ACCELERATED WOUND HEALING OF LOWER EXTREMITIES BY MEANS OF ELECTRICAL STIMULATION

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ABSTRACT

The aims of this study were to examine effects of electrical stimulation on healing of chronic ulcers and oxygen supply in the stimulated tissue. Forty-nine patients with chronic vascular and posttraumatic, most frequently postamputation-wounds, were treated with this modality. Out of them forty-six wounds healed completely. It was found that posttraumatic wounds heal more than two times faster than vascular wounds. The observed outcome of oximetric measurements shows increased partial pressure of oxygen in the stimulated tissue which represents a good foundation for enhanced healing. Based on the results of this study, effective clinical use of electrical stimulation for accelerated wound healing is suggested.

KEY WORDS: wound healing, electric stimulation, atherosclerosis, trauma, amputations

INTRODUCTION

With the prolongation of the life span the number of patients with atherosclerosis and its complications is increasing. The atherosclerotic process affects mainly the blood supply of important organs and the lower limbs. When the blood supply is reduced to such extent that the cells do not get enough oxygen and nutrients, the tissue begins to decay - gangrene sets in.

More than 80% of all lower limb amputations are caused by ischemia. Due to bad circulation the postoperative healing of the amputation stump is often long. This disables the patient to join in the rehabilitation process and use a prosthesis. He could then return to his former social environment.

A great number of patients admitted to the Rehabilitation Institute in order to join in the process of postamputational rehabilitation still have wounds on their stumps, which heal very slowly. The wounds are either vascular wounds caused by ischemia or postamputation wounds in patients who suffered trauma.

In the present paper results of a two year study of wound healing acceleration with electrical stimulation (ES) will be discussed. During this period more than one hundred chronic wounds of different etiologies were treated according to this method at the University Rehabilitation Institute Ljubljana, Yugoslavia.

The idea of applying electrical current for the enhancement of wound healing arose in our environment along with functional electrical stimulation (FES) which is being used routinely for strengthening muscles atrophied by disuse and for eliciting functional movements in patients with motor disfunctions. In these paretic or paralyzed patients pressure sores are very common. Besides functional effects of FES, therapeutic ones could soon be observed. Already existing ulcers healed more rapidly and significantly less new pressure sores were developed in patients who received FES [1,2,3]. Therefore the same type of tetanizing trains of electrical stimuli as those being used at FES for eliciting muscle contractions, was soon successfully used for enhanced healing of chronic ulcers.

This application of electrical current for the acceleration of wound healing is far from being the first. Carey and Lepley in 1962 published results of their study of the effects of continuous direct current on healing and already pointed to the importance of the selection of the polarity of the electrode, which is being placed on the wound. They noticed the positive electrode to attract inflammatory cells to a wound, which induced an increase in the inflammatory reaction at the positive pole. They also observed a greater wound tensile strength at the cathode (negative electrode) than at the anode (positive electrode) [4]. In the extensive study by Wolcott et al. 83 chronic ischemic skin ulcers of different etiologies were treated with low intensity direct current. They showed dramatically faster healing compared to the control wounds. In this study the negative electrode was initially applied directly to the ulcer until it became aseptic. Thereafter the polarity was reversed in order to stimulate the healing [5]. This basic idea, that cathodal stimulation slows down the growth processes and therefore is used for its antibacterial effect and that anodal stimulation enhances growth processes, has been confirmed in numerous clinical as well as experimental model studies [6,7,8,9,10,11]. In spite of that its mechanisms are still unexplained. Alvarez et al. in 1983 applied anodal direct current stimulation to the experimental wounds in pigs. They found the collagen synthetic activity and epithelialization significantly increased in the treated animals [12]. Some studies on the other hand reported continuously applied direct current of negative polarity to augment healing [13] and to cause increased fibroblast ingrowth into the sponge near the cathode [14].

In case that we accept the opinion that electrical currents can accelerate healing, still it seems like the researchers are more or less graping in the dark by choosing the stimulation parameters. We are looking for "windows of beneficial effects" in the wide spectrum of possible, physiologically acceptable stimulation types, which certainly is a time- and effort-consuming work. The way, leading over the results of multiple studies with not necessarily optimally chosen parameters to the knowledge about underlying mechanisms, is namely much longer than the way in the opposite direction, from known mechanisms to the selection of optimal stimulation parameters and thereupon also to optimal results.

In this light the present study is just another report about the beneficial effects of empirically found appropriate parameters which probably could still be optimized. However the method described is already being widely used in rehabilitation practice and many patients have experienced its effectiveness. They were able to return to normal life at the end of a successful treatment of their previously non-healing or else slowly-healing ulcers.

MATERIAL AND METHODS

Patient population

Forty-nine inpatients were included in the study of effects of electrical stimulation on the healing of chronic wounds.

Out of them 17 otherwise healthy patients had postoperation-, most frequently postamputation-wounds as a consequence of different types of trauma (traffic accident, congelation, bruise, ...). This type of wounds sometimes heals very slowly, often because of local infection. The mean age of this group of patients was relatively low - 38 years.

Thirty two patients with wounds of vascular origin due to gangrene or diabetes were assigned to the second group. Damaged peripheral vascularisation causing insufficient blood supply in the lower extremities leads to chronic pain and very often also to the development of ischemic ulcers. Many of these patients live months and even years with sores, which while conventionally treated don't heal and finally lead to amputations. The mean age of this group of patients was 67 years.

The electrical stimulation program

For electrical stimulation two self-adhesive electrodes (ENCORE™ PLUS) were placed on healthy skin at the edge of the wound. Biphasic, charge-balanced asymmetrical current stimuli with a pulse duration of 0.25 ms were used. They were delivered in 4 s lasting trains with a repetition rate of 40 Hz. The stimulation trains rhythmically exchanged with pauses of the same duration (i.e. 4 s). The amplitude was adjusted for each individual patient in order to achieve minimal contraction of the adjacent muscles, usually at 15-25 mA. The electrical stimulation treatment was given daily in a session of 60 minutes.

THE EVALUATION OF THE HEALING PROCESS

In order to evaluate the healing process weekly measurements of the wound area were carried out. At the end of the treatment the gathered wound sizes were plotted as a function of time for each individual patient. Examinations of the time plots showed that they can be fitted by exponential curves (Fig.1), the healing process thus showing exponential behaviour [15].

The time relation of the wound size or the healing process can be described with the following formula: $S = S_0 e^{-t\Theta}$, where S_0 represents the initial wound area, S wound area at the time t and Θ the normalized healing rate, expressed in weeks^{-1}. In the calculation of the normalized healing rate Θ, all values of the wound area are normalized according to the initial wound area S_0: $\Theta = \frac{\ln\left(\frac{S_0}{S}\right)}{t}$

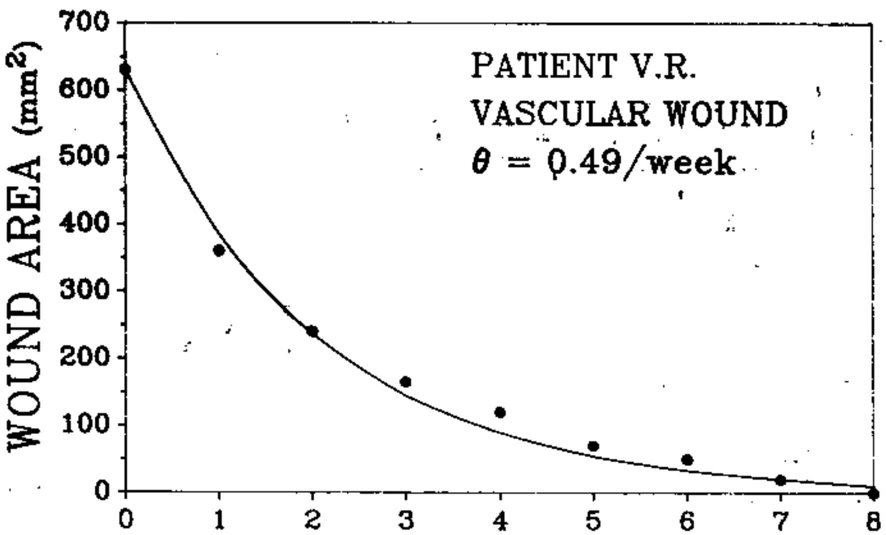

Figure 1. An example of the time course of the healing process for a vascular wound, fitted by the exponential curve.

Now the healing rates can be compared in spite of the fact that the wounds are initially of very different sizes.

This assumption yields the parameter Θ as a measure of the speed of wound healing in the following manner: If Θ equals zero ($\Theta = 0$), the respective wound doesn't heal, it's size remains unchanged. Increasingly negative and positive values of Θ characterize the wounds whose areas are increasing ($\Theta < 0$) and decreasing ($\Theta > 0$) with time, respectively (Fig. 2).

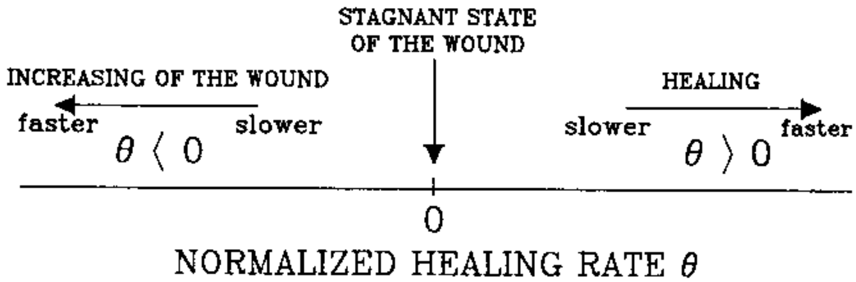

Figure 2. Normalized healing rate as a measure of the speed of wound

OXIMETRY

Patients treated with electrical stimulation in order to accelerate the healing process often stated a feeling of warmth. Rest pains, often present also in static condition, were lessened or even vanished. We supposed the circulation in the stimulated area to improve, influenced by the ES. This should be objectified by means of oximetry - a method where the partial pressure of oxygen (pO_2) in peripheral blood is measured transcutaneously. The conditions in which the measurements took place remained unchanged: the patients were always sitting, the temperature remained constant (22°) and the instrument (Radiometer Transcutaneous Oxygen/Carbon dioxide Monitoring System TCM3, Radiometer, Copenhagen) was calibrated for each measurement according to the daily atmospheric pressure. The probe for the measuring of pO_2 was placed on the skin near the wound. The pO_2 was measured for thirty minutes, the average of the last fifteen minutes (i.e. when the value became constant) was taken for the calculation.

RESULTS

In a study without the control group the treated patients have to serve as their own controls. At the beginning of the electrical stimulation treatment posttraumatic wounds already existed on average for 7.7 weeks and vascular wounds existed on average even for 99.4 weeks (= 1.9 years) before the beginning of ES treatment. During this time they were conventionally treated. They did not heal at all or else they healed very slowly.

After ES application 39 out of 49 treated wounds healed completely during the patients' stay at the Rehabilitation Institute. Another 7 patients left the Rehabilitation Institute with good chances for closure of their wounds. They continued the ES therapy at home until the wounds healed up. Three wounds however failed to respond to ES treatment.

In table 1 average healing rates for posttraumatic wounds and for vascular wounds are given. Data concerning the duration of wound existence before the beginning of ES and initial wound sizes are presented as well. Mean values ± standard errors are given for the corresponding groups.

WOUND TYPE	NO. OF WOUNDS TREATED	WOUND DURATION PRIOR TO ES (weeks)	INITIAL WOUND AREA (mm^2)	NORMALIZED HEALING RATE Θ (weeks-1)
Posttraumatic wounds	17	7.7 +/- 1.4	1696 +/- 850	1.02 +/- 0.26
Vascular wounds	32	99.4 +/- 36.4	1769 +/- 737	0.47 +/- 0.09

Table 1.

The slower healing ulcers seem to be the vascular wounds with a mean normalized healing rate of 0.47/week which reveals a mean treatment time of about 10 weeks. Posttraumatic wounds are healing much faster with a mean normalized healing rate of 1.02/week and with the treatment time as short as 4.5 weeks.

Approximated time courses of wound areas for the two groups of wounds with their respective mean normalized healing rates Θ are presented in figure 3. It can be seen, that the calculated healing rates in real life actually mean drastically different treatment times for wounds of different etiologies.

As mentioned above, three wounds did not heal after ES application. They were of vascular origin, in patients with diabetes mellitus and already established lower limb gangrene. Two of these wounds were located on the ankle and one on the heel. They were deep (20, 23, and 18 mm) and existed for several months (5, 10, and 12) at the beginning of ES treatment. They were surrounded by necrotic tissue, where damaged vascularisation already caused irreversible changes in the tissue structure and the destroying process could not be stopped by ES.

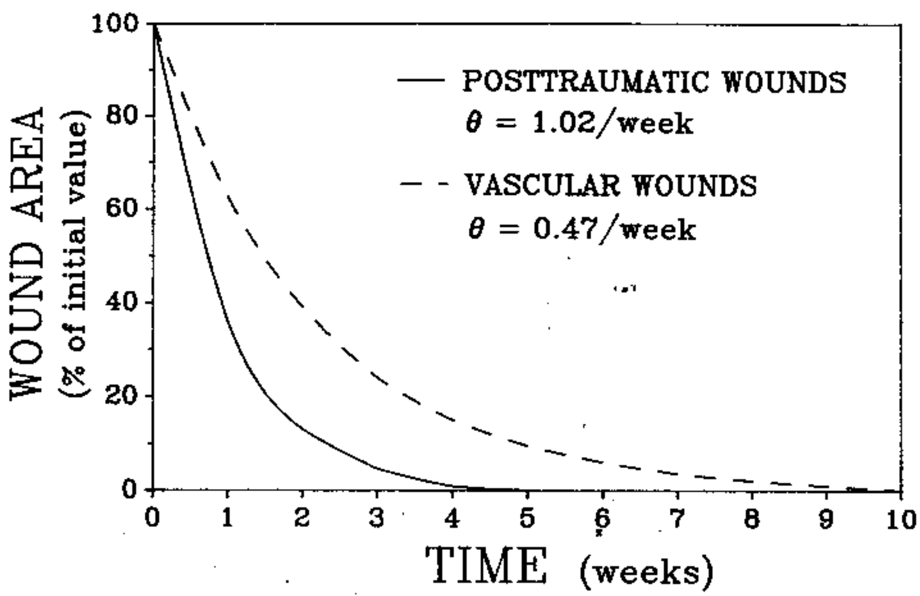

Figure 3. Time courses of wound areas for posttraumatic (continuous line) and vascular wounds (dashed line).

On the basis of oximetric measurements lasting over a period of several weeks, for a group of patients who received ES in order to speed up the healing of their wounds and for not stimulated control group, the mean values of pO_2 and statistic deviations were calculated. All these values were normalized according to values measured during the first week, i.e. before the beginning of the therapy. These values were significantly lower in patients (40 to 60 mmHg) compared to healthy examinees (cca. 80 mmHg).

In the figure 4 a positive trend of pO_2 in the stimulated patients can be noticed. In a period of 8 weeks the pO_2 has raised for cca. 20%.

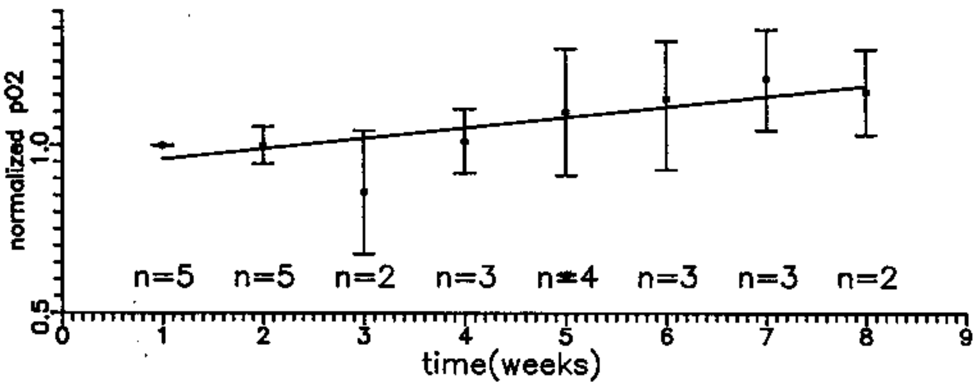

Figure 4. pO_2 values (mean 0 standard deviations) for the group of patients with vascular wounds who were treated with electrical stimulation.

No increase of pO_2 is to be noticed in the control group as shown in figure 5.

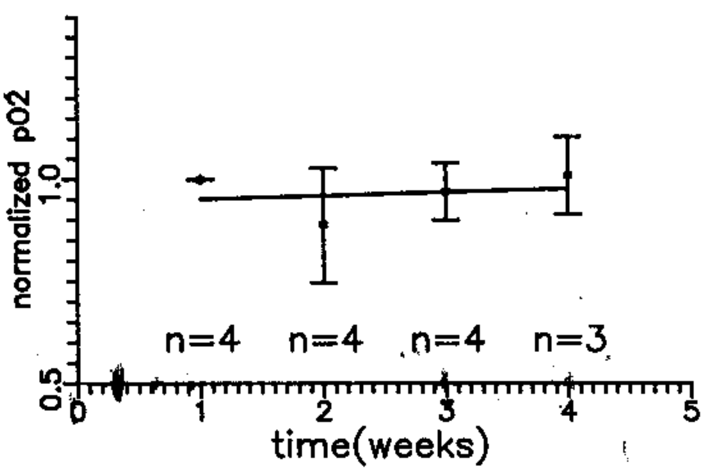

Figure 5. pO2 values for the control group of patients.

CONCLUSION

The application of electrical currents in order to accelerate healing of chronic wounds is virtually unknown by a large majority of clinicians. While first reports were published decades ago few well controlled and quantitative studies are available. Another reason for poor acceptance of this technique is a lack of knowledge regarding the mechanisms by which various currents act on the wound.

In this paper we presented quantitative data supporting the observations that electrical currents can indeed produce accelerated healing of chronic wounds. We are still far from understanding the mechanisms by which electricity affects the healing process but we showed that increased oxygen supply might be one of the parameters contributing to enhanced healing.

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