail to the matrix and removing embedded debris and ingrown portions from the eponychium. If bleeding occurs, a silver nitrate applicator effectively cauterizes the bleeding site. Because of the extent of the debridement, the toenail and adjacent eponychium should be "painted" with an iodine solution or similar disinfectant.

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development in the feet and legs are present, the skin and toenails are without question the first line of defense for their prevention. Fortunately, as this article shows, evaluation and management of skin and toenail problems can be objective as well as quick and easy to accomplish. ■

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Complications Associated with Lymphedema

By Heather Hettrick PT, PhD, CWS, CLT-LANA, CLWT

Lymphedema is a chronic disease that requires lifelong management. Early recognition and diagnosis improve patient outcomes and reduce the likelihood of associated complications. This article will highlight the more common complications associated with lymphedema to enable the health-care provider to more readily identify these issues early.

Most complications associated with lymphedema are due to the excess fluid burden placed upon the tissues. This can lead to a variety of impairments and complications, many of which are interrelated. Other complications may arise from medical interventions that may lead to a secondary lymphedema as well as other medical challenges for the patient. Complications can include but are not limited to the following:

- disturbance of local cellular metabolism
- increased rates of infection due to fluid stagnation and associated integumentary changes
- integumentary dysfunction (i.e., fibrosis, papillomatosis, denudement/ulceration, alterations in skin barrier function/acid mantle)
- progressive lymphatic damage and associated impairments in the arterial and venous vascular systems
- lymphatic arthropathy and related orthopedic impairments
- malignant degeneration

It is also important to note that the underlying cause of lymphedema and the associated body areas affected will play a part in the potential complications that may arise. It is incumbent upon the health-care provider to thoroughly evaluate the patient, review all the body systems, and ask specific questions to elicit a complete clinical picture.

It is well recognized that many secondary lymphedemas are due to various forms of cancer. Most forms of cancer are treated with surgery, radiation and/or chemotherapy, or any combination thereof. Certain complications may arise secondary to lymphedema and the related cancer interventions. For example, breast-cancer-related lymphedema is often associated with axillary web syndrome (AWS), radiation injury/dermatitis and fibrosis, and radiation-induced brachial plexopathy.

AWS (also known as Mondor's disease, lymphatic cording, subcutaneous fibrous banding, fiddle-string phenomenon, lymph vessel fibrosis, lymphangiofibrosis thrombotica occlusive, and lymph thrombosis) is due to disruption of axillary lymphatics usually related to node dissection, sentinel lymph node dissection, trauma, or obstruction from cancer. The injury interrupts the lympho-venous channels resulting in thrombosis and stagnation of fluid, which in turn results in inflammation, fibrosis, and a shortening of surrounding tissue. AWS is a visible and palpable web of tissue that becomes taut with shoulder abduction. It is typically located in axilla and can extend distally along the anterior, medial upper arm toward antecubital space; it may also extend to the thumb. It is best managed with specific manual techniques and at times is self-limiting.

Radiation injury results from morphological and functional changes that occur in noncancerous tissue due to ionizing radiation. These changes can be mild to life-threatening. Irradiation of the skin causes dose-dependent damage to the skin and can result in acute or chronic radiation dermatitis. Acute radiation dermatitis is an inflammatory reaction due to direct injury to the cell, whereas chronic radiation damage occurs as a summation effect after multiple exposures to low-level radiation. It is important to note that roughly 85% of patients treated with radiation therapy will experience a moderate to severe skin reaction.[1]

Typically, within the first week of radiation there may be visible or faint erythema due to capillary dilatation and an increase in vascular permeability. During the second to third week, radiation inhibits mitotic activity in germinal cells of the epidermis, causing hair follicle and sebaceous gland epilation and xerosis. Cell production decreases, and dry desquamation or scaling begins. Endothelial swelling and proliferation causes obstruction, which is due to fibrin thrombi in the arterioles. During the third to fourth week, moist desquamation may result from skin peeling, vascular dilatation, edema, and oozing of serum from denuded areas; the skin is red, warm, tender, and edematous with telangiectasias. Chronic radiation dermatitis develops after a more severe acute radiation reaction or as a result of high amounts of total radiation. Latency, however, can be 2 to 10 years following radiation therapy.[2] In either situation, patients with concomitant lymphedema should have modifications made during complete decongestive therapy (CDT), particularly with manual lymph drainage and compression, so further disruption to the radiated tissue is mitigated.

Radiation fibrosis is another potential complication with a unique presentation that may present in patients with lymphedema. It is a reaction of the skin to irradiation with visible and palpable changes. The skin is bound down with reddish-brown discoloration and telangiectasia. Radiation causes slow retreat of microcirculation in soft tissues, leading to ischemia, scar-tissue formation, and fragile skin. Health-care providers must consider the secondary effects of radiation fibrosis and the potential impact these have on patient function and quality of life. Patients with radiation fibrosis also require modification with CDT to prevent skin integrity issues at the already compromised areas. Deeper manual lymph drainage and fibrosis techniques are not recommended on areas with radiation fibrosis due to the tissues fragility.

Another complication related to radiation therapy is radiation-induced brachial plexopathy (RIBP). This is caused by radiation damage to the brachial plexus. Symptoms may include paresthesia (tingling, pricking, numbness), dysesthesia (abnormal sense of touch, such as burning, itching, feeling of an electric current, "pins and needles," pain), decreased sensitivity, partial loss of movement (muscle weakness and difficulty performing simple tasks such as opening jars or containers, holding objects), complete paralysis of the arm, muscular atrophy, impaired mobility, and even partial dislocation of the shoulder joint. The exact mechanism of RIBP is not completely understood. Damage to the brachial plexus results from a combination of direct nerve cell damage from ionizing radiation and progressive damage from scar tissue (radiation fibrosis) in and around the nerves, combined with damage to adjacent vessels that supply these nerves with oxygen and nutrients. Most patients develop symptoms within the first three years; however, the average interval between the last dose of radiation and the onset of RIBP symptoms reported in the literature varies widely with a range between 6 months and 20 years. The prevalence of RIBP is reported to be between 1.8% and 4.9%, and RIBP is more common after radiation in combination with chemotherapy.[3]

PHOTO 1. Papillomatosis and fibrosclerotic skin changes

Other specific anatomical sites subject to lymphedema include the genitals as well as the head and neck. Genital lymphedema in men can lead to complications including loss of sexual function, infertility (depending upon the severity), difficulties in urination, severe social stigma, skin rashes, and fungal infections. Head and neck lymphedema can lead to significant impairments in eating and mastication, swallowing, speech, and breathing. Both require specific management techniques and interventions. These conditions, however, are readily manageable with good functional outcomes and usually a return to a near-normal morphology.

The most common complications seen in patients with lymphedema are secondary infections of the skin and underlying tissues. Cellulitis is an inflammation of the skin and connective tissues, whereas lymphangitis is an inflammation of the lymph vessels often seen as red streaking up the extremity. Moisture lesions and fungal infections, particularly of the lower extremities and toenails, are also common in this patient population. These secondary infections and complications develop due to the protein-rich fluid that can stagnate in the interstitial tissues. Stagnating high-protein edema in the interstitial tissues leads to a pathohistological state of chronic inflammation.[4] This creates a migration and infiltration of macrophages leading to excess collagen deposition. Fibroblasts migrate into the connective tissues, which become fibrocytes (creating collagen tissue) and adipocytes (creating fatty tissue). Ultimately, fibrosis and fibrosclerosis result in the typical skin changes often associated with Stage III lymphostatic elephantiasis.

Photo 1 depicts a classic representation of the associated skin changes seen in patients with Stage III lymphostatic elephantiasis. Table 1 highlights the common skin lesions and conditions associated with lymphedema.

Deep vein thrombosis (DVT) is another potential complication more readily seen in patients with mobility impairments as they do not have an adequate muscle pump to support proper hemodynamics. The impaired lymphatic system along with the associated fluid burden and fibrotic changes lead to fatigue and impairments in the venous system, making the patient more susceptible to the development of DVT.

Patients with chronic long-standing lymphedema are at risk for developing a rare and deadly cutaneous angiosarcoma known as Stewart-Treves Syndrome.[5] In most cases, the tumor is a result of lymphedema secondary to radical mastectomy. The syndrome can be broadly applied to any angiosarcoma present in a chronically lymphedematous

TABLE 1. Common Skin Lesions and Conditions with Lymphedema

Atrophy	Thinning of the skin
Acute inflammatory episode	Probable infection/acute inflammation; cellulitis
Dermatitis	Inflammation and pruritic skin from irritant or allergen
Hyperkeratosis	Overgrowth of stratum corneum; thickening
Lichenified	Thick, leathery patches of skin that occurs in response to excessive itching or rubbing. Epidermis thickens in response to extra irritation.
Lymphangioma	Dilation of the initial lymphatics which herniate through skin
Lymphorrhea	Weeping of lymphatic fluid through skin; when dry, forms yellow crusts on skin, may lead to denudement
Lymphatic cysts	Blister like vesicles due to lymph fluid reflux; common locations include axilla, cubital, genital and popliteal areas
Papillomatosis	Cobblestone appearance relating to fibrosis of dilated lymphatics
Scaly telangiectasia	Flaking/scaling of skin; abnormal visible dilation of blood vessels
Tinea pedis	Fungal infection/athlete's foot
Vesicle	Small fluid filled blister

body partly due to any cause. For point of clarification, the malignancy actually arises from blood vessels rather than lymphatic vessels and is more accurately described as a hemangiosarcoma. Although prognosis is poor, early recognition can improve a patients' quality of life and reduce other deleterious complications associated with this syndrome.

Although there is currently no cure, patients with lymphedema can achieve good functional outcomes and quality-of-life improvements with proper interventions by trained health-care providers. Challenges arise when associated complications exacerbate lymphedema and/or impact complete decongestive therapy. Although the more common complications were addressed in this article, many issues can arise in patients with lymphedema. The recognition of such complications, followed by proper management in concert with the patient's lymphedema, requires astute awareness by health-care providers and access to trained practitioners who can manage the issues safely and individually for each patient. ■

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About the Author

HEATHER HETTRICK, PT, PHD, CWS, CLT-LANA, CLWT, is an associate professor in the Physical Therapy Program at Nova Southeastern University in Ft. Lauderdale, Florida. As a physical therapist, her expertise resides in integumentary dysfunction with clinical specialties in wound, burn and lymphedema management. Hettrick has three certifications including: Certified Wound Specialist by the American Board of Wound Management, Certified Lymphedema Therapist by the Academy of Lymphatic Studies, and is dual certified internationally as a Certified Lymphedema and Wound Therapist through the International Lymphedema Wound Training Institute.

Hettrick has diverse work experience in academia and the private sector. Her more recent employment history includes Assistant Professor and Director of Clinical Education at the University of New Mexico; Vice President of Academic Affairs and Education for Gordian Medical, Inc. dba American Medical Technologies; Clinical Assistant Professor in the Department of Physical Therapy at New York University; Adjunct Professor at Drexel University; Program Coordinator for Burn Rehabilitation Research at the William Randolph Hearst Burn Center at NY Presbyterian Hospital and a Master Clinician at the Hospital for Joint Diseases at the Diabetic Foot and Ankle Center.

Hettrick is a past president of the American Board of Wound Management and served on the Executive Committee and Board of the Association for the Advancement of Wound Care. She was recently appointed to the Board of the World Alliance of Wound and Lymphedema Care, and she is helping to establish a lymphatic filariasis morbidity plan for Haiti. She is actively involved in numerous professional organizations, conducts research and publishes, presents and teaches nationally and internationally on integumentary-related issues.

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Q&A: Commonly Misdiagnosed Ulcers and Atypical Ulcers

Excerpt from Textbook of Chronic Wound Care *by Shah, Sheffield, and Fife. Coming in 2017*

By Jayesh B. Shah, MD, CWSP, UHM

Textbook of Chronic Wound Care: An Evidence-Based Approach to Diagnosis and Treatment by Drs. Jayesh Shah, Paul Sheffield, and Caroline Fife, editors, is a companion reference book for the *Wound Care Certification Study Guide*, 2nd edition. Due for publication by Best Publishing Company in the first quarter of 2017, this textbook provides the best diagnostic and management information for chronic wound care in conjunction with evidence-based clinical pathways illustrated by case studies and more than 350 pictures. The textbook provides up-to-date information for the challenging chronic wound-care problems in an easy-to-understand format and includes the following features:

- chapters written by more than 50 well-respected leaders in the specialty of wound care
- balanced evidence-based multidisciplinary approach to chronic wound care
- exclusive key concepts in every chapter for a quick review
- excellent resource for preparation of wound care certification exams with 250 questions and answers
- chapters specifically focus on understanding wound care in different settings
- chapter on telehealth and wound care addressing the future of chronic wound care
- deep understanding of value-based care in wound care in United States
- separate section on approach to wound care in various countries globally

This book belongs in the library of every practitioner who treats chronic wound-care patients. It proves to be a valuable text for medical students and all health-care professionals — including doctors, podiatrists, physician assistants, nurse practitioners, nurses, physical and occupational therapists — in various settings. It provides thorough understanding of the evidence-based multidisciplinary approach for caring patients with different kinds of wounds.

The following question-and-answer excerpt is from Chapter 15, "Approach to Commonly Misdiagnosed Ulcers and Atypical Ulcers," by Dr. Jayesh Shah.

1. All of the following are local factors contributing to nonhealing wound except
   a. hypoxia
   b. edema
   c. microvascular disease
   d. malnutrition
   e. necrosis

2. Malignancy should be suspected with
   a. history of repeated trauma
   b. exuberant granulation tissue
   c. rolled out edges
   d. purple red color around the ulcer
   e. wounds secondary to burns
   f. all of the above

3. Match the following:
   a. basal cell cancer
   b. Marjolin's ulcer
   c. Kaposi's sarcoma
   d. pyoderma gangrenosum
   e. calciphylaxis

   1) arises from keratinizing epidermal cells
   2) arises from epidermal basal cells
   3) associated with hyperparathyroidism
   4) malignant changes in edges of chronic wound
   5) associated with inflammatory bowel disease
   6) associated with AIDS

4. Match the following:

a. fish tank granuloma
b. Buruli ulcer
c. actinomycosis
d. Hansen's disease
e. sporotrichosis

1) *S. schenckii*
2) Gram +, nonspore-forming anaerobic bacteria
3) *Mycobacteria leprae*
4) *Mycobacteria marinum*
5) *Mycobacteria ulcerans*

Answers:

1. d
2. f
3a. 2
3b. 1 and 4
3c. 6
3d. 5
3e. 3
4a. 4
4b. 5
4c. 2
4d. 3
4e. 1

About the Author

JAYESH B. SHAH, MD, CWSP, UHM, is president of South Texas Wound Associates, PA, and of TIMEO2 Healing Concepts, LLC, both in San Antonio, Texas. His degrees include an MBBS (bachelor of medicine and surgery) from Maharaja Sayajirao University in Baroda, India, and an MD in internal medicine from St. Luke's Roosevelt Hospital, Columbia University, New York. He is board certified in internal medicine and in undersea and hyperbaric medicine and certified in wound management and in hyperbaric medicine.

Shah has more than 18 years' experience in wound care and hyperbaric medicine practice and more than 12 years' experience as program director for continuing medical education courses. He currently serves as the medical director for the Northeast Baptist Wound Healing Center. An adjunct professor in the Department of Family and Community Medicine at the University of Texas Health Science Center, Shah is coeditor of the *Wound Care Certification Study Guide, First Edition* (published by Best Publishing Company). He created the WoundDoctor app for smartphones and authored 19 chapters on various wound topics in four books in addition to more than 30 scientific articles on wound care and hyperbaric medicine.