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Differences Between Ultrasound and Electrical Stimulation in Wound Healing

Josette Bryngelson
University of North Dakota

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DIFFERENCES BETWEEN
ULTRASOUND AND
ELECTRICAL STIMULATION
IN WOUND HEALING

by

Josette Bryngelson
Bachelor of Science, Chadron State College, 1994
Bachelor of Science in Physical Therapy
University of North Dakota, 1997

An Independent Study

Submitted to the Graduate Faculty of the

Department of Physical Therapy

School of Medicine

University of North Dakota

in partial fulfillment of the requirements

for the degree of

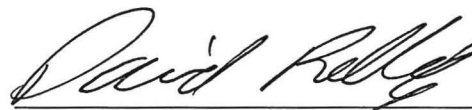
Master of Physical Therapy

Grand Forks, North Dakota

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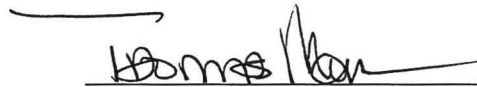
This Independent study, submitted by Josette Bryngelson in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.



(Faculty Preceptor)



(Graduate School Advisor)



(Chairperson, Physical Therapy)

PERMISSION

Title Differences between Ultrasound and
Electrical Stimulation in Wound Healing

Department Physical Therapy

Degree Master of Physical Therapy

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Date 12/8/97

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To Dave Relling MPT, thank you for your help with this Independent Study. Finally, to all of the instructors and personnel at the Department of Physical Therapy for supplying me with my educational and home environment in North Dakota.

In loving memory....
to
May Lochmiller (October 8, 1997)
and
Harold Symonds (November 17, 1997)

Grandma and Papa, I look to the time when we
can be together again...
I love and miss you.

ABSTRACT

When a patient enters a physical therapy clinic for wound therapy, a physical therapist must decide the best way to provide care. The therapy that is decided upon depends on the client, the therapist, and the goals that are trying to be achieved.

Through a literature review, I will compare two methods of wound care treatment: therapeutic ultrasound and electrical stimulation. This paper will look at the way these two treatments work and how these treatments are beneficial in wound healing.

The benefit of this literature review will be to provide a source of information in choosing an effective or optimal treatment regime for the patient with delayed wound healing. This literature review has found that ultrasound works by stimulating the release of mediators and attracting monocytes to the area, stimulating fibroblasts, epithelial cells, and indirectly, monocytes in accelerating the growth of new tissue. Electrical stimulation is used to accelerate and enhance healing by retarding bacterial growth, increasing local circulation, and enhancing the natural process of tissue repair. Finally, electrical stimulation increases the number of leukocytes, increases collagen synthesis, and accelerates wound epithelialization.

Chapter I Introduction

Every type of wound has an emotional cost for the patient plus a financial cost for the patient, family and society. There is an estimated 3% to 5% incidence rate of pressure ulcer formation in hospitalized patients.¹ With a spinal cord patient, the incidence increases to 25% to 85%.² In 1977 the cost of care of a pressure ulcer was \$15,000.² If only 5% of Americans are hospitalized in a year the estimated total cost would be \$750,000,000 when using 1977 costs not counting for inflation.² This paper is a literature review on wound therapy and two treatments used for wounds.

A wound is described as a break in the continuity of the skin and/or soft body parts caused by trauma or violence.³ In wound therapy, there are a number of selected methods to promote healing. This paper compares the physical attributes of ultrasound and electrical stimulation in promoting healing through therapeutic wound treatment.

The first chapter will classify wounds as either chronic or acute and then describe the stages of wound healing. The next two chapters will describe ultrasound and electrical stimulation and what physiological effects they produce to improve the rate of wound healing. Finally, the last chapter will discuss future research questions to determine the most appropriate modality to produce beneficial wound healing.

Wound therapy is a big part of physical therapy. As a therapist, one has to decide which treatment will better accommodate patient comfort while satisfying the needs of the therapist and wound healing goals. Both ultrasound and electrical stimulation are used for wound healing. The problem is which wound healing treatment protocol is more effective. This paper will look at both methods to see where each method is better suited to produce desired effects.

Purpose: The purpose of this literature review is to demonstrate differences in physical properties and physiological effects of ultrasound and electrical stimulation during the wound healing process. This will provide the therapist with information to choose the most beneficial protocol.

Research Questions:

1. How are ultrasound and electrical stimulation different in their effect on the wound healing process?
2. What effect does ultrasound have in wound healing?
3. What effect does electrical stimulation have in wound healing?
4. To what phase of healing is ultrasound best applied?
5. To what phase of healing is electrical stimulation best applied?
6. What is the difference between 3MHz and 1MHz soundhead application in ultrasound when used for wound healing?

7. What is the difference between direct current and alternating current when electrical stimulation is used for wound healing?
8. Where is ultrasound applied to the wound area?
9. Where is electrical stimulation applied to the wound area?

Chapter II

Wound Classification and Wound Healing

Wounds can be classified into two major areas. These areas are chronic and acute wounds. According to Mark Romanick (Fall, 1995), chronic wounds are anything over three months of age, have a loss of skin integrity and/or underlying tissue, often recur, and need help to heal. Chronic wounds are caused by prolonged pressure, arterial insufficiency, venous insufficiency, or diabetes. Acute wounds are wounds that are less than three months old, often heal by themselves, and heal in a timely manner. These wounds are due to burns and trauma.

Chronic Wounds

Pressure ulcers, on a cellular level, occur when tissues become ischemic due to pressure that is applied for a prolonged period of time. Tissue necrosis or tissue death is caused by a bony prominence on one side and a hard surface on the other causing abnormal pressure on the tissue between these surfaces.⁴ Tissues closest to the bone will undergo necrosis first. Redness and skin discoloration may be indicators of underlying adipose and muscular necrosis. Other forces that co-exist with pressure are frictional and shearing forces. Decreased general health, decreased skin texture and turgor, decreased patient mobility, and decreased nutritional status will increase the person's risk for pressure sores.

In an arterial insufficiency wound, there is a complete or partial blockage of the artery which may lead to necrosis and/or ulceration.⁵ Some clinical signs of arterial blockage are no pulse in the extremity, painful ulceration, small punch-out ulcers that are usually well circumscribed, cool or cold skin, delayed capillary return time, atrophic appearing skin (shiny, thin, dry) and loss of digital and pedal hair. These ulcers usually occur on the toes, feet, and lower one-third of the leg.⁶ They have an irregular shape, a pale base, poor granulation, and cause severe pain.

Venous ulcerations are the most common type of ulceration affecting the lower extremity.⁷ The normal vein has valves that prevent backflow of blood. When these valves fail, venous congestion occurs. Red blood cells escape and leak into the extravascular space. When these are broken down, a brownish discoloration occurs in the area. This ulcer typically appears on the medial aspect of the lower one-third of the leg (i.e., the medial malleolus) in combination with an edematous and indurated lower extremity.⁷ The ulcer is shallow, not too painful, and may present with a weeping discharge. According to Mark Romanick (Fall, 1995) a venous ulceration can also be due to a deep vein thrombosis (DVT).

Last to be discussed is the diabetic foot ulcers. These ulcers are foot ulcers due to both neurologic and vascular complications.⁸ These complications can cause an altered or complete loss of sensation in the foot or leg. Any injury to the foot may go unnoticed for weeks due to this altered sensation. A person with intact sensation will automatically determine when there is too much pressure and shift to relieve it. A person with advanced neuropathy will not sense this sustained pressure; therefore, tissue ischemia and

necrosis may occur. Microfractures in the foot go unnoticed which may result in disfigurement, chronic swelling, and additional bony surfaces. There is no cure for this neuropathy, but strict glucose control slows down the progression.

Chronic Wound Classification

Pressure ulcers are staged by the amount of skin breakdown.⁴ The AHCPR (Agency for Health Care Policy and Research) Publication uses four stages to describe the breakdown.⁹ Stage 1 is a nonblanchable erythema of intact skin, announcing the possibility of a skin ulceration. Individuals may present with darker skin, discoloration of the skin, warmth, edema, induration, or hardness. The skin is intact in a Stage 1 ulcer. Stage 2 is a partial thickness skin loss involving the epidermis, dermis, or both. The ulcer is superficial and looks like an abrasion, blister, or shallow crater. A Stage 3 ulcer is a full thickness skin loss involving damage or necrosis of subcutaneous tissue and may extend down to, but not through, underlying fascia. This presents as a deep crater with or without undermining of the adjacent tissue. Finally, a Stage 4 ulcer is a full thickness loss with extensive destruction, tissue necrosis, or damage to muscle, bone, or supporting structures (e.g. tendon, joint capsule). Undermining and sinus tracts may also occur at this stage.

Most studies have shown that the lost fat, muscle, and dermis will be replaced by granulation tissue, which is red appearing tissue in the base of the wound.^{3,9} This granulation tissue fills the ulcer space before re-epithelialization. Re-epithelialization may be kept under control by the therapist, so that the wound bed can fill with granulation tissue before wound closure can take place. Therefore, a healing ulcer can not have a

reversed stage.⁴ This means that a Stage 3 ulcer will become a healing Stage 3 ulcer, but it will never be classified as a Stage 2 ulcer or a healing Stage 2 ulcer.

Chronic wounds are classified similarly to the pressure ulcer classification.

Chronic wounds, including pressure ulcers, are classified as either a primary or secondary lesion.⁶ A primary lesion contains macules, papules, and vesicles arising from what was the normal skin. A secondary lesion has changes in the wound that was classified as a primary wound. Ulcers will fall into the secondary lesion.

Acute Wounds

Acute wounds are classified as either burns or trauma wounds. There are different ways that a burn may occur. Scalding may occur from hot water, grease, or radiator fluid.¹⁰ A thermal burn may occur from flames. Thermal burns are usually deep burns. A chemical burn may occur from acid and alkali. Chemical burns are also usually deep burns. An electrical burn may be caused by either low voltage around the house or high voltage at work. An explosive flash is usually only a superficial injury. A contact burn is usually deep and may occur from muffler tail pipes, hot irons, and stoves.

Burns are classified by the depth of destroyed tissues.¹¹ The duration and intensity of heat, skin thickness and area exposed, vascularity, age, and a person's pigmentation are factors that will influence the depth of the damage. The classifications are a superficial burn, a superficial partial-thickness burn, a deep partial-thickness burn, a full-thickness burn, and a subdermal burn.¹¹

In a superficial burn, cell damage occurs only to the epidermis. A sunburn would be the classic example where the skin appears red or erythematous. The surface of the

burn is dry, meaning that there is no blister formation, and the skin becomes tender to the touch. The patient may experience pain. Skin healing is spontaneous in about 2 to 3 days. There is no scar formation present.

A superficial partial-thickness burn, occurs when damage extends through the epidermis and the upper layers of the dermis. The epidermis is destroyed, but there is only mild to moderate damage to the dermis. Intact blisters are noticeable in this stage. This burn is painful due to the injury sustained by the nerve endings. Healing takes place in about 7 to 21 days. There is some skin discoloration due to the melanocytes that were destroyed, but scarring is minimal.

In a deep-partial thickness burn, there is destruction of the epidermis and severe damage to the dermal layer. Structures involved in this destruction include nerve endings, hair follicles, and sweat glands. The appearance of the wound is a mixed red or waxy white color. The wound surface is wet with broken blisters and alterations of the dermal vascular system are present. This is a painful injury because not all nerve endings are destroyed. There will be a scar upon healing.

A full-thickness burn is described as all epidermal and dermal layers being destroyed. The subcutaneous fat layer may have also suffered some damage. This type of burn is classified by eschar which is a hard parchment-like substance on the wound. The color of eschar can range from black to white. The patient will not have pain in these areas because the nerve endings have been destroyed. The patient may have pain from other adjacent areas that do not have the full-thickness burns. Grafting of tissue will be necessary because of the loss of viable growth tissue.

The last classification is the subdermal burn. The epidermis, the dermis, and subcutaneous tissue are all destroyed. The muscles and bone may also be damaged. This is usually caused by electricity. There is a loss of sensation due to the damaged nerve endings. The patient feels no pain which is also due to damaged nerve endings. This type of burn will need to have a skin graft because of the loss of viable growth tissue.

A traumatic wound may compromise the arterial, venous, or lymphatic systems.¹² It may change the bony or soft tissue structure of the skeleton. There may be loss of skin layers, subcutaneous soft tissue, muscle, or bone. It may damage or cause the loss of body parts or organs.

WOUND HEALING

There are three stages of wound healing: the inflammatory phase, the proliferative phase, and the remodeling phase.¹³ The inflammatory phase starts as soon as the wound is acquired and can last up to two to five days. In this stage, return to homeostasis begins, this is defined as vasoconstriction, platelet aggregation, and thromboplastin making clots to stop the blood flow. Progression in the inflammation phase results in vasodilation which brings serous fluids into the injury site causing edema.⁶ Phagocytosis, where leukocytes and macrophages begin to remove cellular debris, begins to occur at approximately the same time.^{6,13} According to Langemo (Wound Healing, Medstar Health Education Network, 1995) and other sources, macrophages, through the release of chemotactic factors (for example fibronectin) will attract fibroblasts into the wound area.⁶ These fibroblasts will proliferate and begin to increase collagen production. At this time

there are signs of inflammation, swelling, redness, heat, and pain. Near the end of the first phase, fibroblasts begin to synthesize collagen.

The next phase is the proliferative phase. This phase lasts from two days to three weeks. The first part of this phase is called granulation. This occurs when fibroblasts lay down a bed of collagen and new capillaries are formed.¹³ The new tissue is composed of fibroblasts, which produce newly generated collagen fibers in a rich vascular network. According to Langemo (Wound Healing, Medstar Health Education Network, 1995), the tissue is shiny, beefy, and bleeds easily. Near the end of this phase, re-epithelialization and wound closure begin to take place. Epithelial cells cross the moist surface of the wound. The cells travel about three centimeters from the point of origin in all directions to resurface the wound area. The wound edges move toward the center helping to fill the wound bed. At this time collagen fiber density has increased and blood supply has decreased. The scar begins to remodel itself.

The final phase is the remodeling phase.¹³ This phase takes place from three weeks to two years. Although new collagen has formed to increase the tensile strength of the wound, the subsequent scar tissue that has developed will only be 80% as strong as the original tissue.

Chapter III Ultrasound

General properties of Ultrasound

Ultrasound has been used for more than 40 years as a physical therapy modality. One of its uses is to stimulate wound healing. Ultrasound is a mechanical disturbance of molecules in a media that oscillates at a frequency above the limit of human hearing.⁶ Ultrasound is transmitted as compressional waves. These waves have been compared to the ripples caused by an object that is thrown into the water. Compressional waves can take alternate courses resulting in molecules being pushed together (rarefaction) or pulled apart (rarefied). When waves travel in liquids or soft tissue, the waves are longitudinal, creating the molecular displacement that is parallel to the direction of wave movement. In the above example of a stone being thrown into the water, the ripples would hit the shore line causing parallel movement of the sand away from the center of wave motion. In solids, a transverse or shear wave is produced, which means that the solid particles will oscillate perpendicularly to the direction of wave movement. Tissues in the body, except compact bone, will produce a longitudinal wave, as if transmitting through a liquid. This is clinically important to know because periosteum and hard tissues such as bone will readily absorb the ultrasound waves causing localized heating and sometimes pain.¹⁴

Equipment

Ultrasound equipment is made up of a micro-computer controlled by a high frequency generator.¹⁵ This generator is linked by a co-axial cable to a transducer called a soundhead. The soundhead contains a disc of piezoelectric material that converts one type of energy into another. The piezoelectric material consists of crystals like quartz, or synthetic polarized ceramics such as lead zirconate titanate (PZT) and barium titanate. Synthetic materials are generally used instead of naturally occurring crystals because the synthetic material seems to have better electrical and mechanical properties. The piezoelectric phenomenon develops an electric charge on certain crystals by applying a mechanical pressure. This may be reversed to produce mechanical energy by placing an electrical charge across the crystal. When a charge runs through the crystal, there is a deformation of the crystal that takes place. This deformation will continue until the electrical current changes direction. The amount of crystal deformation is proportional to the amount of voltage applied. By using alternating current, a mechanical vibration of the crystal can be produced. The oscillation of the crystal develops the ultrasound waves which are introduced into the body.

Waveforms

Ultrasound machines can produce either a continuous or pulsed wave.^{6,15} A continuous ultrasound wave is a wave produced without interruption. A pulsed wave is set up to deliver pulses of ultrasound or also called marked time ultrasound. These pulsed waves typically run from 0.5 to 2 milliseconds separated by pauses lasting a few milliseconds.⁶ Breaks in the wave of energy reduce the amount of overall energy that the

patient receives as compared to the continuous wave. Pulsed waves must be activated for a longer time to produce the same thermal effects as a continuous wave. In wounds, a nonthermal effect is required because of the compressed material in the area therefore a pulsed wave is used. For continuous ultrasound, there are some guidelines for the intensity of the treatment. These guidelines are:

< 0.3 W/cm² is considered low intensity

0.3-1.2 W/cm² is considered medium intensity

1.2-3.0 W/cm² is considered high intensity¹⁶

The lowest intensity that will produce the desired clinical effect should be used.⁶ Acute injuries use the low range, where chronic conditions will use the middle of the medium intensity. For an increase in temperature, the intensity can be raised by 0.5 W/cm². Non thermal effects can be obtained with a lower intensity pulse wave.¹⁵

Duty Cycle

The term duty cycle, when used with ultrasound, describes the ratio of pulsed time. This is used to determine the amount of energy a patient receives. The term duty cycle is a ratio or percentage of the pulse duration (on-time of the pulse) to the pulse period (the sum of the on and off time of the pulse cycle).¹⁵ Duty cycles ranging from 5 to 50% are available with some of the ultrasound equipment used. Duty cycles usually consist of 20-100% of the energy coming from the soundhead.¹⁷

Energy Field

The energy field produced by the ultrasound depends on the size and shape of the transducer or soundhead.⁶ The ultrasound applicator produces pressure variation mainly

in front of the soundhead and around the soundhead. Ultrasound is emitted from the transducer as a beam that is somewhat cylindrical. This region of the beam is called the near field, and the energy from this beam distribution is highly variable. Away from the transducer, the energy beam diverges to what is called the far field. This is where the energy distribution becomes more regular. The energy of the beam is not evenly distributed; the energy of the beam is high in some areas more than others. Most ultrasound therapies are given with the target tissue located in the near field. This is where nonuniformity ratio is highest. The beam nonuniformity ratio (BNR) is a numerical value that represents the peak intensity (highest intensity of the ultrasound field) and the spatial average intensity of the ultrasound meter.¹⁵ The spatial average intensity represents the average intensity of the energy beam. In wound therapy, machines with the lowest BNR are recommended for use because there is a decreased chance of potential damage to the healthy tissue.^{6,15} According to Michlovitz, a BNR of 2:1 to 6:1 is appropriate.¹⁸ Moving the soundhead instead of keeping it stationary will also reduce the chance of damage to the tissues.

Characteristics

Any exposure to ultrasound should consist of variables such as power, intensity, and frequency of treated tissue relative to the applicator.¹⁵ Power is normally measured in watts. It is considered to be the total energy of the beam. The power value is an indicator of the amount of energy a patient receives. This means that the greater the power value the greater the temperature increase.

Intensity is the amount of energy per unit area per unit time. This is measured in watts/cm².⁶ Intensity is figured by the spatial average intensity (W) divided by the effective radiating area (ERA) of the soundhead.¹⁵ This represents the strength of acoustic energy. The ERA is not the same size as the face of the soundhead, but depends on the size of the crystal within it. When using therapeutic ultrasound, the general statement is that the more acute the condition, the less the intensity should be to provide a comfortable, non-painful experience for the patient. Intensity is power per area. Therefore, if power is too high in a small area, the heat could be too high. This could cause damage to the healing wound, therefore, a low intensity would be appropriate.

Frequency is recorded in megahertz (MHZ).⁶ As frequency increases, the penetration of sound waves decreases. For most dermal wounds, a 3 MHZ frequency is utilized because of minimal depth of wound.¹⁷ A larger frequency of 1 MHZ can be used to effectively treat deeper structures or periwound skin.

Application

When applying therapeutic ultrasound, one must use a coupling media to produce a lessening of the effect of the impedance of the skin.⁶ There are many oils, degassed water and aqueous gels that can be used. This promotes better application of the sound waves to the area being treated. Ultrasound can also be transmitted to a wound through degassed water. The wound is immersed in the degassed water and ultrasound energy travels through the water into the wound. The therapist needs to be aware that the soundhead is contaminated for other patients needing ultrasound. The ideal medium would be something that has excellent ultrasonic propagation properties, chemically inert,

sterile, nonstaining, doubles as a wound dressing, nonirritating, not too rapidly absorbed, slow to evaporate, free from gas bubbles and other foreign material, transparent, and inexpensive.⁶ When working with wounds the best medium seems to be a sterile wound dressing like a hydrogel dressing, because they have similar acoustic properties to soft tissue. This dressing should be able to be easily coupled to and be able to exclude air from the wound. Ultrasound is transmitted into the wound by placing the applicator on the dressing and moving it gently over the wound. A small amount of aqueous gel can be added to ease the movement of the soundhead.

Treatment Regimen

When selecting the treatment regimen, frequency of treatments, absorption, desired effect, and duration need to be considered. The frequency of treatments depends on the depth of the target tissue, the other tissues lying in the path of the target tissue, and the mechanisms involved in producing the effect that is desired.⁶ Acute injuries should be treated as soon as possible. Acute conditions are treated 1 to 2 times a day to relieve pain and swelling and then alternate days until the condition is resolved. Chronic wounds are treated less frequently (approximately 3 times a week).

Upon entering the tissues, ultrasonic energy is either absorbed or scattered. Absorption is when the ultrasonic energy is converted to heat; whereas, scattering, is due to the differences between the tissues, and redirects the energy out of the beam.¹⁹ The amount of absorption or scattering depends on the tissue being treated. Areas of tissue that are higher in protein content, like muscles, more readily absorb the ultrasonic beam than do areas with a high fat or water content.⁶ This means that areas like muscles will

accept the heat faster and will take less time to heat to produce the desired effect. For instance, a 3MHz ultrasound loses half its intensity after passing through 16 mm of fat or 32 mm of muscle where as a 1MHz ultrasound will travel through 48 mm of fat or 9 mm of muscles before losing half its intensity.²⁰ The end result being that 3MHz is better for superficial injuries of the epidermis and collagenous dermis where as 1MHz is better for deeper injuries.^{6,17}

When selecting treatment times, the effect produced should also be considered. Absorption produces a heating effect and occurs faster at a high frequency. Three MHz is recommended if the desired effect in superficial tissues is to produce a thermal mechanism. Some mechanical effects, like acoustic streaming, occurs at a high frequency while stable cavitation occurs more at a lower frequency. This will also tend to affect treatment times.

Duration is based on the surface to be treated. Most researchers suggest that the area of the wound should be broken down into zones of 1.5 times the area of the soundhead, and one to two minutes should be spent in each of those areas.^{15,20} Others¹⁶ recommend a maximum treatment of 15 minutes, spending 1 minute on an area 1 cm².

General Effects of Ultrasound

The effects of ultrasound are physical changes and therapeutic changes.⁶ Ultrasound can be potentially damaging to tissues of the body if it is not properly used. Ultrasound can produce physical effects that are classified as thermal or nonthermal. Thermal effects are a result of absorption. Absorption can be increased depending on the amount and size of the area to be treated, the efficiency of the treated area to disperse

heat, and the frequency of the ultrasound. The effect of thermal ultrasound is an increase in blood flow to stimulate wound healing. Along with warming of the muscular tissues, other tissues like periosteum, fibrotic muscle, cortical bone, joint menisci, major nerve roots, tendon sheaths, and intermuscular interfaces are also heated.¹⁵ If vascular flow is compromised, thermal heating may produce damage because the blood is unable to dissipate the heat produced.⁶ There is an increase in cell metabolism with increased heating, but if there is too much heating cell destruction can occur.²¹ An increase in tissue heating can also be produced by other things such as a metal prosthesis. If these situations become present or are present, a decrease in intensity or a different modality is desired.

Nonthermal effects include cavitation, acoustic streaming, arteriolar vasoconstriction or dilation, and micromassage.^{6,15} Ultrasound may cause micron-size bubbles to form in biological tissues such as blood, lymph, tissue fluid, and possibly elsewhere in the body. These bubbles may also travel to different parts of the body. The ultrasound field can cause the bubbles to vibrate in response to the pressure change (stable cavitation) or implode violently (unstable or collapse, transient cavitation).⁶ Transient cavitation produces localized damage. There is no set range where unstable cavitation becomes present.^{14,18} It seems to occur when there is an increase in frequency in the MHZ range or when energy is delivered in the form of multiple short pulses of millisecond duration. Unstable cavitation also causes free radical formation.⁶ Free radicals are a natural part of cell metabolism that are removed by scavengers within the body, but excessive free radical exposure can be dangerous and has been implicated in

molecular damage and aging.^{15,21,22,23} Since stable cavitation can be done in vivo with lower intensity levels, it is again seen or suggested that lower intensity is better for wound healing. Stable cavitation may be partly responsible for stimulation of tissue repair through modifying cell membrane permeability and diffusion of metabolites.⁶

Acoustic streaming causes a change in diffusion rates and membrane permeability of the cells.¹⁵ Ultrasound produces a 'streaming' effect which causes a change in the permeability of the cell membrane.²¹ The end result is the increase in the rate of diffusion of ions into or out of the cell. If it does not cause damage to the cell membrane by too much movement in one direction, it can help facilitate transport of ions and molecules. Ultrasound exposure to fibroblasts can increase ion uptake.^{24,25} Also, stimulation of protein synthesis by fibroblasts can increase the release of wound factor,²⁶ sodium uptake in muscles²⁷ and nerves,²⁸ increase serotonin release from platelets,^{29,30} and may aid pain relief by endorphin secretion. Acoustic streaming is associated with cavitation, but does not occur by itself. It occurs as a result of radiation torque which is a force through which ultrasound induces a circulatory flow of fluids and angular displacement of objects exposed to it.²⁴

Arteriolar vasoconstriction or dilation is considered to be a nonthermal effect of ultrasound, but if there is any effect or just a nonthermal effect is not clear.⁶ Studies have been done that have produced a nonthermal effect at higher intensities. Hogan, et al³¹ used intensities of 5-10 W/cm² with a stationary technique to show vasoconstriction of the small arterioles of the rat cremaster muscle. The temperature of the muscle was monitored, but vasoconstriction occurred by the ultrasound exposure with greater

significance than what could be attributed to an increase in muscle temperature. They later used pulsed ultrasound to demonstrate vasodilation in rat cremaster muscles which were chronically ischemic.³² They used 1.0 MHz at 2 W/cm² for 5 minutes.³² These results produced only a nonthermal effect. Vasoconstriction would produce a narrowing of the vessels that supply the wound area with phagocytic cells and growth factor material. Vasoconstriction should be avoided during ultrasonic treatment. Vasodilation will increase fluid and other material to the area. This is needed to produce wound healing. Therefore the use of continuous ultrasound may be more beneficial than pulsed ultrasound for creating vasodilation and wound healing.

Micromassage is the last nonthermal effect. As a result of exposure to ultrasound, microscopic movements or oscillations of the body fluids and tissues occur.¹⁵ In the opinion of Hecox, it is suggested that all nonthermal effects produced by ultrasound may be contributed to the micromassage.⁶

Effects on Wounds

When used during the inflammatory stage of wound healing, ultrasound causes a degranulation of mast cells³³ resulting in the release of histamine.¹⁷ The release of histamine and other chemical mediators from the mast cells plays a role in attracting neutrophils and monocytes to the injured area. With these events and other chemical mediators, ultrasound helps to accelerate the acute inflammatory phase and promote healing. In the proliferative phase, ultrasound stimulates fibroblasts^{34,35} to secrete collagen.³³ The result is an acceleration of wound contraction and an increase of the tensile strength of the healing tissue.³⁶ Ultrasound does not seem to be effective in the

remodeling phase of wound healing. Ultrasound can be used to try to improve the mechanical properties of the scar, but there is not conclusive evidence that it is successful.

Chapter Four Electrical Stimulation

General properties of electrical stimulation

An electrical circuit is described as a current through which electrons and charged particles travel.¹⁵ In order for a current to exist, all parts of the circuit must be in contact with each other so that the charged particles can move. These parts include the battery, electrodes, and switches. A current is the flow of the charged ions.

In order to have a continuous flow of current there must be a driving force, an electromotive force (EMF).¹⁵ The EMF is the difference in potential between two points of the circuit and determines if energy will travel from one point to another. The EMF is considered a measure of the maximum work per unit charge rather than a measure of force. A potential difference is determined when one part of the circuit has a greater amount of charge than another point on the circuit. The difference in potential can be established by a battery. For instance, the cathode part of the battery will have an excess of negative electrons while the anode will not. But if the two ends of the battery are connected the negative electrons can now travel to the anode completing the circuit.

Resistance

Resistance is encountered when there is a flow of electrical particles.¹⁵ There are materials that offer less resistance to the electrical current. These are called conductors.

Some examples would be silver, copper, and tap water. Insulators are materials that offer high resistance and impede the electrical flow. Examples of insulators include rubber, paraffin, and distilled water. Semiconductors are materials that are neither good insulators nor conductors, such as silicon and germanium.

Factors such as the size, shape, and composition of the conduction material will determine the amount of resistance in a circuit. Temperature can also effect the amount of resistance. The type of material used will also determine the level of resistance.¹⁵ For example, metals tend to have less resistance than non-metals. Solutions such as salt water contain many electrolytes and therefore have less resistance than a solution like tap water which contains fewer electrolytes. Body fluids such as blood, sweat, and interstitial fluid are good conductors because they contain many electrolytes.

Arrangement

Electrical currents can be arranged in series or parallel to each other.¹⁵ Most electrical circuits are a combination of both. When a circuit is in series, the electrical circuit flows through each resistor. For instance when electrical stimulation is applied to the skin, the skin and fat layers are said to be in series. When a circuit is parallel, the resistors are arranged so that the circuit can have multiple alternative pathways. In the human body, the current takes the path of least resistance, which is usually a parallel circuit. An example of a parallel circuit in the human body is the deeper tissues including muscle, blood, tendon, and bone.

Characteristics

General characteristics to classify electrical devices are the waveform, duration, and frequency of the electrical output. The waveform is the geometric representation of the electrical wave.¹⁵ The waveform has many variables such as the amplitude, duration, and rise and decay time. All these variables can be pre-set or adjusted on the device used. The waveform is made up of phases, which is the flow of charges in one specific direction for a period of time.

A waveform represented by a stimulus output is called a pulse.¹⁵ A pulse duration is the time, given in units of microseconds to seconds, that it takes from the beginning to the end of one waveform or pulse. The interval pulse is the time that elapses between the ending of one pulse and the beginning of another. The pulse rate or the number of pulses in a second is given in pulses per second (pps).

Other characteristics of the pulse waveform is the rise and decay time. Rise time is the time it takes for the current to rise from baseline to peak amplitude. Depending on the waveform that exists (i.e. faradic, sine, rectangular, biphasic, asymmetrical biphasic) there may be an increase in rise time or very little rise time. Decay time is the amount of time to go from peak amplitude back to baseline. The rise and decay time may effect the response of the tissue to the electrical stimulation. For example, nervous tissue does not respond to a slow rise time but muscles will. This is because nervous tissue will accommodate to the response stimulus.

Frequency and duration of the waveform pulse can be manipulated depending on the type of effect desired. The waveform can change parameters such as intensity,

duration, and pulse rate. This is called waveform modulation or pulse modulation. A common form of modulation is the ramp or surge modulation where the intensity of the pulse is altered (Mohr T, unpublished material, 1996). Each successive pulse will either gradually or abruptly increase to peak amplitude or gradually or abruptly decrease to baseline. In surge modulation, a duty cycle can be applied. The duty cycle is the ratio of on time to the total time. Meaning the percentage of the net on time to the total time period (on and off) of the stimulus. Another waveform modulation is the burst mode. A burst mode is when a series of pulses start and stop at regular intervals.

Peak current, average current, or current density are terms used to describe the amount of current used.¹⁵ Peak current amplitude is the maximum height of the waveform measured from the baseline (Mohr T, unpublished material, 1996). Average current is the total value of current in a given time. The amount of current given out by the electrodes placed on the body is measured in milliamps per unit of area which is the current density. For a given current amplitude, the smaller the electrode the higher the current density and the stronger the stimulus.¹⁵ In therapeutic muscular stimulation the smaller electrode, the active electrode, will provide the electrical current and the larger electrode will be the dispersive electrode that is used to complete the circuit. In order for the circuit to be complete, all stimulators will have at least two leads with at least two electrodes. Since the body is a good conductor, placing the electrodes on any part of the body would be sufficient.

Electrode Placement

For proper therapeutic stimulation, there are two arrangements commonly used. These arrangements are called the monopolar and bipolar placements.¹⁵ In a monopolar arrangement, the active electrode is placed over the area to be stimulated (Mohr T, unpublished material, 1996). The dispersive pad is placed in another area away from the active pad. The smaller pad will have more current density than the larger pad. This will limit the occurrence of an adverse response under the dispersive pad.

A bipolar arrangement is where two electrodes which are usually the same size, but may not be, are placed over a target area.¹⁵ This method concentrates the electrical current on the area to be stimulated. The electrodes can be split or bifurcated to stimulate more than one area, there may or may not be a dispersive pad.

Frequency of Electrical Stimulation Devices

The frequency of the device is based on the stimuli output. The classification includes a low frequency output (1-1000 Hz), a medium frequency output (1000-10,000 Hz), and a high frequency output (10,000 Hz or more).¹⁵

Types of Current

There are two types of currents used for therapeutic purposes. One is DC and the other is AC. DC (direct current), which is a constant unidirectional flow of charged particles, and interrupted DC current with a “make-break” switch.¹⁵ This means that the charged particle can either be positive or negative but never both. When tissues are stimulated, the positive or negative electrical fields will be established and maintained under their respective electrode.

DC current can produce an electrochemical reaction. The anode, the positive field, results in an acid reaction and the cathode, the negative field, results in an alkaline reaction. The extent of the reaction depends on the intensity and duration of the current applied. DC can be either a continuous or interrupted waveform. The waveform that represents direct current is called a monophasic waveform. This waveform does not change directions in its electrical field.

Interrupted DC current seems to be best applied when stimulating motor, sensory, and autonomic nerve and muscle tissue. This current has a monophasic pulse of long duration. The flow of current can be interrupted with a “make or break” key. This method is not used for wound healing. Interrupted DC stimulators, such as high voltage pulse stimulators, deliver unidirectional monophasic waveforms. The duration of each pulse of the waveform is less than 100 microseconds. This does not produce a chemical charge or stimulate denervated muscles. This stimulator is used to stimulate neuromuscular and other soft tissues that are still intact.

Low voltage continuous microamperage is a unidirectional flow of charged particles that do not stop or change direction during treatment.⁶ These charged particles are delivered to the wound site by either a positive (anode) or negative (cathode) electrode. Ideally, the amplitude of the current should remain constant. For instance, if tissue impedance changes, the voltage will change to keep the amplitude steady. The usual amplitude for most clinicians is 0.2 to 1.0 milliamps. Over time electrochemical reactions may occur (Mohr T, unpublished material, 1996). This may result in a raise of pH to an alkaline level at the cathode or an acidic level at the anode. The alkaline

reaction may produce a bacteriocidal effect at the cathode. The acidic reaction may produce a coagulation of blood leaking from small vessels which may help with wound closure producing a congealed scar. Low voltage pulsed microamperage current can be delivered either as a constant-polarity monophasic pulse or as reversed polarity biphasic pulse through a paired-probe or carbonized rubber electrodes.

Another example is high voltage pulsed current.⁶ This current is delivered in twin-peak pulses of either negative or positive polarity. The duration of the pulse is fixed but varies within a range of 45 to 100 microseconds. The pulses may be delivered to the tissue between 1 and 125 pps. The voltage to drive the pulses into the skin is high. This can be explained by the classic inverse relationship between the amplitude of a pulse and its duration. Since the pulses are of short duration, the peak currents must be high resulting in the driving voltage being high. HVPC does not alter the pH of the skin, but it does deliver monophasic pulses that can be either positive or negative.

Alternating current or AC is the other type of current used.¹⁵ This current changes its direction of flow. Thus the electrodes can become either positive or negative. Unlike DC current, the electrical fields change under the electrodes. The current will rise to a positive peak amplitude, return to an isoelectric point (a zero point), rise to a negative peak amplitude, and finally return to its isoelectric point.

Two other names for AC current are biphasic waveform and bidirectional current. If there is any build up of charge under one electrode, it is wiped out by the subsequent wave of reversed polarity resulting in no net polar charge. Waveforms that contain an alternating current which crosses the isoelectric line and contains a positive and negative

phase is called the biphasic wave form. If the shape under the positive and negative phases are equal the biphasic waveform is said to be symmetrical. If the positive and negative phases are unequal, the waveform is said to be asymmetrical. The area under the phase represents the phase charge. An asymmetrical wave can be either balanced or unbalanced. In a balanced asymmetrical wave the total phase charges equal neutral, or zero, thus meaning there is no build up of electrical charge. In an unbalanced waveform the net charges do not equal; therefore, a positive or negative charge will remain. An unbalanced waveform is good for wound therapy. In wound therapy, the positive electrode is used for tissue healing and the negative electrode is used for a bacteriocidal effect.^{15,37} Electrical stimulation with a positive field stimulates the natural process of tissue recovery and promotes tissue healing.^{338,39} The average rate of healing is 1mm per day.¹⁵ If a plateau is reached during healing, the polarity should be changed.

In vitro studies have shown that stimulation of E-coli (*Escherichia coli*)⁴⁰ and Staph aureus (*Staphylococcus aureus*)⁴¹ with low intensity direct current has a bacteriocidal effect. This either retarded or inhibited the growth of the bacteria. The exact mechanism is unknown. One idea is that there is a depletion of substrates due to the continuous excitability of the cell membrane as it tries to reach homeostasis. A second idea is that the electrical fields change internal processes of the cell resulting in death. The bacteriocidal effect is produced by the negative electrical field with a low amplitude current.

An example of AC is the low voltage pulsed milliamperage current.⁶ It is traditionally a TENS (transcutaneous electrical nerve stimulation) that produces

symmetric biphasic pulses. The quantity of charge contained in the pulses are equal so there is no build-up of residual charge. In some TENS units the pulses may be of unequal charges. This produces a slight build up of charges that produces a transient skin erythema. Because of this the electrodes are placed on the skin around the wound site.

Lastly, the effectiveness of electrical stimulation is dependant on the amount of current used, the tissue composition of the area to be treated, the size of the electrodes, the intensity, and the area of tissue to be treated. An example from Hecox¹⁵ states that the amount of subcutaneous fat in obese people will have a higher resistance thus a higher intensity is needed.

Physiological effects

Electrical stimulation affects wound healing in the inflammatory phase by initiating the wound repair process by its effect on the “current” of the injury.^{15,37} Electrical stimulation can accelerate tissue healing by changing the charge of the injured tissue. When a wound occurs, the wound site has a difference in electrical potential as compared to the surrounding tissues. The difference is the wound site is positive for the first 24 to 48 hours. After 8-9 days post-injury, the wound site now becomes negative and begins to heal. Electrical stimulation will increase blood flow,^{42,43,44} promote phagocytosis,⁴² enhance tissue oxygenation, reduce edema from microvascular leaks, attract and stimulate fibroblasts and epithelial cells,⁴⁵ control infection, and solubilize blood products including necrotic tissue.⁴² In the proliferative phase, electrical stimulation stimulates fibroblasts and epithelial cells to secrete collagen, stimulate protein synthesis, increase ATP generation,^{42,44} produce a better collagen matrix organization,⁴²

and stimulate wound contraction. In the remodeling phase of healing, electrical stimulation facilitates epidermal cell reproduction and migration and produces a smoother, thinner scar.

Chapter V

Results

Ultrasound and electrical stimulation are two different types of procedures used to facilitate wound closure. As shown in their respective chapters each produces the same result but in a different way. Ultrasound with its varied frequencies is effective in accelerating the inflammation and proliferative phases of wound healing. After these initial stages higher intensities than normal may have to be used.¹⁵ Ultrasound can only be effective for wounds between three to five centimeters in depth. Past this stage the effect of ultrasound is felt not to be effective because of the depth of the target tissue. Ultrasound needs the use of gels, bandages, or degassed water to help the soundhead couple with the wound surface. The soundhead is never in direct contact with the wound which may lower the soundwave effectiveness. Some studies have stated that ultrasound does not provide any beneficial effect beside a small possible bacteriocidal effect.⁴⁶

Electrical stimulation was found to be effective in all phases of wound healing. It also has a good bacteriocidal effect to the wound depending on the polarity.¹⁵ Restated, the two forms of current are DC and AC. DC is a unilateral flow of negatively or positively charged ions, and AC is a bidirectional flow of charged ions that can be either positive or negative. With DC there is an electrochemical reaction which produces a bacteriocidal effect and helps with tissue healing where AC will not produce a

electrochemical reaction. Unlike ultrasound, electrical stimulation was more effective for wounds exceeding five centimeters in depth. This was because the electrode, which is surrounded by wet, sterile gauze, could be placed directly into the wound cavity.⁴²

Alternate placements for the electrode pad are placing the electrode directly on the wound surface or the area surrounding the wound.

Chapter 6

Discussion

In gathering of materials, there seems to be a lack of protocols for electrical stimulation. I would suggest that there is a need to research and establish appropriate electrical stimulation protocols. There is not enough clinical parameters set for various types of ulcers or wounds depending on the depth, the healing potential, and the size of wound.

In one article it was suggested that ultrasound could produce a bacteriocidal effect.⁴⁶ It was not well proven, so further research would be indicated. Other studies have suggested that ultrasound may be good for the remodeling phase of wound healing. This would be another area that would need more supportive data.

One limitation of papers is that the writer is bound by the material available at the time of writing. As part of this literature review, I used material in the University of North Dakota Health Sciences library, interlibrary loan, and electronic media. Key words used to compile sources included: electrical stimulation, ultrasound, and wound healing.

Conclusion

At the time this paper was written, Medicare patients were no longer able to receive electrical stimulation for wound care because reimbursement was stopped. The reasoning used was that there was not sufficient evidence to support the claim that electrical stimulation was effective. According to the research material obtained there is data showing the effectiveness of electrical stimulation in wound care. This could effect electrical stimulation as a treatment modality because some people may not be able to afford treatment costs without third party coverage.

As a therapist, one must look to see what treatment technique would benefit the patient and decide on the appropriate protocol. This literature was designed to give a brief overview about ultrasound and electrical stimulation that may help in that decision making process. In the end, the best result for all treatment programs is to improve the quality of life for the patient.

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