USE OF A SINUSOIDAL CURRENT OF OPTIMAL FREQUENCY TO STIMULATE SKIN WOUND HEALING

A. V. Nikolaev, A. B. Shekhter, L. A. Mamedov, A. P. Novikov, and N. K. Manucharov

UDC 616.5–001.4–003.93–02:615.874

KEY WORDS: wounds, regeneration, granulation tissue, electrical stimulation, sinusoidal currents.

To accelerate wound healing in the skin and muscles, steady [2, 4] and diadynamic [1] currents are used. Besides their beneficial effect on wound healing they also have side effects, manifested as a pain syndrome, hyperemia, and irritation of the tissues in the region of the stimulating electrodes. In recent years an alternating sinusoidal current has come to be used for the treatment of several diseases, including the promotion of bony union after fractures [5].

The aim of this investigation was to study the effect of an alternating sinusoidal current of optimal frequency on the process of skin wound healing. The optimal frequency of the stimulating current, i.e., the frequency at which the threshold of muscular contraction is minimal, but electrical stimulation is most effective, exhibits species specificity: it is 5000 Hz for man, about 500 Hz for rabbits, 300 Hz for rats, and 100–200 Hz for frogs [3].

EXPERIMENTAL METHOD

Experiments (10 series) were carried out on 120 noninbred male albino rats weighing about 200 g, under general anesthesia. The experimental model in series I–VIII consisted of linear incised skin wounds 5 cm long, inflicted on the dorsum of the rats and closed with three interrupted sutures, whereas in series IX–X, full-thickness excised wounds 400 mm^2 in area were inflicted. Electrical stimulation by a subthreshold unmodulated sinusoidal current (0.8–1.2 V, 0.07–0.13 mA) of optimal frequency for rats (300 Hz) was given on the 2nd, 3rd, and 4th days after the operation, once a day. Stimulation was applied through lead plate electrodes 0.8–1.0 cm^2 in area, applied on two opposite sides of the wound and at a distance of 2–3 mm from its edge. Series I of experiments served as the control for the linear wounds, and series IX for the full-thickness excised wounds; in these series the wounds healed without electrical stimulation. In the experiments of series II–V, dependence of the effect on the duration of the stimulation session (5, 15, 30, and 60 min respectively), and in series IV–VIII, dependence on the frequency of the current (5000, 50 and 600 Hz respectively) were determined. The effectiveness of electrical stimulation was assessed visually, by means of a strain gauge (in experiments with incised wounds the breaking strength of the postoperative scars was determined on the 7th day on the RM–30–1 tensile testing machine) planimetrically (in experiments with excised wounds the area of the wounds was measured on the 7th, 10th, and 15th days), and by histological and histochemical methods (sections from pieces of tissue taken on the 4th, 7th, 10th, and 15th days after the operation from the region of the wounds were stained with hematoxylin–eosin, with picrofuchsine by Van Gieson's method, by silver impregnation by Gomori's method, with toluidine blue for glycosaminoglycans, by the PAS reaction for glycoproteins, and by Brachet's reaction for RNA). The results were subjected to statistical analysis.

EXPERIMENTAL RESULTS

The best effect was obtained by stimulation of linear wounds with a sinusoidal current (300 Hz) in sessions 5 and 15 min in duration (Table 1, series II and III). In these series, on the 7th day after the operation, a narrow and hardly perceptible scar, which was stronger than in the control, remained at the site of the linear wound. If the duration of the session was increased to 30 and 60 min their stimulating effect was reduced

TsNIO NICh. Department of Pathological Physiology, I. M. Sechenov First Moscow Medical Institute. (Presented by Academician of the Academy of Medical Sciences of the USSR V. V. Kovanov.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 97, No. 6, pp. 731-734, June, 1984. Original article submitted September 7, 1983.

 0007-4888/84/9706-0812 $08.50

TABLE 1. Results of Measurement of Tensile Strength of Postoperative Wound Scars Healing under the Influence of a Sinusoidal Current

Series of experiments	Frequency of current, Hz	Duration of session, min	Strength of scars on 7th day, g/mm²	Increase in strength compared with control, %
I	Control		37,2±1,28	
II	300	5	74,9±1,88	201
III	300	15	77,7±2,36	208,8
IV	300	30	61,3±1,23	164,7
V	300	60	55,2±2,15	148,6
VI	5000	15	57,0±3,2	153,2
VII	50	15	45,7±1,25	122
VIII	600	15	38,8±1,1	104

TABLE 2. Decrease in Area of Excised Wounds under the Influence of a Sinusoidal Current and Time for Complete Closing

Series of experiments	Stimulating factor	Area of wound, mm²			Mean time of separation of primary scab	Mean time of complete healing	Acceleration of healing
		7 days	10 days	15 days			
IX	Control	243±6,8	167±9,1	95±6,3	12,6±1,1	27,1±0,87	
X	Sinusoidal current (300 Hz, for 15 min)	157±4,3	104±7,1	61±4,2	8,95±0,76	19,7±0,71	27

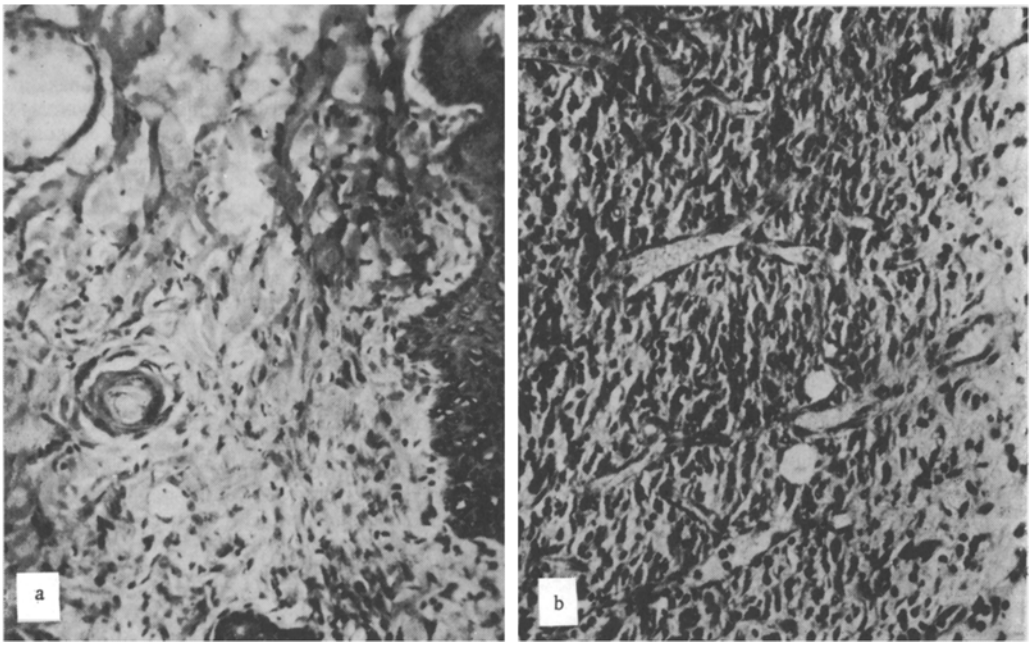

Fig. 1. Narrow linear scar in dermis of rats on 7th day after operation (a) and active proliferation of fibroblasts and formation of granulation tissue on 4th day after operation in excised wound (b). Electrical stimulation with sinusoidal currents of 300 Hz, 15 min in duration. Hematoxylin-eosin, 200 ×.

(Table 1, series IV and V). Reducing or increasing the frequency of the pulses of current appreciably reduced the stimulating effect (series VI–VIII), as shown by a reduction in strength of the postoperative scars.

A sinusoidal current of 300 Hz, given in sessions 15 min in duration, proved effective for stimulating healing of extensive full-thickness wounds (Table 2). The scar of the wounds in the experimental series on the 7th, 10th, and 15th days decreased much faster than in the control; the primary scab separated on average 4 days earlier, evidence of accelerated maturation of granulation tissue. The wounds closed completely on average 8 days earlier than in the control, i.e., 27% more rapidly.

The histological study of the tissue in the region of the linear wounds showed that the skin scar was most mature after stimulation by a sinusoidal current (300 Hz) in sessions 15 min in duration. The scar was much narrower on the 7th day than in the control. Compared with the control, the connective tissue of the scar had fewer cells and more mature fuchsinophilic and regularly arranged collagen fibers, and contained no blood vessels or neutrophilic leukocytes. Fibroblasts were actively fuchsinophilic and their cytoplasm rich in RNA. The epidermis covering the scar on its outer aspect was already well differentiated and its cells rich in glycogen (Fig. 1a).

The structure of the scar was similar after sessions of electrical stimulation lasting 5 min. In the groups whose sessions lasted 30 and 60 min, and also in groups in which the frequency of the current was 600 or 50 Hz, the connective tissue of the scar was much less mature and differed only a little from the control. Epithelization was absent in some animals.

In the series of experiments with excised full-thickness wounds marked acceleration of repair processes was observed after electrical stimulation. On the 4th day after the operation vascular congestion was less marked in the experimental animals, exudation and neutrophilic infiltration were on a smaller scale, and capillary stasis and microthrombosis were absent, evidence of the more rapid ending of the inflammatory phase of wound healing. Compared with the control, proliferation of fibroblasts was more intensive, the RNA content in their cytoplasm was higher, and accumulation of glycosaminoglycans was present. Besides immature argyrophilic fibers, fuchsinophilic fibers also were visible, evidence of more rapid collagen fibrillogenesis. By the 7th day, marginal epithelization of the defect had begun and maturation of granulation tissue took place much more rapidly. By the 10th–15th day, besides contraction and intercalary growth of the dermis, structural changes took place in the granulation tissue, with its conversion into fibrous-scar tissue, and with epithelization of the defect. This process took place much faster in the experimental animals than in the controls. According to [5], sinusoidal modulated currents normalize activity of tissue oxidative enzymes and protein and nucleic acid metabolism in muscle tissues when depressed as a result of a pathological process, they improve the circulation of blood and lymph and the functional state of the neuromuscular system, and stimulate tissue nutrition. It can be tentatively suggested that the mechanism of action of the sinusoidal current on wounds is by improving the microcirculation, reducing the intensity of inflammatory processes, stimulating metabolism in the cells and their functions and interactions, and intensifying proliferation and differentiation of fibroblasts and fibrillogenesis, and also proliferation of the epithelium.

LITERATURE CITED

1. O. T. Gibradze, "Combined method of prevention and treatment of suppuration in postoperative wounds of the anterior abdominal wall by the use of diadynamophoresis of sodium thiosulfate and trisamine," Author's Abstract of Candidate's Dissertation, Moscow (1982).
2. V. Landa, M. Popova, L. Shimkevich, et al., Byull. Éksp. Biol. Med., No. 9, 361 (1978).
3. A. P. Novikov, "Effect of a high-intensity electric field on some functions of the body under conditions of normal and modified reactivity," Author's Abstract of Candidate's Dissertation, Moscow (1971).
4. R. R. Talyshinskii and R. M. Samed-Zade, Sb. Bak. Nauch.-Issled. Inst. Travmatol. Ortoped., No. 16, 187 (1979).
5. V. G. Yasnogorodskii, Vopr. Kurortol., No. 2, 5 (1979).