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In Brief

Various methods of debridement are available to help remove necrotic tissue from chronic wounds. The authors discuss a new technology-ultrasound-that may have the potential to be a breakthrough for wound cleansing and debridement of adherent fibrin.

Preparation of the chronic wound bed often requires debridement of necrotic tissue that may obstruct wound contraction, impede granulation tissue growth, and inhibit migration of epithelial cells from the wound edge.[1] Nonviable wound tissue also serves as a nidus for bacteria, which can proliferate and lead to infection.[2] Debridement should reduce bacterial counts and remove foreign particulate matter that encourage development of wound infection.[3,4] In addition, endotoxins released by bacteria are known to contribute to biofilm production and development of tissue necrosis and to stimulate inflammatory mediators (IL-1b, IL-6, and tissue necrosis factor-α), with subsequent production of matrix metalloproteases and reduction of collagen deposition by fibroblasts.[5] Because of these detrimental effects on wound healing, quick and thorough debridement of necrotic tissue from the wound is a major early goal of chronic wound management.

Several methods of wound debridement are described in the literature and are available to health care providers who specialize in wound management.[6,7] Methods include the use of sharp surgical instruments; mechanical methods, such as whirlpool and pulsed lavage with suction; proteolytic and collagenolytic enzymes; autolysis; and sterile fly larvae (maggots). The use of surgical debridement is generally considered the most efficient method when performed by a skilled physician, who may in one session use his or her discretion to excise some viable tissue along with necrotic tissue in the wound. Sharp debridement performed in a clinical setting is a less aggressive procedure performed by physicians and other qualified health care practitioners. This method selectively removes eschar and slough as well as adherent fibrin, the latter with significant difficulty and time consumption. Frequently, sharp, selective removal of nonviable tissue is limited in efficacy owing to only partial removal of fibrin and/or intolerable pain experienced by the patient. The other debridement methods mentioned are primarily intended for selective removal of eschar, slough, and fibrin, of which fibrin may require several days to a few weeks for complete removal.

The purpose of this article is to describe a new type of debridement that uses ultrasound technology to remove necrotic tissue. In the authors' preliminary experience, this method appears to have the potential to be a breakthrough for wound cleansing and debridement of adherent fibrin.

The Physics and Cellular Effects of Ultrasound

Ultrasound is non-ionizing radiation and, therefore, does not impose the hazards attributed to ionizing radiation, such as cancer production and chromosome breakage. Sound waves are produced by vibration of piezoelectric discs, and the resulting mechanical energy that is transferred to tissue causes molecules to oscillate. The number of oscillations a molecule undergoes in 1 second defines the frequency of a sound wave and is expressed in units of hertz (Hz; 1 Hz = 1 cycle per second [cps], 1 kHz = 1000 cps, and 1 MHz = 1 million cps). The human ear is sensitive only to sound frequencies between 16 Hz and 20 kHz. The acoustic energy of ultrasound has frequencies greater than 20 kHz, which are imperceptible to the human ear.

When ultrasound at a given frequency passes through tissue, molecules vibrate back and forth at that frequency; with increasing depth of penetration, the energy progressively decreases due to scattering and absorption. Scattering is deflection of sound away from the direction of propagation when it strikes a reflecting surface, such as bone or tendon. Absorption is transfer of ultrasound energy to

tissue, and it occurs in part because of the internal friction in tissue that needs to be overcome in the passage of sound.

Ultrasound imparts its effects on tissue through thermal and nonthermal mechanisms. Both high (MHz) and low (kHz) ultrasound frequencies simultaneously produce thermal and nonthermal effects in tissue. The thermal effect and absorption increase with higher frequency, whereas nonthermal effects are predominant with lower frequencies and when ultrasound is pulsed. The predominant thermal effects of 1 and 3 MHz are commonly used to enhance blood flow and to elevate the temperature of soft tissue in musculoskeletal conditions that limit joint range of motion. There are 2 nonthermal ultrasound effects, namely, cavitation and acoustic streaming.[9] Cavitation is the vibrational effect of ultrasound ongas bubbles. Changes in local pressure produced by ultrasound can cause the formation of micro-sized gas bubbles or cavities in tissue fluids or in ultrasound coupling media, such as physiologic saline. Periods of high and low pressure in the ultrasound field can cause the bubbles to respectively increase and decrease in size. If in a low-intensity field, the bubbles do not significantly increase and decrease in size; stable cavities (bubbles) may occur. At sufficiently high ultrasound intensities, bubbles within the ultrasound field collapse (implode), which may result in destruction of tissue close to the bubbles of the ultrasound applicator.[8,9] This unstable or transient cavitation may be one mechanism that contributes to rapid lysis of fibrin on the wound surface. Recent studies have shown that ultrasound can mechanically remove tissue in a localized, controlled manner[10] and that enhanced acoustic backscatter is highly correlated with the erosion process.[11]

Acoustic streaming is the other nonthermal effect of ultrasound, and it refers to the movement of fluids along the boundaries between cell membranes, bubbles, and tissue fibers as a result of the ultrasound pressure wave. Acoustic streaming has been shown to alter cell membrane permeability and second messenger activity,[12,13] which in turn may result in increased protein synthesis,[14,15] degranulation of mast cells,[16] and increased production of growth factors by macrophage.[17] In addition, low-frequency ultrasound (27 kHz) has been shown to increase endothelial cell nitric oxide synthase activity and nitric oxide synthesis in vitro,[18] and investigators have shown that 40 kHz of ultrasound at intensities from 0.25 to 0.75 W/cm improved perfusion and reversed acidosis in acutely ischemic skeletal muscle through a nitric oxide-dependent mechanism.[19] Moreover, low-frequency ultrasound at 40 kHz is reported to have enhanced the healing rate of diabetic foot ulcers by 41% versus 14.3% for sham-treated controls, without macroscopic adverse effects on wound tissue.[20]

Fibrinolytic Effects of Ultrasound

Advances in technology have led to the development of high-frequency (1 MHz to 10 MHz) ultrasound devices used for fetal imaging and duplex scanning and for warming tissue to promote healing. Ultrasound frequencies of 1 and 3 MHz have been shown to enhance enzymatic fibrinolysis in vitro[21-24] and in animal models.[25-28] However, a drawback of using high-frequency ultrasound clinically to enhance fibrinolysis is that as the intensity is increased, tissue heating may reach harmful levels. In addition, at MHz frequencies, tissue absorption and penetration of ultrasound are less than occurs at kHz frequencies.[29]

Low-frequency ultrasound (20 to 60 kHz) has also been reported to have several positive effects following treatment of wounds in animals and humans. McDonald and Nichter[30] demonstrated that 50

to 60 kHz ultrasound effectively removed particulate debris and bacteria from the surface of experimental wounds in rats. Research has shown that low-frequency (40 kHz), low-intensity (0.25 W/cm) ultrasound significantly increased enzymatic fibrinolysis in vitro compared with no ultrasound ($P < .0001$) and that acceleration of fibrinolysis increased with power output ($P < .001$).[31] Other investigators have found that continuous and pulsed mode ultrasound at low frequencies of 27, 40, and 100 kHz significantly accelerated fibrinolysis of radiolabeled fibrin, with the greatest effect observed at 27 kHz, continuous mode.[29] Bessette et al[32] treated full-thickness experimentally infected burns in rats with ultrasound and showed by electron microscopy that fibroblasts increased lysosomal activity and enhanced collagen synthesis without detrimental effects. In patients with chronic wounds covered with adherent fibrin, the authors of this article have observed that wound debridement with 25 kHz ultrasound rapidly and selectively solubilizes the fibrin without harmful macroscopic changes in granulation tissue. Other clinicians have reported similar observations following 25 kHz ultrasound debridement.[33,34]

Antimicrobial Effects of Ultrasound

Although the effects of 25 kHz ultrasound on microorganisms were not evaluated in the present study, several investigators have reported the antibacterial effects of ultrasound. CH Schulze, S Oesser, and J Seifert, from the Endotoxin Laboratory for Surgical Research, Christian-Albrechts-Universitat, Kiel, Germany, designed 2 in vitro models to evaluate the antibacterial effectiveness of 25 kHz ultrasound on 4 planktonic bacterial species commonly found in chronic wounds (personal communication). An immersion model with bacteria cultured in a test tube was designed to simulate a cavity wound containing serous exudate and normal saline. This model allowed the ultrasound applicator to be immersed in the culture fluid that served as the ultrasound coupling medium. A surface model with bacteria plated in culture medium was also designed to simulate a superficial wound in which a saline drip from the ultrasound applicator served as the coupling medium. Bacteria in both models were sonated at different ultrasound power outputs and exposure times. For both models, the bacterial killing was most effective with 100% ultrasound power output delivered for 120 seconds. In the surface model, 15 of 16 culture plates were found to be sterile after exposure to ultrasound at 100% power output for 60 seconds.

Schoenbach and Song[35] found that in experimentally infected rat burns, daily ultrasound treatments significantly reduced bacterial counts and improved survival over controls. Scherba et al[36] assessed the germicidal efficacy of 26 kHz ultrasound on aqueous suspensions of *Escherichia coli, Staphylococcus aureus*, *Bacillus subtilis,* and *Pseudomonas aeruginosa* bacteria and on fungus (Trichophyton mentagrophytes) and viruses (feline herpesvirus type 1 and feline calicivirus). For all bacteria except *E coli*, they found that the percentage killed increased with exposure time and increased intensity. A significant reduction in fungal growth occurred compared with controls, with growth decreasing with intensity. Growth of feline herpesvirus decreased significantly with intensity; however, increasing intensity had no effect on feline calicivirus. Scherba et al[36] attributed the antimicrobial effect to transient cavitation. Recently, investigators have reported that 27 kHz ultrasound had a significant antibacterial effect on highly antibiotic-resistant isolates of *Acineobacter baumannii* recovered from soldiers returning from Iraq.[37]

In 44 Sprague-Dawley rats with uniform paravertebral incisions, Nichter et al[38] compared the efficacy of various wound debridement methods to prevent infection following primary closure of contaminated wounds. Each wound was inoculated with a standard amount of *S aureus* (2 to 7 × 10 bacteria per 0.1 mL) and treated before closure by 1 of 4 debridement methods (surgical scrubbing, high-pressure [8 psi] irrigation, 50 kHz ultrasound, or soaking). Control wounds were closed without debridement. After 7 days, each animal was evaluated for the presence of gross infection. Ultrasound-treated wounds had a 25% incidence of gross infection, compared with irrigation (75%), scrubbing (82%), and soaking (89%). All of the control wounds developed gross infection. Several other studies have reported that low-frequency ultrasound enhances the action of antibiotics and antiseptic drugs.[39,40] Investigators also found that ultrasound works in synergy with gentamicin to sterilize biofilms of *E coli*[41] and to kill a greater number of bacteria in biofilms of *P aeruginosa*.[42] In addition, researchers found lower-frequency ultrasound to be significantly more effective than higher-frequency ultrasound in reducing bacterial viability within a biofilm.[42]

Use Of 25 kHz Ultrasound for Wound Debridement

The presence of necrotic tissue in wounds directly hinders healing by obstructing wound contraction, granulation tissue growth, and migration of epithelial cells and by serving as a nidus for bacterial proliferation. A new technology used for wound bed preparation and debridement is low-frequency ultrasound (Sonoca 180; Soring, Inc, Fort Worth, TX). The ultrasound device Figure 1 generates and transmits 25 kHz alternating current to a hand piece that contains ceramic lead zirconate titanate (PZT) discs that convert 25 kHz electrical input to 25 kHz mechanical (ultrasound) oscillations at the detachable metallic probe tip. Three autoclavable hand pieces designed with different probe tip shapes for debridement of flat, concave, and convex surfaces are available Figure 2. Maximum ultrasound power output with the probe immersed in water or tissue fluids is 1.0 W/cm^2; it may be adjusted during treatment to between 20% and 100% of maximum.

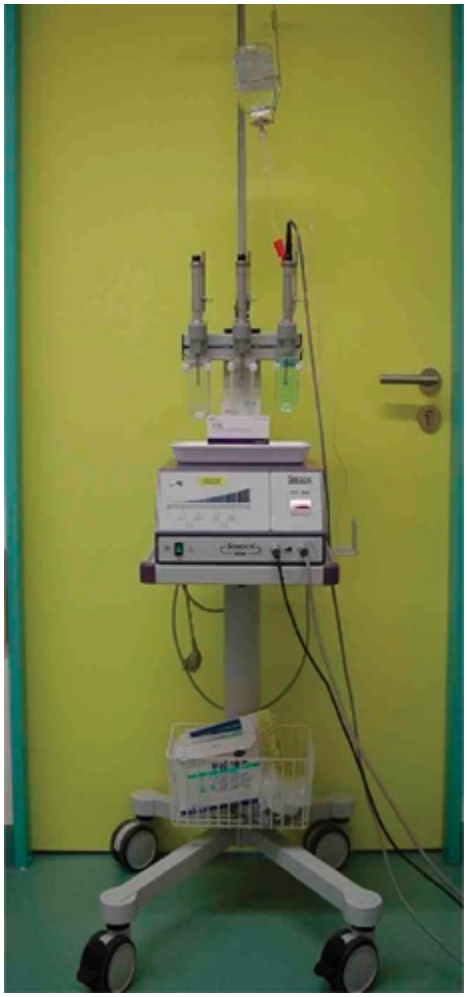

Figure 1: ULTRASOUND DEBRIDEMENT DEVICE This 25 kHz ultrasound generator (Sonoca 180) has 3 debridement hand pieces with different probe tips.

Figure 2: PROBE TIP CONFIGURATIONSThe different probe tips of the autoclavable hand pieces allow the practitioner to reach flat, concave, and convex surfaces. The vertically projecting lever is the saline drip control valve.

The ultrasound probe and the acoustic energy it transmits are coupled to the fibrinous wound surface by saline that drips from the probe tip at a preset rate. When the oscillating ultrasound waves are transmitted through the saline coupling fluid, thousands of micro-sized gas bubbles are created and are visible as a mist. Due to the phenomenon of transient cavitation, the gas-filled bubbles undergo rapid expansion followed by collapse. The turbulence created by the imploding gas bubbles may be

one mechanism by which destruction of bacteria and fibrin occurs. Another possible mechanism by which this ultrasound modality promotes fibrinolysis is through the enhanced mechanical movement of water at the probe tip by moving it forward and back in contact with the fibrin. Moving the probe tip slowly but continuously in contact with the fibrin on the wound surface also prevents an increase of thermal energy and allows greater penetration of the ultrasound energy. By maintaining light constant contact and continuous slow, back and forth movement of the probe tip on fibrin, the authors of this article have not observed any macroscopic harm to granulation tissue.

To comply with Occupational Safety and Health Administration (OSHA) regulations and infection control policies, before initiating the debridement procedure, the clinician dons protective personal equipment (ie, fluid-proof gown, gloves, shoe and hair covers, mask, and face shield) designed to prevent possible inhalation of aerosol mist and spreading of microbes outside of the wound clinic treatment room. The patient also wears a face mask during the procedure. These precautions are recommended for all medical devices that create an aerosol vapor while delivering water or saline to wounds for the purpose of irrigation or debridement.

After selecting the appropriate hand piece, the clinician connects the saline source to the hand piece and adjusts the flow of saline from the ultrasound probe tip to between 3 and 6 drops per second. With the ultrasound generator turned on, the clinician places the autoclavable probe tip in light contact with necrotic fibrin that is adhered to the wound base and slowly and continuously moves the probe across the fibrin. Initially, the ultrasound power output is advanced to the intermediate level of 60%; it may be decreased to 20% or increased to 80% or 100%, depending on patient tolerance. If sensate patients experience discomfort when higher output levels are used to lyze adherent fibrin despite use of topical analgesics, the ultrasound intensity is reduced or the procedure is paused for 15 minutes to achieve wound analgesia by applying additional 4% topical lidocaine (Xylocaine) gel to the wound surface. The hand piece and probe tip are autoclaved after each patient treatment. Both high-frequency and low-frequency ultrasounds are contraindicated in the presence of neoplasm, thrombophlebitis, or hemorrhagic conditions; or tissue previously treated with radiation; or over the exposed spinal cord.[9]

Cases Studies

Figures 3 through 6 show 2 venous ulcers before and after debridement with 25 kHz ultrasound.
In Figures 3 and 4, the venous ulcer is located on the edematous left medial ankle of a56-year-old female patient recently diagnosed with tophaceous gout. The patient presented with a 2-year history of recurring bilateral venous leg ulcers that were treated with 4-layer compression bandaging, followed by compression stockings. The patient stated that she was hypersensitive to several topically applied antimicrobial agents that had been part of her wound treatment regimen in the past. She complained of wound-related pain and previously had taken rofecoxib (Vioxx) and propoxyphene (Darvocet) for pain relief. On the 10 cm visual analogue scale (VAS), her wound pain before ultrasound treatment was 4 the first day and 5 the second day.

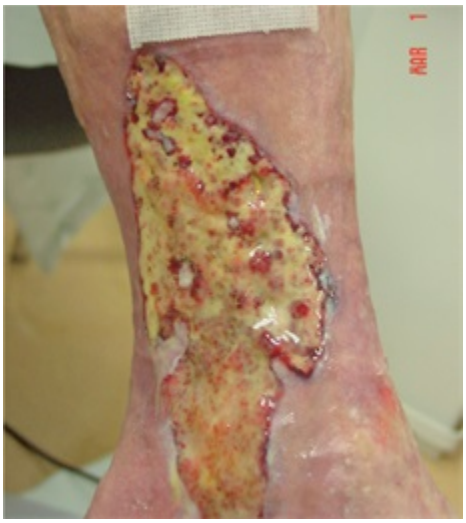

Figure 3: VENOUS ULCER BEFORE ULTRASOUND DEBRIDEMENTThis wound is located on the edematous left medial ankle.

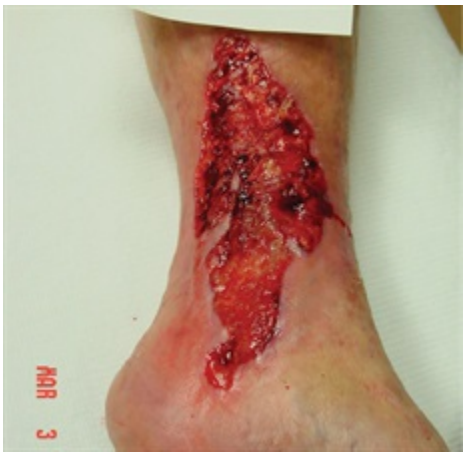

Figure 4: VENOUS ULCER AFTER ULTRASOUND DEBRIDEMENT

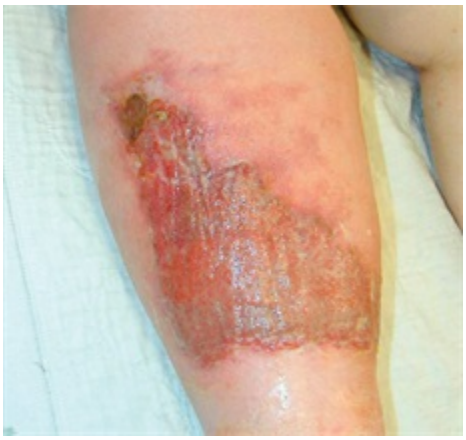

Figure 5: VENOUS ULCER BEFORE ULTRASOUND DEBRIDEMENTThis wound is located on the right anterior edematous leg.

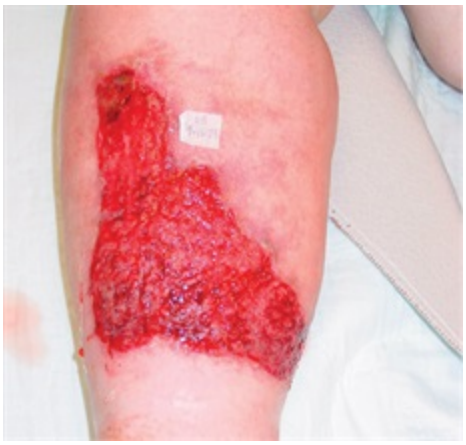

Figure 6: VENOUS ULCER AFTER ULTRASOUND DEBRIDEMENT

Figure 3 shows the patient's fibrinous-covered wound after attempts were made to debride it enzymatically with papain-urea over a 48-hour period. However, the patient could not tolerate the therapy due to a burning sensation. The authors then elected to debride the wound with ultrasound because of previously observed rapid debridement of fibrin with this modality on other patients. On 2 successive days, the patient was premedicated with 4% lidocaine (Xylocaine) gel, which was applied to the wound and periwound border 20 minutes before the procedure. Then the wound was debrided with ultrasound for 5 minutes, with the ultrasound intensity adjusted as necessary to prevent pain to the patient; no undesirable macroscopic effects were noted. The result was the clean wound shown in Figure 4. The dark areas are superficial clotting that disappeared within 24 hours. Following ultrasound debridement, an absorbent dressing was applied to the ulcer to maintain a moist wound microenvironment, and a short-stretch compression bandage was applied to promote edema reduction.

In Figures 5 and 6, the venous ulcer is located on the right anterior edematous leg of a 46-year-old male with a history of morbid obesity, sleep apnea, lymphedema, and lower-extremity cellulitis. Figure 5 shows the wound 95% covered with adherent fibrin after 1 week of attempted debridement with a collagenous enzyme. Although the patient did not complain of wound-related pain (VAS = 0), as a precautionary measure, 4% lidocaine (Xylocaine) gel was applied to the wound bed and periwound border 20 minutes before the procedure.

The wound was debrided for 6 minutes, resulting in the clean wound seen in Figure 6. The ultrasound intensity was adjusted as necessary during the procedure to prevent pain, as with the first patient. Again, no undesirable macroscopic effects were noted. In addition, an absorbent dressing was applied to maintain a moist wound microenvironment, and a 4-layer compression bandage was used to reduce edema.

Figure 7 shows a large sacral pressure ulcer before ultrasound debridement of the right side of the wound. The patient, a 45-year-old obese male, had a primary diagnosis of multiple sclerosis (MS), quadriparesis, neurogenic bladder, and a recent secondary diagnosis of type 2 diabetes. Fifteen years of MS with progressive muscle weakness severely compromised his mobility.

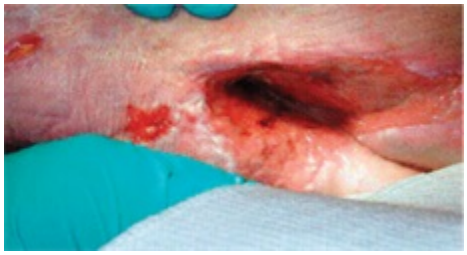

Figure 7: LARGE SACRAL PRESSURE ULCER BEFORE ULTRASOUND DEBRIDEMENT

When the wound was probed to identify the presence or absence of undermining, tunneling, or fistulae, the patient complained of mild wound pain (VAS = 2). Similar to the first 2patients, 4% lidocaine (Xylocaine) gel was applied to the wound bed and periwound border 20 minutes before the procedure to make the patient comfortable during the procedure. The ultrasound intensity was also adjusted as necessary during the procedure so that he experienced no pain. Figure 8 shows the right side of the wound after it was debrided with ultrasound, which took 6 minutes; there were no undesirable macroscopic effects observed.

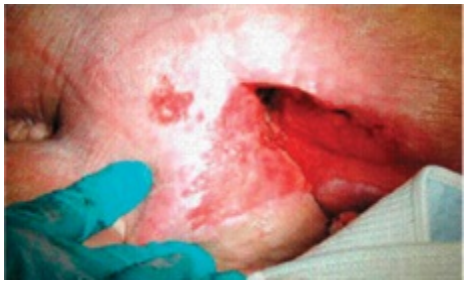

Figure 8: LARGE SACRAL PRESSURE ULCER AFTER ULTRASOUND DEBRIDEMENTThis view shows the right side of the ulcer.

Unlike the venous ulcers, this pressure ulcer exuded a small amount of serosanguineous fluid after debridement; an absorbent, nonadherent dressing was applied. The fibrin-covered left wound surface required 8 minutes for complete debridement of fibrin.

CONCLUSION

The authors have observed rapid and thorough debridement of adherent fibrin from wound surfaces with the 25-kHz ultrasound device without macroscopic evidence of harm to tissue and with no patient discomfort. The rapid fibrinolytic effect observed in the ulcers of the 3 patients presented in this article demonstrates the effectiveness of this intervention in its ability to remove microbe-attracting fibrin from the wound bed. However, additional clinical research is needed to compare the debridement efficacy of this debridement modality with other methods and to evaluate its effect on wound bioburden.

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