EFFECT OF A PULSED ELECTRIC CURRENT ON THE COURSE OF REPARATIVE OSTEOGENESIS

V. A. Landa, A. N. Polyakov, and V. K. Baranov

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Exposure to a pulsed electric current during reparative regeneration of bone in rabbits resulted in stimulation of osteogenesis so that it predominated over fibro- and chondrogenesis to a greater degree than in the control. The degree of mineralization of the microstructures was indistinguishable from the control.

KEY WORDS: reparative osteogenesis; stimulation of reparative regeneration; fractures of bones.

Investigations have now been published in which reparative osteogenesis was observed to be stimulated by an electric current. This method of stimulation of reparative regeneration of bone tissue, in its various modifications, has already found practical application in clinical traumatology and orthopedics [4-6, 9]. However, the character of the action of this factor on reparative regeneration of bone tissue is not yet clear. Statements in the literature on this matter amount to hypotheses. These relate to the possible acceleration of mineralization of the organic matrix of the bony callus under the direct influence of the electric current [10, 12] and the action of the current on the orientation of collagen fibrils [7] and on the architectonics of bone [11]. The view has been expressed that the electric current can influence cell differentiation [8], and so on.

The object of this investigation was to study the character of the stimulant action of a pulsed electric current on reparative regeneration of bone on the basis of histological and microroentgenographic data.

EXPERIMENTAL METHOD

A portion of the middle third of the radial diaphysis measuring 0.5 cm was resected in rabbits. A platinum electrode was inserted perpendicularly to the long axis of the bone into holes drilled in each of the fragments. The end of one electrode was placed in the gap between the fragments. The other ends of the electrodes were exteriorized. Regeneration of bone was stimulated through these electrodes by means of a pulsed electric current. The duration of the pulse was 1 sec and the interval between them 4 sec. Treatment was given five times a week for 3 weeks after injury, i.e., during the period of the reparative reaction. Previous experiments [2] had shown that the optimal strength of the current ranged from 6 to 15 μA. The period of observation continued for 3 weeks after trauma.

To monitor the state of regeneration of the bone tissue histological and microroentgenographic investigations were made. By quantitative microroentgenography it is possible to determine the quantity of the mineral component of bone (hydroxyapatite) in the microstructures of the bone tissue in grams per cubic centimeter. The method used in this investigation was described in detail previously [1, 3]. The usual technique was used for the histological investigations. Sections were stained with hematoxylin-eosin and with picrofuchsin by Van Gieson's method.

EXPERIMENTAL RESULTS

During the first week after trauma the histological picture of the control and experimental sections was practically indistinguishable. An organizing hematoma was present in the gap between the fragments. The

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development of fibrocellular tissue, with osteogenic tissue in some places, was identified. From the periosteal surface, proliferation of the tissue of the periosteum was observed, with the formation of primitive trabeculae of woven bone tissue. From the endosteum also, primitive bony trabeculae were observed to develop. In the lumen of the medullary canal there were areas of proliferation of fibrocellular osteogenic tissue.

The bone defect 2 weeks after trauma in the experimental group was half filled with spongy bone tissue, distributed close to one of the fragments. The newly formed bone was represented by trabeculae of fibrous bone tissue, with layers of lamellar bone on their surface. The other half of the defect was filled chiefly with hyaline cartilage, on the basis of which bone tissue formation could be observed.

In the control series, a zone of newly formed bone tissue could be detected close to one of the fragments, and in its character and maturity it resembled the newly formed bone in the experimental group of sections. Areas of endochondral osteogenesis were present. Newly formed bone tissue filled up to one third of the gap between the fragments. The rest of the bony defect was filled chiefly with fibrous tissue and cartilage, but close to the newly formed bone fibrocellular osteogenic tissue was present.

The microroentgenographic investigation showed that the degree of mineralization of the bony microstructures of the newly formed bone tissue in the experimental group was indistinguishable from that in the control, namely 1.08 ± 0.04 g/cm^3, with variations in the control group from 1.04 ± 0.04 to 1.15 ± 0.04 g/cm^3.

Three weeks after trauma the bone defect in the experimental series was filled with spongy bone tissue, in which the fibers were mainly parallel, and with lamellar bone. In some places osteons were formed. In some cases small areas of hyaline cartilage were seen, chiefly at the periphery of the callus and on the periosteal surface of the fragments. In other cases the callus contained neither cartilage nor fibrous tissue. The electrode channel in the gap between the fragments in some cases was surrounded by a zone of hyaline cartilage and of fibrocellular tissue, beyond which there were extensive proliferating zones of spongy bone, whereas in other cases the channel was formed by trabeculae of spongy bone tissue.

The bone defect in the control series was only half filled with newly formed bone tissue. In its character and maturity, the newly formed bone tissue corresponded to bone tissue of the callus in the experimental group. It was located close to the fragments. At the periphery of the newly formed bone, nearer to the center of the defect, areas of cartilage were seen. Signs of endochondral osteogenesis were observed. In the central part of the bone defect there were extensive areas of proliferating fibrous tissue.

On microroentgenographic investigation during this period the bone defect in the experimental group was filled with newly formed bone tissue. The degree of mineralization of its microstructures was 1.22 ± 0.02 g/cm^3 compared with between 1.18 ± 0.02 and 1.27 ± 0.02 g/cm^3 in the control.

The stimulating effect of the electric current was thus expressed as a larger quantity of newly formed bone and a smaller quantity of cartilage and fibrous tissue in the callus than in the control. The degree of mineralization of the microstructures of the newly formed bone tissue lay within the limits of variation of this index in the control and corresponded to the maturity of the newly formed bone tissue. This is evidence that the electric current does not act directly on the rate of mineralization of the newly formed bone microstructures. The available evidence now points to the conclusion that by applying a pulsed electric current during reparative regeneration of bone osteogenesis can be stimulated and made to predominate over fibro- and chondrogenesis. As a result, in the experimental series the quantity of newly formed bone tissue was greater than in the control. The bone defect between the fragments was thus filled faster than in the control. The rate of maturation of the newly formed bone tissues, however, as quantitative microroentgenography confirmed, was the same as in the control series.

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REGENERATION OF THE PLANTAR SKIN IN MAMMALS

E. A. Efimov

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Two posterior plantar pads together with the surrounding skin were removed from the hind limb in rats, and one plantar pad each without the surrounding skin was removed from the hind and fore limbs of hedgehogs. As a result of healing of the skin wounds in the rats and hedgehogs, areas of regeneration were formed with the typical stratum papillare of plantar skin. In hedgehogs the regenerating skin covered the restored plantar pad. In rats the plantar pads were not restored.

KEY WORDS: plantar pads; regenerating plantar skin; dermal papillae.

The stratum papillare of the dermis is well defined in the plantar skin of mammalian limbs, with the result that the stratum basale of the epithelium, which ultimately forms the thick stratum corneum, is greatly enlarged in area. This type of structure of the plantar skin is undoubtedly adaptive in character, for the thick stratum corneum gives the skin reliable protection against the mechanical action to which it is often exposed and enables it to cope with its increased load.

In many mammals plantar pads covered with skin with a characteristic stratum papillare are present on the sole of the foot. There are indications that these plantar pads in rats can regenerate completely [1]. The author cited removed all six plantar pads from the hind limb of rats together with the surrounding skin and observed regeneration of pads with the typical shape. Under different experimental conditions, when the pads were removed without the surrounding skin, they did not regenerate so well. However, this worker does not give an account of a histological analysis of regeneration of the pads in its successive stages and draws his conclusions mainly from visual observations.

So far in mammals regeneration of the skin with regular restoration of its specific structures (hair and sebaceous glands) has been observed only after full-thickness skin wounds on the concha auriculae in rabbits and on the horns of stags [2-5].

The object of this investigation was to discover whether regeneration of the skin with its characteristic features can take place on the sole in mammals and to determine the conditions under which regeneration of the plantar pads is possible.

EXPERIMENTAL METHOD

Experiments were carried out on 52 noninbred male albino rats weighing 120-150 g and on eight European hedgehogs (Erinaceus europaeus) weighing 550-720 g (two females and six males).

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