Arch Orthop Trauma Surg (1985) 104:121–124

Archives of Orthopaedic and Traumatic Surgery



*Clinical and Experimental Forum*

# Bone Growth Accelerated by Stimulation of the Epiphyseal Plate with Electric Current

**M. Forgon, V. Vámhidy, and L. Kellényi**

Department of Traumatology and Institute of Physiology of the University Medical School Pécs, Jfjuság u. 13, Pécs, Hungary

**Summary.** The effect of stimulation with continuous small amounts (20 μA) of electric current on the distal epiphyseal plate of rabbit femurs was examined. In contrast to control animals 6 weeks after the operation 18 of the 20 experimental animals showed an increased lengthening or broadening of the femur on the operated side. In 14 cases the increased growth resulted in varus or valgus deformities.

**Zusammenfassung.** Es wurde der Einfluß der Elektrostimulation (20 μA) auf die distale Wachstumsfuge von Kaninchenfemura untersucht. Bei der Kontrollserie zeigte sich im Beobachtungszeitraum von 6 Wochen kein unterschiedliches Wachstum. Dagegen wurde bei 18 von 20 Tieren mit Elektrostimulation eine Wachstumsbeschleunigung in Länge oder Breite an der stimulierten Seite festgestellt. In 14 Fällen kam es zum Fehlwachstum im Valgus- oder Varussinne.

Though the idea of using electric current to influence the healing of fractures inspired interest among researchers as early as the end of the last century [7], the positive effect of electric stimulation on osteogenesis has only recently been proven [1–5, 8, 11, 14, 16, 17].

Most researchers agree that small amounts of electric stimulation (10–20 μA) accelerate osteogenesis, whereas higher doses (30 μA or more) cause osteonecrosis [3, 6]. The stimulating effect of electric current can be measured at the cathode, or negative pole [2, 6]. Epiphyseal chondroblast cell structures can be stimulated in vitro by electric current [12], and the growth of embryonic chick tibiae can be enhanced in vitro by electric fields [15]. This latter result suggested that the effect of electric current on the epiphyseal plate of long tubular bones should be studied to see whether a potential increase in bone growth could be used therapeutically.

*Offprint requests to:* M. Forgon, M.D. (see above address)

## Materials and Methods

Femurs of 6- to 7-week-old rabbits, which were still growing, were used for the experiment. Femur growth starts mainly at the distal epiphysis. Figure 1 illustrates the placement of electrodes used to apply continuous low-voltage electrical stimulation to the epiphyseal plate. Electricity (20 μA) was supplied by 1.5-V button batteries through a suitable resistor. Two 8-cm-long, twisted stainless-steel wire electrodes were soldered to the battery and insulated with 1-mm polyethylene tubes. The battery, the resistor, and the soldered wire ends were sealed in a polymethacrylate capsule from which the positive and negative electrodes protruded (Fig. 2).

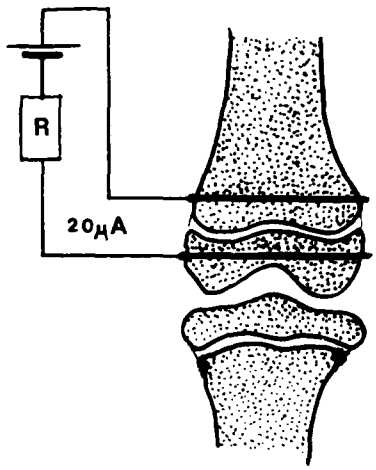



**Fig. 1.** Schematic drawing of our experimental device with small intensity (20 μA) electric current. *R* resistor

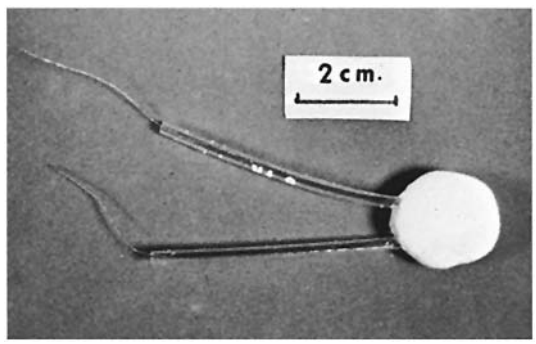



**Fig. 2.** Battery with twisted electrodes insulated in methylmethacrylate and polyethylene tubes

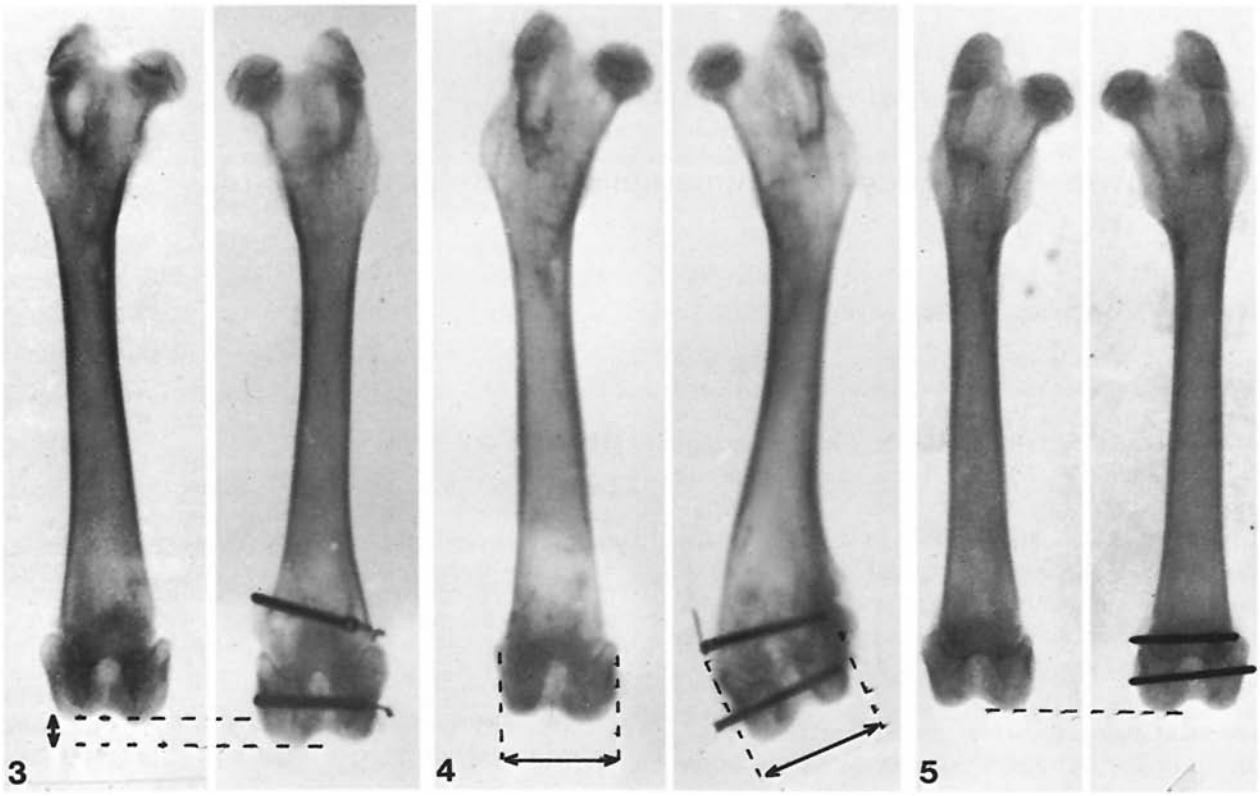



**Fig. 3.** Extra growth (*double headed arrow*) in length of the femur on the stimulated (*right*) side

**Fig. 4.** Irregular growth with valgus deformity and broadening of the distal part of the femur on the stimulated side (*right*)

**Fig. 5.** Control experiment with no electric stimulation of the epiphyseal plate *(right)* shows no difference in length or width

A total of 25 rabbits of both sexes with an average weight 3500 g were used. Under Nembutal anaesthesia and sterile conditions two 0.5-mm-thick Kirschner wires were inserted percutaneously. Using the image intensifier the wire were situated below and above the epiphyseal plate of the right femur (Fig. 1). A small skin incision was made at the protruding ends of the Kirschner wires. A 3-mm incision was then made in the abdomen and the sealed battery package was fixed with one suture to the abdominal wall. The two insulated electrodes were introduced under the skin and connected to the two Kirschner wires so that the cathode was above the epiphyseal plate and the anode below it.

As a control the same operation was performed on five animals, but the Kirschner wires were not connected to the battery.

All experimental animals were killed 6 weeks after the operation with an overdose of Nembutal. Both femurs and battery packages were removed.

The femurs were carefully cleared of soft tissues and fixed in formalin. X-ray pictures were made of the pairs of femurs before further histological study. Femur length could be established from the X-ray pictures with millimetre precision (Fig. 3–5).

## Results

Of the 25 animals 5 died within 4 weeks after the operation. In 16 of the remaining 20 cases we found that the femur on the stimulated side (Table 1) was

**Table 1.** Frequency distribution into 1-mm size classes of extra longitudinal growth for stimulated femurs

| Difference in length in mms. | 0 mm. | 1 mm. | 2 mm. | 3 mm. | 4 mm. |
|---|---|---|---|---|---|
| Number of cases | 4 | 4 | 8 | 2 | 2 |

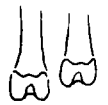
**Table 2.** Frequency distribution into 1-mm size classes of extra width in the distal part of stimulated femurs

| Difference in broadening in mm. | 0 mm. | 1 mm. | 2 mm. | 3 mm. | 4 mm. |
|---|---|---|---|---|---|
| Number of cases | 2 | 7 | 7 | 3 | 1 |

larger than the femur on the unoperated side. There was, however, not only a difference in the length of the two sides, but also in the width of the distal part of the femurs. This was found in 18 of the 20 cases (Table 2). In the control group there was no difference in length or width of the two femurs (Fig. 5).

The extra growth in both length and width appeared in various forms, but was mostly irregular with varus and valgus deformities. We found only two cases where the extra longitudinal growth showed neither varus nor valgus deformities, almost corresponding to physiological growth (Table 3).

**Table 3.** Forms and distribution of extra longitudinal growth

| | | Number of cases |
|---|---|---|
| Overgrowth with valgus deformity |  | 8 |
| Overgrowth with varus deformity |  | 6 |
| Overgrowth similar to the physiological growth |  | 2 |

## Histology

The haematoxylin-eosin-stained sections of decalcified distal femurs showed a broadening of the epiphyseal line even under low-power magnification. The cartilage cells of the unstimulated epiphyseal plate (Fig. 6a) showed a typical longitudinal columnar arrangement ("columnar zone"), below which was a layer without columnar structure ("inert zone") [9]. The columnar zone of the growth plate on the stimulated side was usually wider and the columns longer with many mature cells at the border of ossification (Fig. 6b). The inert zone was also wider with embedded immature cartilage cells. In some cases, especially where the extra growth was irregular and caused varus or valgus deformity, the longitudinal arrangement of the columnar zone was disrupted and there was an increased number of the immature cartilage cells embedded in the "inert zone" (Fig. 7).

After the animals were killed and the battery package had been removed, battery power was measured in every case. The original 20 μA had usually decreased considerably, generally to 5–10 μA. In two

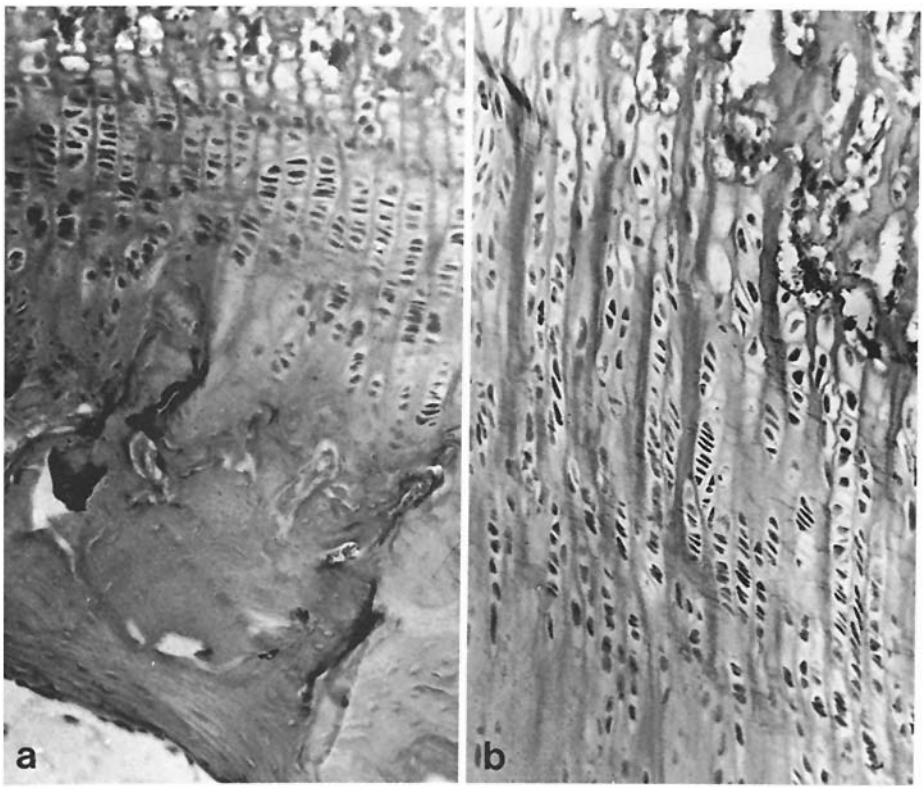



**Fig. 6a, b.** Photomicrographs of the epiphyseal plates. **a** Normal side without stimulation. **b** Stimulated side. (haematoxylin-eosin stain, × 80)

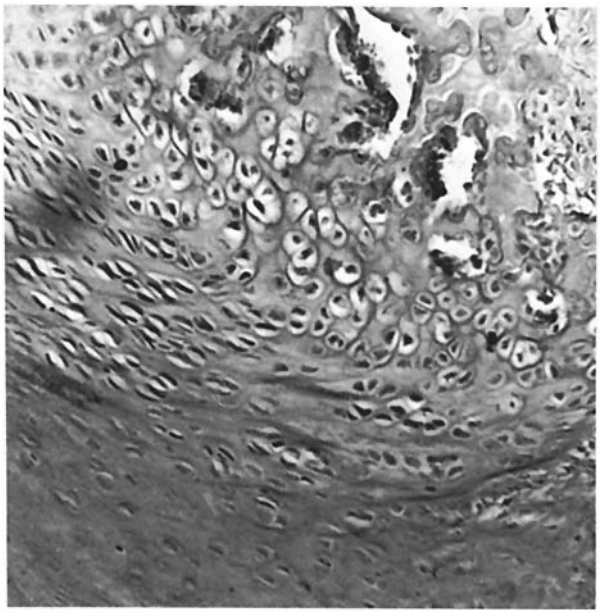


**Fig. 7.** Photomicrograph of the epiphyseal plate in which the extra growth resulted in valgus deformity and broadening of the distal part of the femur (haematoxylin-eosin stain, × 80)

cases the power was 0. The batteries, thus, probably did not provide a constant amount of voltage over time.

## Discussion

In agreement with published reports that electric current of less than 20 μA stimulates osteogenesis [2, 6, 10, 13, 16], we found in 18 of 20 cases that there was extra growth on the side to which current had been applied (Tables 1, 2).

In two cases there was no difference between the stimulated and the non-stimulated sides. Though no definite answer to this can be given, we suspect that the insulation of the battery package was faulty, and that the electric current did not reach the epiphyseal plate but short-circuited through the wall of the abdomen.

In the control group there was no difference between the two femurs either in length or in width (Fig. 5).

From our experiments we conclude that a very small amount of electric current (20 μA) stimulating the epiphyseal plate can accelerate bone growth. This growth is, however, irregular and cannot be properly directed (Table 3). Probably the effect of linear electrodes on a disc-shaped epiphyseal plate is uneven. Perhaps a more even distribution of current would result in more regular growth. Further research is needed to prove this. The rabbit, however, because of the smallness of its epiphyseal plate is not the best subject for this experiment.

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Received March 11, 1985