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Electrical Stimulation as an Adjunct to Healing

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ELECTRICAL STIMULATION AS AN ADJUNCT TO HEALING

by

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(Chairperson, Physical Therapy)

PERMISSION

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TABLE OF CONTENTS

LISTS OF TABLES

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ABSTRACT

The purpose of this overview is to offer a possible avenue for advancing wound or ulcer healing when working with a population who experience complications of skin healing. In respect to their normal functional activities, these persons will experience limitations, and will also require more utilization of medical resources to assist in their progress. Dermal ulcers may predispose them to even further complications. There are many factors which influence the healing rate. Low voltage current and, more recently, the use of high voltage pulsed current, has been researched to serve as an additional treatment possibility for improved skin status.

key words: electrical stimulation, wound healing, dermal ulcers

CHAPTER I INTRODUCTION

Intervention in wound management has evolved and continues to do so in a myriad of techniques. The last twenty years have been a period of more advancement than in all previous recorded history.[1] The use of electrical stimulation in various forms is increasing due to its positive effect on healing.[2-35]

Texts dating back to 3000 B.C. describe initial recorded wound treatment.[36] Early wound control was limited mainly to superficial injuries. By the 1500's, many modifications changed from treatment using honey and flint, metallic salts, and burning oil, to various mixtures and ligations.[36] Most surgical intervention began in the 1900's, but fatal results often made conservative treatment the choice until further advancements were made. Transportation time reduction, improved resuscitation and enhanced care have reduced the mortality rate tremendously. Advancements in biomedical knowledge have resulted in todays use of antibiotics and related medications, specific dressings, and varied intervention techniques which have increased and further improved healing and mortality.[37,38]

Dessication was used as conservative treatment for open wounds before the 1960's. However, it was found in studies during that decade, that superficial wounds healed more readily when kept moist, rather than drying with scab formation. Occlusive dressings promoted epidermal healing, hydrating the surface, and often reducing bacterial growth and discomfort.[39,40] The use of topical agents has also been undergoing change. Some antimicrobial solutions have been reported to create adverse healing or even toxic effects unless used for short periods of one to two weeks.[37,39,41]

Basic principles of good skin care are essential to optomize the healing process. The type of dressing used, topical agents, pressure relief, growth factors, oxygenation, nutrition, and environmental stress are all tenets to be considered.[37,39,42-44] Further complications in delayed healing may include sepis, osteomyelitis, pyarthroses, anemia, and amyloidosis.[37,38,41,43,45,46]

Decubitus ulcers or pressure sores are a frequent problem in patients treated in short or long term care facilities, the elderly, or in those with neurological impairments.[37, 43-45] Berlowitz and Wilking[46] found that patients admitted to a long term care facility with a pressure sore had twice the mortality rate as those without a pressure sore at admission. Those who developed a new sore after institutionalization, or had a pressure sore which did not improve, had three times the mortality rate. The severity of the pressure sore was not found to be associated with the mortality rate itself.[46]

Factors contributing to pressure ulcer formation include shearing forces, pressure itself, friction, and the presence of moisture.[37,41-44]

Prevention is a major factor in skin care, both for intact or compromised skin. Increased mobility, nutrition, repositioning, frequent evaluation, and assessment reduce skin damage.[37,41,43] Use of the team approach to pressure ulcer control demonstrates a 50% reduction in their occurence.[41]

Risk factors for development of decubitus ulcers have been identified through various studies. Though these results suggest various components involved, it appears that all note poor nutrition, history of stroke or cerebral vascular accident, and limited mobility as seen in those who are chair-bound or bed-bound.[41-46]

The use of electric stimulation has evolved to assist in wound healing. In documentation of early electrical stimulation, which originally appeared in 1688 and was republished in 1925, charged gold leaf was used over smallpox lesions noting healing without scarring.[47] In 1940, Burr et al[48] reported electropotentials found over wound surfaces that were positive for four days and then negative until resolution of the wound. Further research in the 1950's and 1960's, revealed a negative electric potential present in mechanically stressed bone.[49] The use of direct current for tissue healing was researched during this time and was also found to be beneficial.[50]

Direct current was initially used for wound healing, but the apparatus tended to be bulky and not easily accessed. Its use continues today for wound healing with improved equipment which is easier to apply, with the same beneficial results.[3-6,9] In addition to wound healing, some direct current research is aimed at prevention of pressure. Levine and Kett et al[51] used low level electric stimulation over the gluteus maximus in production of load changes and undulation of tissues which contributed to pressure relief.

The use of high voltage stimulation in wound healing is often associated with pressure ulcers or decubitus ulcer management.[16-22] High voltage stimulators have been used with human subjects, demonstrating significant improvement in healing of pressure sore complications in those with intact peripheral nervous system functions[16-20] and in spinal cord injured patients.[21,22] Pertinent animal and cellular research has addressed the effect of high voltage stimulation on oxygen uptake,[23,24] wound closure,[26-30] increased tensile strength,[31] stimulation of blood flow,[32] and specific cell activation.[33-35,52,53] Further studies will hopefully increase our understanding of electrical stimulation and advance its use in promoting wound care and healing.

CHAPTER II ELECTRICAL STIMULATION STUDIES

History

Utilization of electrical stimulation in the healing process has continued to change with ongoing electropotential studies.[48] During the early 1960's, the idea of a direct current system associated with tissue healing was suggested by Becker.[54] His research began on regeneration of extremities of the salamander. Intact animals were found to have a negative charge of 8-10 millivolts at each extremity. After the amputation of an extremity, the "current of injury" was initially positive, increasing to over 20 millivolts. Six to ten days post injury, the polarity reversed, becoming negative 30 millivolts. This higher negative value, gradually returned to original figures of approximately negative 10 millivolts with restoration of skin and scar tissue.[54] Similar studies were undertaken on frogs, and though they do not regenerate, they had the initial reversal in polarity from a negative baseline. This was followed by a gradual decline in positive values which returned to original figures with healing.[54] Investigations continued, noting that the skin of mammals and amphibians maintains a battery and a voltage gradient which is measurable in epidermal wounds.[54,55]

Studies utilizing exogenous electrical stimulation to wound sites have continued and have demonstrated significant advancement in the healing rates.[2-22,25-31] Electrical stimulation appears to increase speed of healing and protein synthesis with an ease of performance that is non-invasive and cosmetically acceptable.[37,56,57] Contraindications for the use of electric stimulation include cancer, seizure disorders with frequent occurrences, demand-type pacemakers, osteomyelitis, or life-threatening ulcers that require surgical intervention.[5,6,37,57,58]

Low Voltage Studies

Clinical Studies

Gault and Gatens[2] studied 106 ischemic skin ulcers, and revealed mean healing ratios in the treatment group that were more than twice that of the control group. Six symmetrical ulcers served as controls in this research. The treatment group demonstrated complete healing in 48 ulcers, and greater than 95% reduction in the size of 11 more. All treatment group ulcers revealed some degree of success.

Thirty hospital inpatients were involved in the findings by Carley and Wainapel.[3] Division into pairs determined by diagnosis, age, wound etiology, location, and approximate size, formed random control and treatment groups. One member received low intensity direct current and the other received traditional therapy intervention using dressings or whirlpool. Treatment group patients had increased rates of healing that were one and a half to two and a half times those of the control group results.

Karba et al[4] conducted research on 63 patients with postoperative wounds, pressure ulcers, or vascular lesions. These patients served as their own control group as 59 of the 63 had had their ulcers for averages from 7.7 to 99.4 weeks. Results demonstrated complete healing in 49 of the wounds during hospitalization. Only three wounds, which were vascular lesions with established gangrene, failed to respond.

Mulder[5] studied 59 patients having either surgical wounds, pressure ulcers, or vascular lesions. Pulsed current on wound sites revealed a 56% decrease in initial wound size, compared to a 33% reduction for control group patients in a ten week period.

Investigations by Gentzkow et al[6] were completed on 40 pressure ulcers. Four week, double-blind results demonstrated treatment group healing of 49.8%, more than twice the control group rate of 23.4%. A cross over group displayed a 47.9% healing rate with active stimulation for four weeks. Continued stimulation in this group from five to sixteen additional weeks, had 63.9% healing, with complete healing noted in 40% of the ulcers after an average of nine weeks.

Feedar, Kloth and Gentzkow[7] completed research involving 47 patients with 50 wounds. Healing rates of 14% per week for the treatment group and 8.25% for the control group were demonstrated after a four week period. A cross over group of 14 from the original group had an increase in their healing rate of 12.8% per week; they displayed a reduction of wound size four times greater than their response when in the sham group.

Animal Studies

In related animal studies, Assimacopoulos[8] used direct current stimulation on surgical skin defects in rabbits. Observations demonstrated a 25% reduction of healing time and an increased connective tissue density. Scars healed with greater tensile strength.

Alvarez et al[9] worked with Yorkshire pigs that were surgically wounded. A significant increase in the biosynthesis of collagen in treatment group animals was found after four days of stimulation. Wound resurfacing was also found to be accelerated.

Studies by Stromberg[10] on pigs concluded that alternating currents in treatment group animals increased wound closure over a 3 week period. Negative current stimulation was seen to retard the contraction process.

Akai et al[11] found ligament repair in New Zealand rabbits enhanced by direct current through proportions of collagen types. Collagen content itself was no different between groups; the authors felt that the stimulation improved ligament repair through the changes in collagen type ratios.

Im, Lee, and Hoopes[12] found improved survival rates in electrically stimulated skin flaps of Yorkshire pigs. Skin flap survival rates were greater in those animals who received two stimulation treatments as opposed to those receiving only one.

Research on diabetic mice by Smith et al[13] demonstrated improved healing rates and greater tensile strength among treatment animals. Those receiving stimulation demonstrated near normal epidermal development whereas the sham group had large gaps in the connective tissue, fewer sebaceous glands, and fewer hair follicles. Albino Hartley guinea pigs were used in a wound healing study by Dunn et al.[14] Cathodal stimulation resulted in greater collagen alignment and fibroblast migration promoting enhanced healing. Cheng et al[15] found increased ATP concentrations and amino acid incorporation following direct current stimulation on Wistar R rats. These effects add to the increase in protein synthesis.

High Voltage Current

Clinical Studies

Clinical studies have demonstrated good results with high voltage stimulation. Unger[16] has completed several studies with high voltage pulsed current, measuring healing by the change in size of each wound during research. Her results showed 82% healing in eight weeks in a study involving 13 skilled care patients with decubitus ulcers. In a second study, involving 154 geriatric patients with 223 wounds, 89.7% experienced healing in an average time span of 10.85 weeks.[17] Research by Unger, Eddy and Raimastry[18] studied 17 patients with pressure ulcers. Eight of nine patients in the treatment group demonstrated complete healing resulting in an 88.9% healing rate. Average healing time was seen after 51.2 days of stimulation.

Control group healing was seen in three out of eight patients for a 37.5% healing.

In a pilot study, Feedar and Kloth[19] demonstrated a 100% healing over a mean period of 7.3 weeks in five patients treated with high voltage pulsed current. Mean healing rates during this research were 25.3% per week. Kloth and Feedar[20] completed another investigation of high voltage current with 16 patients having stage IV ulcers and intact peripheral nervous systems. They found that the mean healing rate was 45% per week with a treatment group of nine patients. Three patients initially assigned to the control group of seven experienced a 38.1% healing per week after reassignment to a secondary treatment group, and then complete healing after 8.3 additional weeks.

Akers and Gabrielson[21] treated 14 patients with pressure ulcers in three therapeutic measures: one group received whirlpool, one group received whirlpool and high voltage stimulation, and a third group received stimulation only. They found the greatest degree of healing occurred in the high voltage stimulation only group followed by the whirlpool and stimulation group and, lastly, by the whirlpool only group.

Griffin et al[22] researched a spinal cord injured group of 20 patients with pressure sores of grades II,III, and IV. In their findings, the mean percentage of reduction of wound surface area was significantly greater in the high voltage stimulation group than that in the sham stimulation group.

In ten diabetic patients, Dodgen et al[23] found electrical stimulation to increase oxygen tension leading to increased circulatory and wound healing benefits. Three settings were utilized and all displayed corresponding results without polarity influences.

Gagnier et al[24] completed similar research on ten paraplegic patients using high voltage stimulation and monitoring oxygen levels with oximetry. These investigations found significant oxygen saturation increases which would assist in promotion of healing.

In work using high voltage transcutaneous electrical nerve stimulation, Alon et al[25] found that diabetic foot ulcers responded to positive polarity stimulation. Complete healing resulted in 12 of 15 patients over a mean period of 2.6 months after stimulation was completed over ulcer sites.

Animal Studies

Animal studies on high voltage pulsed stimulation have been explored for wound healing and tensile strength. Focusing on high voltage bioelectric wound healing, a series of investigations were undertaken on New Zealand rabbits. Brown and Gogia[26] demonstrated initially that cathodal high voltage stimulation over wounds for four to seven days did not result in increased tensile strength or wound closure. A following study by Brown and McDonnell[27] suggested increased epithelialization of treatment animals using anodal stimulation. A later set of investigations by Brown, McDonnell and Menton,[28] demonstrated positive polarity accelerating closure of wounds from days four through seven. A subsequent study by the same authors using negative polarity stimulation for days one through three and positive polarity stimulation from days four through seven, resulted in enhanced epithelialization and suggests improved wound closure.[29]

A study of high volt galvanic pulsed stimulation on burn wounds in domestic pigs by Cruz, Bayrón and Suárez,[30] demonstrated accelerated wound healing and had a higher number of fibroblasts present in treatment group animals. Increased collagen and fibroblast rates were thought to explain the accelerated healing.

Investigations utilizing tendons of Sprague-Dawley rats by Owoeye et al[31] employed one of three methods: anodal stimulation, cathodal stimulation, and no stimulation in their comparison of tendon ruptures. Increased tendon strength was noted in the groups utilizing anodal current. Those receiving no stimulation were found to have tendon strength greater than the group who received cathodal stimulation.

Mohr, Akers and Wessman[32] found high voltage stimulation to increase blood flow in Sprague-Dawley rats with clinical suggestions in its use to improve wound healing. This research finds high voltage stimulation to have generally long lasting results in blood flow velocity and increased blood flow to the involved musculature.

Tissue Studies

Tissue studies of high voltage pulsed current and low amperage direct current have been compared in their bactericidal effects against *staphlococcus aureus.* High voltage stimulation has been assumed to have bactericidal effects such as those demonstrated with direct current. In a study by Guffey and Asmussen,[33] direct current produced bactericidal results even at low intensities, while high voltage stimulation did not produce inhibition of the bacterial growth.

Work by Kincaid and Lavoie[34] demonstrated inhibition of *staphylococcus aureus, escherichiacoli* and *pseudomonas aeruginosa* in vitro with high voltage pulsed current. Findings suggest voltage and treatment duration required for killing bacteria in vitro would require substantial increases in voltage and time that may not be tolerated clinically. Both studies suggest increased treatment time if stimulation is for treatment of infected wounds.[33,34]

Bourguignon and Bourguignon[35] completed tissue studies with high voltage stimulation which resulted in increased collagen and DNA synthesis. In their study on human fibroblast cultures, high voltage pulsed current maximized synthesis of collagen and DNA at 50 and 75 volts. Both DNA and collagen synthesis were inhibited at intensities greater than 250 volts. Results suggest high voltage stimulation prompts fibroblasts to increase protein and DNA production proximal to the negative electrode.

Associated Article Reviews

In a 1991 article by Swanson,[59] a cost-outcomes analysis on wound care procedures was completed as it affects the Medicare program.

The two procedures compared were hydrotherapy and high voltage pulsed current. Cost comparisons demonstrated reduced costs due both to lower average unit charging and shorter duration of treatment when high voltage pulsed current was used instead of the more traditional hydrotherapy.

In a statistical technique used to synthesize related studies, Meyers[36] added five electrical stimulation studies with a total of 78 treatment wounds and 72 control wounds. In this meta-analysis, the treatment groups either healed or healed significantly; all responses were improved over control group responses.

A number of literature reviews cite electrical stimulation as an addition to wound or chronic ulcer healing.[37,39,40,42,56-58,60-62] Various ideas have been presented as to possible explanations for the physiological response of the body to electrical stimulation. These include but are not limited to increases in: fibroblastic action,[14,28,30,35,57,62,63] protein synthesis,[15,57] cutaneous oxygen tension,[23,24,58] blood flow,[4,32,57,63] bactericidal activity,[5,16,33,34,57,63] and a reduction of mast cells.[52,53,63] The number of electrical stimulation studies as it relates to wound healing will continue. One article by Reich and Tarjan[64] urges future studies to follow guidelines in establishing electric parameters which permit reproducibility and comparison. They also encourage specific research to determine absolute charge transfer and determination of the sequencing of polarity. The future in electric stimulation should be intriguing and advances in equipment and techniques should prove beneficial to both providers and those they service.

CHAPTER III SUGGESTED CLINICAL PROTOCOL

The use of electrical stimulation as an adjunct to wound management has been recommended through clinical trials and reviews. Protocol differences are noticed between low voltage and high voltage currents as well as divergence among research groups.

In general, patient studies agree on the importance of initial cleansing or debridement of skin and wound surfaces prior to treatment. Most utilized saline irrigation or flushing for cleansing[2,3,5,6,17,19,20] while other techniques mentioned were hydrogen peroxide[16] and whirlpool.[2,6,7] Debridement as needed was completed either manually[6,7,17,19,20,22] or with enzymes.[19,20] Strict standards of wound and nursing care have been advocated throughout.[2,5-7,16,22]

Reduction of pressure was specified through multiple methods as an integral facet of treatment. Specific means cited were: repositioning or turning,[6,16,22] elevation of extremities[6] and avoidance of sitting with either a gluteal or an ischial ulcer or supine positioning with either a sacral or a coccygeal ulcer.[22]

Additional components of management utilized in research were: reduction of shearing and friction,[2,3,16,20] control of heat, moisture, and hygiene,[2] control of edema,[2] treatment of medical problems,[2,3,16] nutrition, emphasizing a high protein diet,[2,20] reduction of pain and discomfort,[3] and effleurage around, but not over the reddened area.[16]

As a rule, both low voltage and high voltage studies suggest electrode placement directly over the wound site. Saline soaked gauze pads provided the necessary moisture under the electrodes.[2,3,5-7,16-22] The exception in these studies is Karba et al[4] who positioned self-adhesive electrodes on healthy skin adjacent to wound edges. Stimulation time, treatment duration, intensity, and frequency settings as well as electrode polarity vary as seen in Table 1.

Clinical research was corroborated by documentation. Type of current used, treatment time and settings should be included in clinical practice as they are in research. This information will support patient care. Documentation is needed at the initial evaluation and appropriate intervals thereafter. The addition of electrical stimulation to the clinical wound management program can be a significant factor in the advancement of wound or pressure ulcer healing as suggested in patient investigations.[2-7,16-22]

Table 1. Protocols in Clinical Electrical Stimulation Research

Low Voltage Studies

Reference	Electrode Placement	Stimulation Time	Treatment Duration	Intensity Setting
Gault & Gatens[2]	over wound	2 hours	TID x 7 da	200-1000 microamps
Carley & Wainapel[3]	over wound	2 hours	BID x 5 da	300-500 500-700 microamps
Karba et al[4]	at wound edges on healthy skin	1 hour	daily	15-25 milliamps
Mulder[5]	over wound	30 minutes	BID	30-40 milliamps
Gentzkow et al[6]	over wound	30 minutes	BID x 4 weeks	35 milliamps
Feedar et al[7]	over wound	30 minutes	BID	29.2 milliamps

High Voltage Studies

Reference	Electrode Placement	Stimulation Time	Duration	Polarity	Frequency	Intensity
Unger[16]	over wound	30 minutes	BID	(-)7 da then (+)	50pps 80pps	150 V
Unger[17]	over wound	30 minutes	BID	(-)6 da then(+)	50pps 80pps	150 V
Unger et al[18]	over wound	30 minutes	BID	(-)6 da then (+)	50pps 80pps	150 V
Feedar& Kloth[19]	over wound	45 minutes	5 da a week	(-)3 da then (+)	105Hz or pps	just under visible m. contraction
Kloth& Feedar[20]	over wound	45 minutes	5 da a week	(+) until healing then daily reversal	105Hz or pps	just under visible m. contraction
Griffin et al[22]	over wound	1 hour	20 da	(-)entire time	100 pps	to 200 V

LIST OF REFERENCES

1. Hunt TK. Basic principles of wound healing. *J Trauma.* 1990;30(suppl):122-128.

2. Gault WR, Gatens PF. Use of low intensity direct current in management of ischemic skin ulcers. *Phys Ther.* 1976;56:265-269.

3. Carley PJ, Wainapel SF. Electrotherapy for acceleration of wound healing: low intensity direct current. *Arch Phys Med Rehabil.* 1985; 66:443-446.

4. Karba R, Vodovnik L, Presern-Strukelj M, Klesnik M. Promoted healing of chronic wounds due to electrical stimulation. *Wounds.*1991;3:16-23.

5. Mulder GD. Treatment of open-skin wounds with electric stimulation. *Arch Phys Med Rehabil.* 1991;72:375-377.

6. Gentzkow GD,Pollack SV, Kloth LC, Stubbs HA. Improved healing of pressure ulcers using Dermapulse, a new electrical stimulation device. *Wounds.*1991;3:158-170.

7. Feedar JA, Kloth LC, Gentzkow GD. Chronic dermal ulcer healing enhanced with monophasic pulsed electrical stimulation. *Phys Ther.* 1991;71:639-649.

8. Assimacopoulos D. Wound healing promotion by the use of negative electric current. *Am Surg.* 1968;34:423-431.

9. Alvarez OM, Mertz PM, Smerbeck RV, Eaglstein WH. The healing of superficial skin wounds is stimulated by external electrical current. *J Invest Dermatol.* 1983;81:144-148.

10. Stromberg BV. Effects of electrical currents on wound contraction. *Ann Plast Surg.* 1988;21:121-123.

11. Akai M, Oda H, Shirasaki Y, Tateishi T. Electrical stimulation of ligament healing. An experimental study of the patellar ligament of rabbits. *Clin Orthop.* 1988;235:296-301.

12. Im MJ, Lee WP, Hoopes JE. Effect of electrical stimulation on survival of skin flaps in pigs. *Phys Ther.* 1990;70:37-40.

13. Smith J, Romansky N, Vomero J, Davis RH. The effect of electrical stimulation on wound healing in diabetic mice. *J Am Podiat Assn.* 1984;74:71-75.

14. Dunn MG, Doillon CJ, Berg RA, Olson RM, Silver FH. Wound healing using a collagen matrix: effect of DC electrical stimulation. *J Biomed Mater Res.* 1988;22(suppl):191-206.

15. Cheng N, Van Hoof H, Bockx E, Hoogmartens MJ, Mulier JC, DeDijcker FJ, Sansen WM, DeLoecker W. The effect of electric currents on ATP generation, protein synthesis, and membrane transport in rat skin. *Clin Orthop.* 1982;171:264-272.

16. Unger PG. Wound healing using HVGS. *Stimulus.* 1985;10:8-10.

17. Unger PG. A randomized clinical trial of the effect of HVPC on wound healing. *Phys Ther.* 1991;71(suppl):S119.Abstract.

18. Unger P, Eddy J, Raimastry S. A controlled study of the effect of high voltage pulsed current (HVPC) on wound healing. *Phys Ther.* 1991;71(suppl):S119.Abstract.

19. Feedar JA, Kloth LC. Acceleration of wound healing with high voltage pulsating direct current. *Phys Ther.* 1985;65:741. Abstract.

20. Kloth LC, Feedar JA. Acceleration of wound healing with high voltage, monophasic, pulsed current. *Phys Ther.* 1988;68:503-508.

21. Akers TK, Gabrielson AL. The effect of high voltage galvanic stimulation on the rate of healing of decubitus ulcers. *Biomed Sci Instrum.* 1984;20:99-100.

22. Griffin JW, Tooms RE, Mendius RA, Clifft JK, Vander Zwaag R, El-Zeky F. Efficacy of high voltage pulsed current for healing of pressure ulcers in patients with spinal cord injury. *Phys Ther.* 1991;71:433-442.

23. Dodgen PW, Johnson BW, Baker LL, Chambers RB. The effects of electrical stimulation on cutaneous oxygen supply in diabetic older adults. *Phys Ther.* 1987;67:793.Abstract.

24. Gagnier KA, Manix NL, Baker LL, Rubayi S. The effects of electrical stimulation on cutaneous oxygen supply in paraplegics. *Phys Ther.* 1988;68:835.Abstract.

25. Alon G, Azaria M, Stein H. Diabetic ulcer healing using high voltage TENS. *Phys Ther.* 1986;66:775. Abstract.

26. Brown M, Gogia PP. Effects of high voltage stimulation on cutaneous wound healing in rabbits. *Phys Ther.* 1987;67:662-667.

27. Brown M, McDonnell MK. The effect of positive polarity high voltage stimulation (HVS) on wound healing in rabbits. *Phys Ther.* 1987;67:793. Abstract.

28. Brown M, McDonnell MK, Menton DN. Electrical stimulation effects on cutaneous wound healing in rabbits. *Phys Ther.* 1988;68:955-960.

29. Brown M, McDonnell MK, Menton DN. Polarity effects on wound healing using electric stimulation in rabbits. *Arch Phys Med Rehabil.* 1989;70:624-627.

30. Cruz NI, Bayrón FE, Suárez AJ. Accelerated healing of full-thickness burns by the use of high-voltage pulsed galvanic stimulation in the pig. *Ann Plast Surg.* 1989;23:49-55.

31. Owoeye I, Spielholz NI, Nelson AJ. Low-intensity pulsed galvanic current and the healing of tenotomized rat achilles tendons: preliminary report using load-to-breaking measurements. *Arch Phys Med Rehabil.* 1987;68:415-418.

32. Mohr T, Akers TK, Wessman HC. Effect of high voltage stimulation in blood flow on the rat hind limb. *Phys Ther.* 1987;67:526-533.

33. Guffey JS, Asmussen MD. In vitro bactericidal effects of high voltage pulsed current versus direct current against *staphlococcus aureus. J Clin Electrophysiol.* 1989;1:5-9.

34. Kincaid CB, Lavoie KH. Inhibition of bacterial growth in vitro following stimulation with high voltage, monophasic, pulsed current. *Phys Ther.* 1989;69:651-655.

35. Bourguignon GJ, Bourguignon LY. Electric stimulation of protein and DNA synthesis in human fibroblasts. *FASEB.* 1987;1:398-402.

36. Caldwell MD. Topical wound therapy-an historical perspective. *J Trauma.* 1990;30(suppl):116-122.

37. Kloth LC, McColloch JM, Feedar JA. *Wound Healing: Alternatives in Management.* Philadelphia, Pa: FA Davis Co;1990:221-256.

38. Shires, GT. Evolution of trauma and trauma research. *J Trauma.* 1990;30(suppl):107-115.

39. Cuzzell, JZ, Stotts NA. Trial & error yields to knowledge. *Am J Nurs.* 1990;90:53-63.

40. Mulder GD, LaPan M. Decubitus ulcers: update on new approaches to treatment. *Geriatrics.* 1988;43:37-50.

41. Allman RM. Pressure ulcers. In: Rakel RE, ed. *Conn's Current Therapy 1991.* Philadelphia, Pa:WB Saunders Co;1991:778-780.

42. Romanko KP. Pressure ulcers. *Clin Podiatr Med Surg.* 1991;8:857-867.

43. Reuler JB, Cooney TG. The pressure sore: pathophysiology and principles of management. *Ann Intern Med.* 1981;94:661-666.

44. Maklebust J. Pressure ulcers: etiology and prevention. *Nurs Clin North Am.* 1987;22:359-377.

45. Berlowitz DR, Wilking SV. Risk factors for pressure sores: a comparison of cross-sectional and cohort-derived data. *JAGS.* 1989;37:1043-1050.

46. Berlowitz DR, Wilking SV. The short-term outcome of pressure sores. *JAGS.* 1990;38:748-752.

47. Robertson WS. Digby's receipts. *Ann Med Hist.* 1925;7:216-219.

48. Burr HS, Taffel M, Harvey SC. An electrometric study of the healing wound in man. *Yale J Biol Med.* 1940;12:483-485.

49. Fukada E, Yasuda I. On the piezo electric effect in bone. *J Physiol Soc Jpn.* 1957;12:1158.

50. Thurman BF, Christian EL. Response of a serious circulatory lesion to electrical stimulation. *Phys Ther.* 1971;51:1107-1110.

51. Levine SP, Kett RL, Cederna PS, Brooks SV. Electric muscle stimulation for pressure sore prevention: tissue shape variation. *Arch Phys Med Rehabil.* 1990;71:210-215.

52. Reich JD, Cazzaniga AL, Mertz PM, Kerdel FA, Eaglstein WH. The effect of electrical stimulation on the number of mast cells in healing wounds. *J Am Acad Dermatol.* 1991;25:40-46.

53. Weiss DS, Eaglstein WH, Falanga V. Exogenous electric current can reduce the formation of hypertrophic scars. *J Dermatol Surg Oncol.* 1989;15:1272-1275.

54. Becker RO, Selden G. *The Body Electric*. New York, NY: William Morrow & Co Inc;1985:68-76.

55. Jaffe LF, Vanable JW. Electric fields and wound healing. *Clin Dermatol.* 1984;2:34-44.

56. Weiss DS, Kirsner R, Eaglstein WH. Electrical stimulation and wound healing. *Arch Dermatol.* 1990;126:222-225.

57. Kyes K. Electrotherapy for wound healing. Five researchers discuss the advantages of electrostimulation for tissue repair. *Rehab Manage.* 1991:38-46.

58. Unger PG. Electrical enhancement of wound repair. *Phys Ther Pract.* 1992;12:41-49.

59. Swanson GH. Use of cost data, provider experience, and clinical guidelines in the transition to managed care. *J Insur Med.* 1991;23:70-74.

60. Unger PG. Wound healing currents. *Rehab Manage.* 1992;42-43.

61. Meyers RS. High voltage pulsed current enhancement of chronic dermal wound and ulcer healing. A meta-analysis. (unpublished manuscript, accepted for presentation at World Congress of Physical Therapy),July 1990.

62. Biedebach MC. Accelerated healing of skin ulcers by electrical stimulation and the intracellular physiological mechanisms involved. *Acupunct Electrother Res.* 1989;14:43-60.

63. Gentzkow GD, Miller KH. Electrical stimulation for dermal wound healing. *Clin Podiatr Med Surg.* 1991;8:827-841.

64. Reich JD, Tarjan PP. Electrical stimulation of skin. *Int J Dermatol.* 1990;29:395-400.