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The Roles of Physical Therapists in Wound Management, Part III: Select Biophysical Technologies and Management of Patients With Diabetic Foot Ulceration

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Physical therapists (PTs) have several decades of history of using high-frequency (1- and 3-MHz) ultrasound (US) to facilitate healing of musculoskeletal tissues (eg muscle, fascia, tendon, ligament, joint capsule) that become wounded or inflamed following many accidents or sports injuries, but not exposed, because the trauma leaves the skin intact. These US frequencies (often referred to as *therapeutic US*) transmit acoustic energy, which delivers the nonthermal physical properties of stable cavitation and microstreaming to the *closed wound* tissues via direct contact gel or water coupling to the skin. With megahertz US, the acoustic pressure waves created by stable cavitation and microstreaming are less forceful than the pressure waves created by unstable cavitation that is associated with low-frequency (kilohertz) US. This is because acoustic pressure is inversely proportional to frequency, and since higher frequencies have shorter wavelengths, at the power (wattage) levels used for megahertz US, less acoustic energy is transmitted to tissues per unit of time. The more prominent unstable cavitation produced by low-frequency US (eg 22.5, 25, and 35 kHz) is a major contributing source

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of energy by which contact US debrides nonviable, adherent fibrin and slough via fragmentation, emulsification, or a combination. The combination of stable cavitation and microstreaming that are characteristic of megahertz US do not generate the destructive energy levels that are associated with kilohertz US frequencies. Owing to the lower level nonthermal effects that 1- and 3-MHz acoustic energy has on tissues and cells, these frequencies are also used to treat open wounds by applying the US to the periwound skin with either aqueous gel or water as the coupling medium. Bear in mind that megahertz US is also capable of generating thermal energy in soft tissues. Although mild heating of closed and open wounds may be desirable when the objective is to enhance blood flow, generally the nonthermal effects of US on wound healing are considered more desirable and are supported by more research evidence. Essentially, the combined effects of stable cavitation and acoustic streaming excite or upregulate the cell membrane, thereby increasing the activity levels of the entire cell. The US energy acts as a *trigger* for this process, but it is the increased cellular activity that is in effect responsible for the therapeutic benefits of the modality.[1-6] The combined effects of stable cavitation and microstreaming associated with 1- and 3-MHz US that may impact wound healing include a temporarily increase in uptake of calcium ions by fibroblasts exposed to therapeutic levels of ultrasound.[7,8] In addition, with ultrasound pulsed at a 20% duty cycle and a frequency of 1 MHz, intensity levels as low as 0.5 W per square centimeter have been shown to increase collagen synthesis by fibroblasts.[8] This effect is highly significant for cell membrane permeability changes. In particular, the important second messenger, calcium, could act as an intracellular signal for some of the events that lead to ultrasound-induced stimulation of tissue repair.[9] Possible examples include the stimulation of protein synthesis by fibroblasts[8] and the increased release of growth factors from mast cells[10] and macrophages.[11] Another clinically significant change in membrane function resulting from acoustic streaming is serotonin release from platelets.[12,13] In addition to serotonin, platelets contain chemotactic factors that promote the migration of cells essential for successful repair to the wound site.[14] If streaming can stimulate serotonin release, it may also stimulate the release of these factors, thus stimulating wound healing. Finally, in an animal model, wound treatment with 3-MHz US for 5

minutes daily for 5 days resulted in significantly more blood vessels compared with control wounds.[15]

Low-Frequency Kilohertz Ultrasound for Wound Treatment

Recently, low-frequency ultrasound devices of 22.5, 25, 35, and 40 kHz have become available and are being used by PTs as options for wound debridement and antibacterial effect and for enhancing wound healing processes.[16-19] These devices transmit US energy to the wound bed either through microsized gas bubbles or through atomized saline mist coupling (40 kHz) that is delivered to the wound via a handpiece applicator. For the 22.5-, 25-, and 35-kHz device, the US applicator is placed in light contact with nonviable wound tissue and is slowly moved to and fro during treatment. For the 40-kHz device, the noncontact applicator is held 5 to 15 mm from the wound bed, and the atomized saline is slowly scanned over the wound surface. When low-frequency US waves are transmitted through the saline coupling fluid, thousands of microsize gas- and vapor-filled bubbles or cavities are formed in the solution and are visible as a mist. Owing to the US phenomenon of unstable 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 fibrinolysis occur with commercially available frequencies between 22.5, 25, and 35 kHz.

The commercially available 40-kHz US device delivers the acoustic energy to wound tissues without making physical contact with the wound. In this case the US is transmitted to the wound via saline vapor or mist coupling. The mechanical pressure changes in the US field also cause unidirectional movement of fluids along cell membranes, known as *microstreaming*. As with megahertz US frequencies, the combined effects of cavitation and microstreaming are thought to result in diffusion changes along cell membranes that alter cell function and may be responsible for upregulating cellular processes that contribute to wound healing.

Pulsed Lavage With Suction

This portable modality is really a hydrotherapy intervention that is used by PTs for wound cleansing and debridement of unattached fibrin and slough. The use of pulsed lavage with suction (PLWS) as a substitute for wound treatment with whirlpool has increased substantially, perhaps because PLWS is less time-consuming and less costly than whirlpool and because there is less risk of wound contamination with PLWS because sterile, disposable attachments are used with each patient. PLWS allows delivery of saline irrigant to the wound bed under variable pressure (4-15 psi)[20] and simultaneous aspiration of the saline, exudates, debris, slough, loosely clinging nonviable tissue, and microorganisms via negative pressure that can be varied between 60 and 100 mm Hg.[21] The magnitude of suction pressure applied to the granulating wound with this device can be adjusted to fall within the suction pressure range of other negative pressure wound healing devices. Thus, it is reasonable to expect, and in fact it has been observed, that when PLWS is routinely applied over a beefy-red wound, granulation tissue growth is enhanced. Instrumentation consists of a handpiece "gun" applicator, positive and negative pressure pumps, and tubing that connects the handpiece with a bag of sterile saline.

PT Management of Patients with Diabetic Foot Ulceration

For patients with diabetes mellitus who have developed insensate, biomechanically deranged, and anhydrotic feet from sensory, motor, and autonomic neuropathy, there is much the PT can offer, whether plantar foot ulceration is present or absent.

To rule out the presence of vascular compromise in the lower extremities of patients with advanced diabetes, the PT assesses macro and microvasculature blood perfusion. The ankle-brachial index (ABI) test is used to appraise macrovascular blood flow; however, in patients with advanced diabetes, an ABI greater than 1.2 correlates with high cuff pressures required to occlude calcified large vessels in the leg during ankle systolic pressure evaluation.[22,23] In this case, the ABI alone is not a reliable indicator of peripheral arterial disease, and other

indicators, such as claudication pain and segmental limb pressures, need to be evaluated in conjunction with the ABI.[24] To assess perfusion in soft tissues distal to the ankle in the patient with advanced diabetes, systolic toe pressures provide a more accurate indication of blood flow since in these patients, calcification does not appear to extend into the toes.[25]

The PT evaluation of the diabetic foot also includes sensory testing with Semmes-Weinstein monofilaments, to determine the status of protective sensation in both feet, and proprioceptive assessment of both lower extremities by evaluation of patient sitting, standing, and ambulation balance and queries to the patient about previous loss of balance and falling. A manual muscle test would also be performed to assess strength of all muscle groups of both lower extremities, including the intrinsic foot muscles. Some reports suggest that motor neuropathy[26,27] and glycosylation of collagen[28] may lead to calf muscle tightness and stiffness of the Achilles tendon, both of which may contribute to decreasing ankle dorsiflexion, which in turn would increase forefoot pressures during ambulation. Thus, measurement of ankle range of motion is important to assure that the necessary therapies are included in the patient's overall wound care plan. Bilateral inspection of lower extremity integument would be performed to assess for skin hydration and to determine whether callous or fissuring of the plantar skin, or a combination, is present.

PTs would address findings of diminished or absent sensation and compromised proprioception by helping the patient with shoe modification or finding protective footwear. If there is no plantar ulcer but there are prominent metatarsal heads, claw toes, or Charcot deformity, the PT can assist the patient with getting fitted with appropriate footwear designed to decrease the risk of ulceration caused by repetitive ambulatory stresses applied to metatarsal heads and other bony prominences. In addition, if there is loss of protective sensation and altered proprioception, treatment of the feet and distal one-third of the lower extremities with 890-nm monochromatic infrared has been reported in small uncontrolled studies to partially reverse sensation loss[29-34] and to reduce the number of falls in elderly diabetic patients.[30]

A decrease in strength of pretibial and intrinsic foot muscles and reduced ankle dorsiflexion range of motion would be addressed by ongoing dorsiflexion strengthening exercises and stretching of calf musculature and the Achilles tendon to decrease forefoot pressures during ambulation. If evaluation of foot and leg integument reveals that the plantar skin is fissured or dry and needs hydration, the PT will encourage the patient to inspect and wash the feet daily with mild soap and water and to avoid soaking the feet, because excessive hydration (eg 15- to 20-minute whirlpool) can cause skin maceration. To keep the skin of both legs and feet moist and supple, the patient would be encouraged to apply moisturizing creams that contain urea and are devoid of alcohol.

In managing the diabetic neuropathic and/or dysvascular foot with a plantar ulcer, the PT has a variety of interventions to facilitate wound closure and ultimately healing. A thorough wound evaluation is performed as previously mentioned, with emphasis on determining the viability of tissues, whether the wound is infected or inflamed, and whether the amount of wound moisture is adequate. If a callous surrounds the ulcer, the PT will perform sharp selective debridement to shave thin layers of the callous down to soft viable pink tissue. Additional selective debridement of nonviable tissue from the wound bed is also performed. In the absence of significant peripheral arterial disease and a plantar noninfected ulcer with Wagner grades 1 or 2, a series of total contact casts or an orthosis is an option the PT may select to prevent ambulatory pressures from being applied to the ulcer, allowing it to heal.[35,36] Appropriate wound inspection, cleansing, dressing changes, and weekly reapplication of casts are part of this off-loading protocol. Recognizing that casting is contraindicated for infected foot wounds, the PT, in consultation with the physician and other team members, would regularly perform selective sharp debridement and irrigation and apply antimicrobial topical agents and dressings to the wound. Once the wound is closed, the patient is fitted with accommodating footwear that redistributes weight-bearing pressures away from the former wound site. Finally, the therapist would educate the patient regarding the importance of glucose control, diet, and exercise.

References

1. Watson T. Masterclass: the role of electrotherapy in contemporary physiotherapy practice. Man Ther. 2000;5(3):132–141.
2. Watson T. Ultrasound in contemporary physiotherapy practice. Ultrasonics. 2008;48(4):321–329.
3. Watson T. Ultrasound in contemporary physiotherapy practice. Ultrasonics. 2008;48:321–329.
4. Dinno M.A., Dyson M., Young S.R. The significance of membrane changes in the safe and effective use of therapeutic and diagnostic ultrasound. Phys Med Biol. 1989;34:1543–1552.
5. Leung M.C., Ng G.Y., Yip K.K. Effect of ultrasound on acute inflammation of transected medial collateral ligaments. Arch Phys Med Rehabil. 2004;85(6):963–966.
6. Mummery C.L. University of London; 1978. The Effect of Ultrasound on Fibroblasts In Vitro. [PhD thesis]
7. Mortimer A.J., Dyson M. The effect of therapeutic ultrasound on calcium uptake in fibroblasts. Ultrasound Med Biol. 1988;14:499–506.
8. Webster D.F., Pond J.B., Dyson M. The role of cavitation in the in vitro stimulation of protein synthesis in human fibroblasts by ultrasound. Ultrasound Med Biol. 1988;4:343–351.
9. Rasmussen H., Weismann D.M. Modulation of cell function in the calcium messenger system. Rev Physiol Biochem Pharmacol. 1983;95:111–148.
10. Fyfe M.C., Chahl L.A. Mast cell degranulation: a possible mechanism of action of therapeutic ultrasound. Ultrasound Med Biol. 1982;8(suppl 1):62–65.
11. Young S.R., Dyson M. Macrophage responsiveness to therapeutic ultrasound. Ultrasound Med Biol. 1990;16(8):809–816.
12. Williams A.R. Release of serotonin from platelets by acoustic streaming. J Acoust Soc Am. 1974;56(5):1640–1649.
13. Williams A.R., Sykes S.M., O'Brien W.D. Ultrasonic exposure modifies platelet morphology and function in vitro. Ultrasound Med Biol. 1977;2(4):311–317.
14. Ginsberg M. Role of platelets in inflammation and rheumatic disease. Adv Inflamm Res. 1981;2:53–58.
15. Young S.R., Dyson M. The effect of therapeutic ultrasound on angiogenesis. Ultrasound Med Biol. 1990;16(3):261–269.
16. Stanisic M.M., Provo B.J., Larson D.L. Wound debridement with 25 kHz ultrasound. Adv Skin Wound Care. 2005;18(9):484–490.
17. Pierson T, Niezgoda JA, Learmonth S, et al: Effect oflow frequency ultrasound applied in vitro to highly antibiotic-resistant acinetobacter

isolates recovered from soldiers returning from Iraq. Oral abstract 32.3 presented at: 18th Annual Symposium on Advanced Wound Care. April 23, 2005; San Diego, CA.

18. Kavros S.K., Miller J.L., Hanna S.W. Treatment of ischemic wounds with noncontact, low frequency ultrasound: the Mayo Clinic experience, 2004-2006. Adv Skin Wound Care. 2007;20(4):221–226.
19. Ennis W.J., Valdes W., Gainer M. Evaluation of clinical effectiveness of MIST ultrasound therapy for the healing of chronic wounds. Adv Skin Wound Care. 2006;19(8):437–460.
20. Bergstrom B, Allman RM, Alvarez OM, et al: Treatment of pressure ulcers. US Department of Health and Human Services, Public Health Services, Agency for Health Care Policy and Research; 1994. Clinical Practice Guideline No. 15, AHCPR Publication No. 95-0652, page 51.
21. Loehne H.B. Wound debridement and irrigation. In: Kloth L.C., McCulloch J.M., editors. Wound Healing Alternatives in Practice. 3rd ed. F.A. Davis Co; Philadelphia, PA: 2002. pp. 203–231.
22. Goss D.E., de Trafford J., Roberts V.C. Raised ankle brachial pressure index in insulin-treated diabetic patients. Diabet Med. 1989;6:576–578.
23. Newman A.B., Siscovick D.S., Manolio T.A. Ankle arm index as a marker of atherosclerosis in the cardiovascular health study. Circulation. 1993;24:43–48.
24. Holland T. Utilizing the ankle brachial index in clinical practice. Ostomy Wound Manage. 2002;48(1):38–49.
25. Ramsey S.E., Manke D.A., Summer D.S. Toe blood pressure: a valuable adjunct to ankle pressure measurement for assessing peripheral arterial disease. J Cardiovasc Surg. 1983;24:43–48.
26. Birke J.A., Patout C.A., Jr., Foto J.G. Factors associated with ulceration and amputation in the neuropathic foot. J Ortho Sports Phys Ther. 2000;30(2):91–97.
27. Danials T.R. Diabetic foot ulcerations: an overview. Ost Wound Manage. 1998;44(9):76–84.
28. Birke J.A. Management of the insensate foot. In: Kloth L.C., McCulloch J.M., editors. Wound Healing Alternatives in Practice. 3rd ed. F.A. Davis Co; Philadelphia, PA: 2002. pp. 385–405.
29. Kochman A.B., Carnegie D.H., Burke T.J. Symptomatic reversal of peripheral neuropathy in patients with diabetes. J Am Podiatr Med Assoc. 2002;92:125–130.
30. Kochman A.B. Restoration of sensation, improved balance and gait and reduction in falls in elderly patients with use of monochromatic, infrared photo energy and physical therapy. J Geriatr Phys Ther. 2004;27:16–19.

31. Leonard D.R., Farooqi M.H., Myers S. Restoration of sensation, reduced pain and improved balance in subjects with diabetic peripheral neuropathy. Diabetes Care. 2004;27:168–172.
32. Prendergast J.J., Miranda G., Sanchez M. Reduced sensory impairment in patients with peripheral neuropathy. Endocr Pract. 2004;10:24–30.
33. Powell M., Carnegie D.H., Burke T.J. Reversal of diabetic peripheral neuropathy and new wound incidence: the role of MIRE. Adv Skin Wound Care. 2004;17:295–300.
34. DeLellis S.L., Carnegie D.H., Burke T.J. Improved sensitivity in patients with peripheral neuropathy: effects of monochromatic infrared photo energy. J Am Podiatr Med Assoc. 2005;95(2):143–147.
35. Mueller M., Diamond J., Sinacore D. Total contact casting in treatment of diabetic plantar ulcers. Diabetes Care. 1989;12:384–388.
36. Fleischli J.G., Laughlin T.J. TCC remains the gold standard for off-loading plantar ulcers. Biomechanics. 1998;5:51–52.