CORRELATION of HEALING and PHYSICAL THERAPY
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Regardless of the type of wound, whether surgical or accidental, all wounds heal in the same sequence of events. The three overlapping phases in the healing process include the inflammatory, the proliferative and the remodeling phase. The clinician caring for a wound must recognize characteristics of inflammation and the types of cells involved during the inflammatory process. By understanding the roles of various cells in directing and controlling the inflammatory process, the clinician may best determine how various treatment interventions and the timeliness of their use may be advantageous to enhance or inhibit cellular repair and/or chemotactic processes in wound healing.

Numerous interventions have been shown to enhance and accelerate the wound healing process. These include electrical stimulation, ultrasound, extracorporeal shockwave therapy, and MIRE (monochromatic infrared energy). Each modality will be discussed in greater detail.

Electrical Stimulation

There are many forms of electrical stimulation typically referred to by their rehabilitative application, by the inventor's name or by the companies that produced them. Examples include galvanic current, faradic current, high voltage, low voltage, transcutaneous electrical nerve stimulation (TENS), electrical muscle stimulation (EMS), functional electrical stimulation (FES), Russian stimulation and interferential stimulation.

For centuries, electrical charge has been applied from various sources to facilitate healing of injured tissue.[1-2] However, it has only been in the past 40 years that controlled research studies have documented convincing support that bone, tendon, and dermal / subdermal tissues respond differently to positive and negative direct current. Research has shown that electrically augmented bone healing is best achieved by invasive cathodal stimulation with between 5 and 20 microamperes of direct current.[3-5] In contrast, research related to electrically augmented healing of human dermal ulcers indicated that healing is promoted by application direct current via the anode to wound tissue.[6-8] However, the negative electrode has been shown to suppress healing and infection.[9] In addition, both the anode and cathode effectively enhanced healing and increased the breaking strength at the severance site when direct current was applied to severed tendons in animals.[10,11]

Wolcott, et al[6] designed a battery operated device capable of delivering 200-1000 microamps of continuous direct current to wound tissue via an anode or cathode. In an 18-month clinical trial, they used constant direct current to determine if electrical charge introduced into tissue of ischemic dermal ulcers from an anode would accelerate healing when compared to control wounds. Initially, wounds were treated with the cathode for three days or until the infected wounds became aseptic. When anodal treatment resulted in a healing plateau, the polarity was reversed until healing resumed, followed by reapplication of anodal stimulation. Of the 75 ulcers treated with direct current, in 9.6

weeks, 45% healed completely at a rate of 18.4% per week. The remaining 55% of ulcers healing incompletely in 7.2 weeks, to an average volume decrease of 64.7% percent at a rate of 9.3% per week. The control group consisted of 8 other patients (6 paraplegics) with 16 bilateral ulcers of comparable size and location. With no administration of direct current, these control ulcers healed at a rate of 5% per week compared with 27% per week of their treated counterparts.

Gault and Gatens[7] treated 100 ischemic skin ulcers with continuous direct current. Using the same protocol as Wolcott and his colleagues, the control group consisted of six patients with 12 bilateral symmetric ulcers. These six control ulcers healed at a rate of 14.7% per week compared to the six treated ulcers which healed at a rate of 30% per week. During the 4-week treatment period, three of the treated ulcers healed completely, whereas two of the untreated control ulcers increased in size. The 100 ulcers treated with direct current healed at a similar rate of 28.4%, resulting in complete healing of 48% of these ulcers in 4.7 weeks.

These studies show several commonalities that may be consisted with the application of direct current to chronic wounds producing favorable outcomes. These include: 1.) Initial cathodal application to a wound for 3 or more days may have a bacteriostatic effect, followed by 2.) Anodal stimulation for 2 hours, 2-3 times per day, for 5-7 days per week 3.) If healing cessation is observed, reversal of polarity daily or every 3 days may be beneficial 4.) Constant current stimulation is necessary with 200-1000 microamps of direct current. This is significantly higher than the above-mentioned parameters found necessary to augment bone healing in cases of delayed or non-union fractures. [12]

High-voltage pulsed current, or high-voltage monophasic pulsed current (HVPC), was initially discovered to enhance tissue healing by a veterinarian in 1966.[13] He applied this current to the hindlimbs of four dogs whose limb circulation was compromised for 12 hours by proximal tourniquet application. After removing the tourniquet 24-hours later, each dog was treated daily with HVPC for 5 minutes at 150 volts, a frequency of 12-14pps, with a pulse duration of 4 microseconds, for 14 days. The control group of 4 dogs who did not receive HVPC after tourniquet removal developed pronounced edema and superficial necrosis of their hind limb. The treated dogs walked without a limp with no observable differences between the normal and traumatized limbs. All of the control dogs developed severe gangrene.

Kloth and Feedar[14] studied 16 people with stage IV dermal ulcers, randomly assigning them to a treatment of control group. HVPC was applied at 105 pps with the amplitude set to just below that which produced a visible muscle contraction. The treatment group received 45 minutes of anodal stimulation to the wound 5 days per week; whereas, the control group received a placebo stimulation for 45 minutes 5 days per week. The treatment group's wounds healed completely in 7.3 weeks, at a rate of 45% per week. The control group experienced an increase in wound size of 29% in 7.4 weeks. Findings of the HVPC studies suggest that this form of electrical current is as effective as constant direct current in augmenting wound healing.

Ultrasound
Ultrasound is a mechanical disturbance in which the molecules of media that transmit it, for example, biological tissues, are made to oscillate or vibrate at an extremely high frequency (above the upper limit of human hearing). The interaction of ultrasound with biologic tissues can result in a thermal (ability to result in elevation of tissue temperature) or non-thermal (attributed to mechanisms other than an increase in tissue temperature) effects.[15]

Called cavitation and mechanical and chemical alterations, it is these nonthermal effects that have the greatest effect on healing tissues. Cavitation is the vibrational effect on gas bubbles by an ultrasound beam. Expansion and compression of small gas bubbles present in blood or tissue fluids can causes changes in local pressures. If sufficient intensity exists, this bubble pulsation in the ultrasound field can cause changes in cellular activity and tissue damage. If the bubbles do not increase much in overall amplitude, stable cavities result causing diffusional changes along cell membranes thus altering cell function. Acoustic streaming is the movement of fluids along cell membranes as a result of a mechanical pressure wave. This is thought to cause ion fluxes and subsequent change in cellular activity.

Low-intensity continuous-wave or pulsed-wave modes may be used in the treatment of wounds to enhance the reparative process. Enwemeka[16] found that exposure of tenotomized, repaired and immobilized rabbit tendons to ultrasound at 1MHz / 1 W/cm^2 for 5 minutes over 9 consecutive days resulted in a significant increase in both energy absorption capacity and tensile strength.

Paul et al[17] have been successful in treating chronic skin ulcers using dosages of 0.5 – 1.0 W/cm^2 three times per week to manage pressure sores in patients with spinal cord injuries. When previous methods had failed, the application of ultrasound healed thirteen of the 23 ulcers. Five improved and five did not benefit from the treatment.

Knowing the time in the course of healing is important when administering ultrasound. The amount of ultrasound energy that is delivered to the tissues may determine either positive or negative healing effects. If ultrasound is applied in the early stages of wound healing, within the first week, repair may be hindered if excessive therapy is applied. However, if ultrasound is administered at low intensities after 2 weeks during the proliferative phase of healing (fibroblastic infiltration and collagen formation) and early into the remodeling phase, ultrasound at low intensities may be beneficial. In contrast, at higher intensities of 1.5 W/cm^2 was more significant in healing traumatized soft tissues than lower intensities of 0.5 W/cm^2. [18]

Extracorporeal Shockwave Therapy (ESWT)
Extracorporeal shockwave therapy (ESWT) is a new modality in veterinary medicine. Traditionally, shock waves were used for human lithotripsy to reduce the size of bladder and kidney stones. Now, it is being studied in horses and small animals for pain relief

associated with osteoarthritis and degenerative joint disease, osteochondrosis, non- and delayed unions, tendonitis and spondylosis. To better understand the mechanism of ESWT, one must first understand the physics of sound waves.

Sound travels in waves and requires some form of matter (gaseous, liquid or solid) in which to be transmitted. Sound is propagated faster in more dense materials. For example, sound waves move through liquid faster than air and through solids faster than liquid. The term *acoustic impedance* refers to how sound waves travel at different speeds through different materials.

Acoustic impedance relates to how materials absorb and transmit sound. Sound does not readily transfer between materials of different acoustic impedance; even though independently they may both be capable of propagating a sound wave. Air and liquid have very different acoustic impedances. Thus, sounds waves are completely reflected at these interfaces. Similarly, 40% of the sound waves are reflected when propagated through soft tissue to reach bone.

Pressure fluctuations generated by sound waves are propagated through matter. There are regions of increased and decreased pressure causing compression (increased density) and rarefaction (decreased density) of the media within which it travels. As the power of the wave increases, the difference in pressure becomes greater. Waves of increased power have areas of lower pressure that can develop cavitations (micro gas bubbles). These cavitations may be stable or unstable. Unstable cavitations occur when pressure fluctuations are so great that the bubbles have large volume fluctuations generally followed by a violent implosion of the bubble with a release of energy. It is these cavitations that can create some of the biologic effects seen with ESWT.

The pressure wave produced with ESWT is a high amplitude, high energy sound wave. High mechanical tension and pressure at the front of the shock wave distinguishes these shock waves from therapeutic or diagnostic sound waves. The pressure rises at the wave front within nanoseconds from atmospheric pressure reaching a maximum positive pressure. This is followed by a rapid decrease to atmospheric pressure where a negative pressure follows and finally a return to atmospheric pressure.

Shock waves travel through the skin without damaging it. They meet at the interfaces of different acoustic impedances (bone, muscle, tendons, etc.) where pressure and shear loads develop resulting in a loss of kinetic energy. Here, cavitations develop and the unstable cavitations collapse, releasing energy causing tissue alternations.

The term 'extracorporeal' relates to shockwaves that are created outside of the human or animal body. Sources of a shock wave may include electrohydraulic (spark gap method), electromagnetic, or piezoelectric.

Electrohydraulic (spark gap method) creates the most effective shock for medical purposes and is the oldest of the three methods. A capacitor is charged to a high voltage and discharges electrical energy abruptly at the first focal point over two electrode tips located in water (underwater spark discharge). The shock wave is created by the explosive evaporation of water focused by an ellipsoid and finally releases its maximum energy at the second focal point. The shock wave is conveyed into the body via a water cushion.

Electromagnetic shock wave generation (EMSG) is a principle that is similar to loudspeakers. An electrical impulse is sent through an inductance coil, generating a magnetic field which repulses a metallic membrane. The acoustic impulse created by this repulsion is focused by an acoustic lens to form a shock wave. This method requires an extensive water-based cooling system.

The piezolelectric source of a shock wave is generated by a thousand piezoelectric crystals arranged on the inside of a conical segment. An intermittent application of high voltage to the crystals causes them to alternately contract and expand. These acoustic impulses are bundled into a shock wave depending on a particular arrangement of the crystals on the conical segment.

There are many theories that surround the physiology behind successful treatments with ESWT. Pressure waves release most of their kinetic energy at sites with changes in acoustic impedance. It has been proposed that ESWT increases cellular permeability, stimulates cellular division, possibly stimulates cytokine production by cells.[19,20] Studies have also shown that shock waves induce neovascularization of targeted tissues (relieving pain, improving tissue regeneration / repair)[21], transform growth factor-β1 (which is chemotactic and mitogenic to osteoblastic cells), and have an effect on nitric oxide synthase systems associated with bone healing and remodeling.[22]

More recently, Dahlberg et al investigated the feasibility and efficacy of treating dogs with osteoarthritis of the stifle joint using ESWT. In this study, dogs with persistent stifle lameness despite previous surgical or medical intervention were either treated with ESWT or served as untreated controls. The most lame rear limb of each dog was determined via force platform analysis. Stifle range of motion (ROM) was assessed using goniometric measurements. Both force platform analysis and ROM measures were performed on both groups for four visits at three-week intervals and a final examination four weeks later. ESWT was performed three times on the treated dogs, once at each of the first three examinations. Placebo treatment consisted of clipping and wetting the hair was performed on the control animals. Vertical forces were evaluated finding that four of seven treated dogs improved, while only one of five control dogs improved. Though the peak vertical force (PVF) for the within group analysis did not show any significant change for the treated group, the control group has a significant decrease in PVF consistent with an increase in lameness. Stifle range of motion improved in five of seven treated dogs and three of five control dogs. The subjective data provided by client questionnaire did not show significant difference between groups.[23]

Low energy levels are suggested to be effective in promoting wound healing. Whereas, high energy levels may be detrimental to healing, yet effective in stimulating new bone formation, especially in delayed unions. Complications may include petechiation of the skin, tissue necrosis with excessive energy levels and pulses directed at soft tissue structures, lung and intestinal damage if directed at the intercostal-lung border or gas/tissue interfaces, arterial damage (avoid major blood vessels), premature closure of physes, an analgesic effect, speculating potential nerve damage, and microfractures.

Equi-Light (Anodyne)

The Equi-Light is considered a monochromatic infrared energy (MIRE) source or low-intensity laser emitting a wavelength of 890 nanometers. At this wavelength, The Equi-Light is capable of stimulating the local release of nitric oxide from hemoglobin, which has been shown to be beneficial in many capacities. Notably, nitric oxide is one of the most natural vasodilators. It is capable of increasing circulation to facilitate wound and soft tissue healing. It is also useful in increasing lymphatic flow, decreasing pain by stimulation endorphin and enkephalin production, retarding and breaking down scar tissue, in the proliferation of osteoblastic-like cells, decreasing edema and possibly promoting cartilage healing.

The terms Equi-light and Anodyne are synonymous. The term Equi-Light is used when referring to the application of MIRE on animals and Anodyne for its application on human patients. This new modality began on humans for the treatment of diabetic neuropathy[24], decubitus ulcers[25], sprains, tendonitis, fasciitis, deep tissue bruising, wound healing[25,26], fractures[27,28] and arthritic pain.[29] It has also been studied on horses for the treatment of wounds, pressure sores, laminitis, seromas and proud flesh.[30,31] In dogs, this modality has shown promising results for treating decubitus ulcers, lick granulomas and delayed unions with other applications, such as generation of cartilage in osteoarthritic dogs, still being investigated.

There are a variety of devices that employ different wavelengths of photo energy. The term photo therapy or light therapy must not be mistaken for monochromatic infrared energy. Photo, or light therapy, is visible energy. Therapeutic monochromatic infrared energy sources are found just outside of the visible wavelengths on the light spectrum. At this wavelength of infrared light, photo dissociation of nitric oxide from hemoglobin has been demonstrated. Currently, there is no evidence that other phototherapeutic devices effect serum nitric oxide levels.

America's Food and Drug Administration clearance for human use was approved in 1994 to enhance circulation and reduce pain. The Equi-Light consists of flexible diode treatment pads with 60 near infrared diodes in each pad arranged in a 2- or 4-pad configuration. Treatment times vary from 20 – 45 minutes depending on the condition being treated.

As outlined in this lecture, there are a variety of techniques that may be employed to facilitate wound healing. With an understanding of the three major phases of wound healing, the practitioner may intervene throughout the process to augment and maximize the repair.

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