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THE EFFECT OF TRANSISTOR-REGULATED DIRECT CURRENT ON NON-FRACTURED RABBIT FEMUR

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An experimental study was performed to examine the effects of transistor-regulated 20 microampère direct current on rabbit femur and to evaluate methods of measuring the effects. The anode and the cathode were both placed in drill holes in the anterior aspect of the cortex of the right femur, the left femur being used as a control with the electrodes without current. The effects of the electrical stimulation were evaluated by means of roentgenograms, photomorphometric measurements of the cortical width and measurements of bone volume, ash-weight and ^{85}Sr uptake. In the roentgenograms it could be seen that osteogenesis was induced both at the anode and at the cathode. Also, an increased uptake of ^{85}Sr was demonstrated indicating an increased bone formation rate.

Key words: bone formation; electrical stimulation; osteogenesis

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During the last few decades there have been a considerable number of reports on electro-osteogenesis, both experimental and clinical (Friedenberg et al. 1971a, b, Jörgensen 1972, 1978, Becker et al. 1977, Brighton et al. 1977, Basset et al. 1978, von Satzger & Herbst 1978, Aro et al. 1980). A variety of methods of electro-stimulation have been presented (Spadaro 1977). Yet, as pointed out by Becker (1979), there are still many unanswered questions.

One problem is to quantify the osteogenic effect. Friedenberg et al. (1970, 1974) showed that direct current in the microampère range could stimulate new bone formation in rabbit femur and tibia with an optimal effect at 20 microampère, resulting in an osteogenic response around the cathode and bone destruction around the anode.

The purpose of this investigation was to evaluate the effect of direct current on rabbit femur and to estimate the osteogenic effect.

MATERIAL AND METHODS

Seven adult rabbits, average weight 3,600 g, were used. They were operated on under intravenous Mebumalether anaesthesia. Both femora were exposed with an antero-lateral incision. On both sides two 1 mm drill holes were made through the frontal cortex with a distance of 2 cm between the holes. Two electrodes – polyeten insulated stainless steel (Pacemaker cable Elema-Schönander) – were placed in the drill holes. On the right side the uninsulated ends of the cables were introduced 5 mm into the holes and secured with sutures. The proximal electrode served as anode and the distal as cathode. The electrodes were connected to an insulated electro-stimulator placed subcutaneously. On the left side the electrodes were placed in the holes in the same manner but were not connected to the electro-stimulator.

The electro-stimulator was equipped with six BE-REC® PX/RM 400 1.35 V Mercury cells. The circuit was controlled by a field effect transistor in series with a

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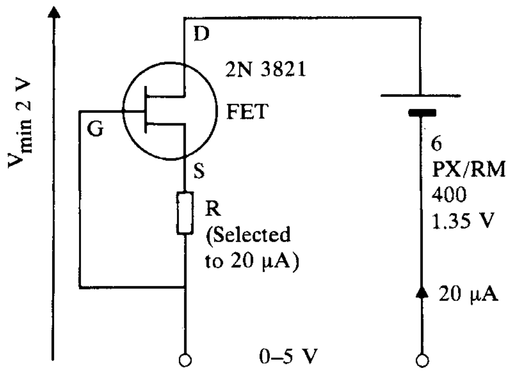

Figure 1. The controlling circuit consists of a field effect transistor and a resistor in a constant current configuration.

resistor. It was adjusted to deliver 20 microampère constant direct current (Figure 1).

The animals were sacrificed after 29 days of stimulation and 48 hours after subcutaneous injection of 5 μCu ^{85}Sr. Both femora were excised. Using fine grain roentgen-film, antero-posterior roentgenograms of the femora were obtained. The femora were then divided into five exactly proportional parts with the use of a template according to Figure 2. The cross-sectional areas of parts B and C were photographed with a constant focus object distance. The photographs were enlarged (2×) and the cortical thickness measured at the same four sites on every cross-sectional photograph. The sum of the widths was calculated for each cross-section (Figure 3) and the right/left ratio calculated.

After measuring the volumes the five pieces of bone from each femur were ashed separately in an electric muffler at 600°C for 16 hours. The ash was weighed and the ^{85}Sr activity was measured in a crystal scintillation detector. The right/left ratios for the volumes, the ash-weights and the activity of ^{85}Sr were calculated for each part of the femur.

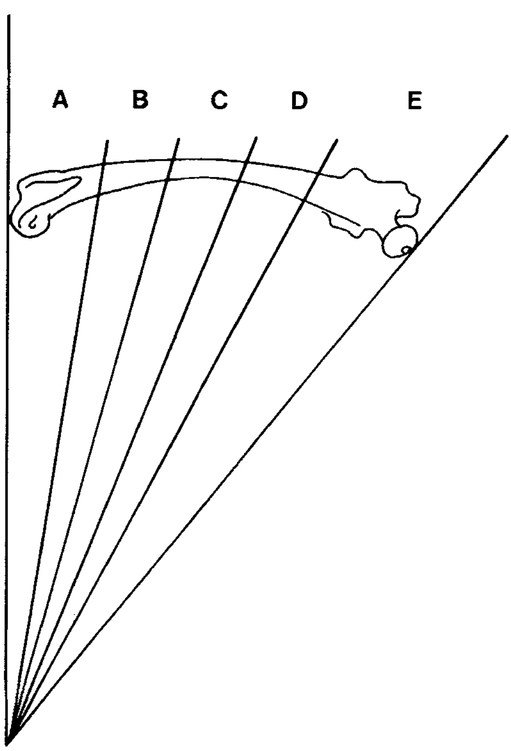

Figure 2. Template used to cut the femora into five exactly proportional pieces of bone.

RESULTS

The roentgenograms showed new bone formation both at the cathode and the anode sites of the stimulated right femora. The bone formation occurred periosteally and endosteally (Figure 4). In the left femur there was no bone formation or only a sparse amount around the non-stimulated electrode sites. Bone resorption at the anode site was not observed. There was a non-significant increase in cortical thickness on the right side compared with the left side (33 per cent). There

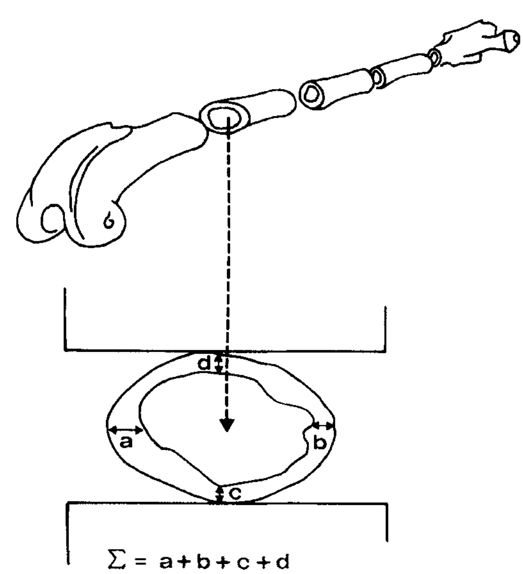

Figure 3. Photo-morphometrical method for determination of cortical thickness. The cortical thickness was determined at the same four points on every cross-sectional picture. The sum of the thicknesses was calculated.

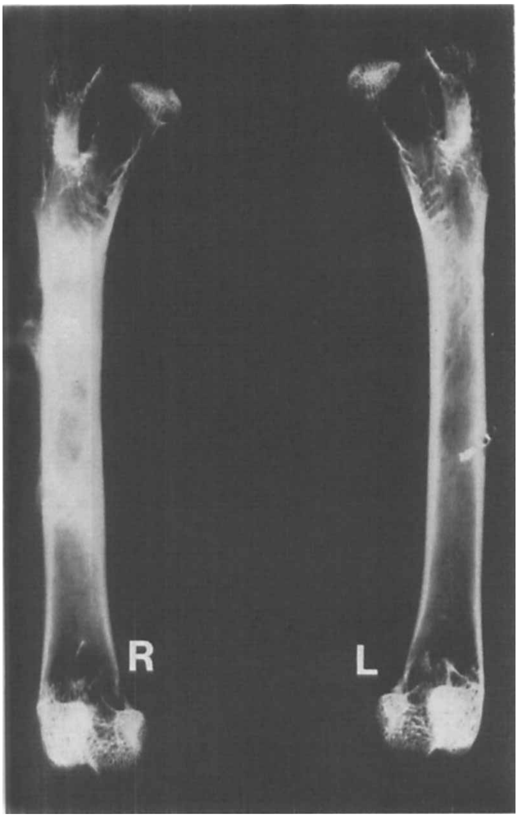

Figure 4. Roentgen picture of a pair of femora, showing new bone formation both at the anode (proximally) and at the cathode. Note intramedullary bone formation.

was also a non-significant increase in the volumes and in the ash-weights of the right femur – 11 per cent and 7 per cent, respectively. The ^{85}Sr activity was significantly increased ($P < 0.05$), the value of the stimulated right femora being double that of the unstimulated left femora (Figure 5a–d).

DISCUSSION

Earlier experiments have shown that the optimum effect on bone formation in rabbits with a direct electric current is obtained with a current of about 20 microampère (Friedenberg et al. 1970) – the same as in the present study. We found new bone formation at the cathode as well as at the anode. Friedenberg et al. (1970), who concluded that roentgen examination was not useful in demonstrating bone formation, had used a stimulation period of only 10 days as compared to 29 days in our experiment. On the other hand, Friedenberg et al. (1974) reported an experiment on rabbit tibia with a stimulation period of 21 days – in this series they found an increased density of the medullary cavity in roentgenograms of many of the animals, changes which they considered to be impossible to quantitate. It is also our impression from the present study that roentgen examination only yields qualitative information.

Friedenberg et al. (1974) used a micro-morphometrical method with a point-counting technique to calculate the area of new bone, expressed as a percentage of the total medullary canal cross-sectional area. They found that 22.6 per cent of the medullary canal was filled with new bone at the level of the cathode after 20 microampère stimulation as compared to 2.2 per cent at the same level in controls. The difference was statistically significant. Our photomorphometric measurement of cortical thickness with determination of the right/left ratio at exactly the same level for each pair of samples showed a difference of at the most 33 per cent. This difference is not significant because of a large scatter. The method, however, seems to be useful. The right/left difference in volume and ash-weights in this experiment was small and insignificant.

Earlier experiments support the concept of ^{85}Sr being absorbed into bone with a direct relationship between bone formation and isotope uptake (Charkes et al. 1966). Hambury et al. (1971) also used this property of the isotope for a scanning procedure to calculate bone formation but found no consistent evidence of increased bone formation in rabbit femora after 3 weeks' stimulation with direct current. The authors thought that their current might have been insufficient owing to polarization effects. Klems et al. (1975) using scintigraphic examination with ^{87m}Sr found an increased uptake in young rabbits treated by direct current of varying intensities. In the present investigation, measurements of ^{85}Sr activity showed significant differences between the stimulated and unstimulated femora.

Our data demonstrate that there is an osteogenetic effect of transistor regulated constant direct current of 20 microampère on rabbit

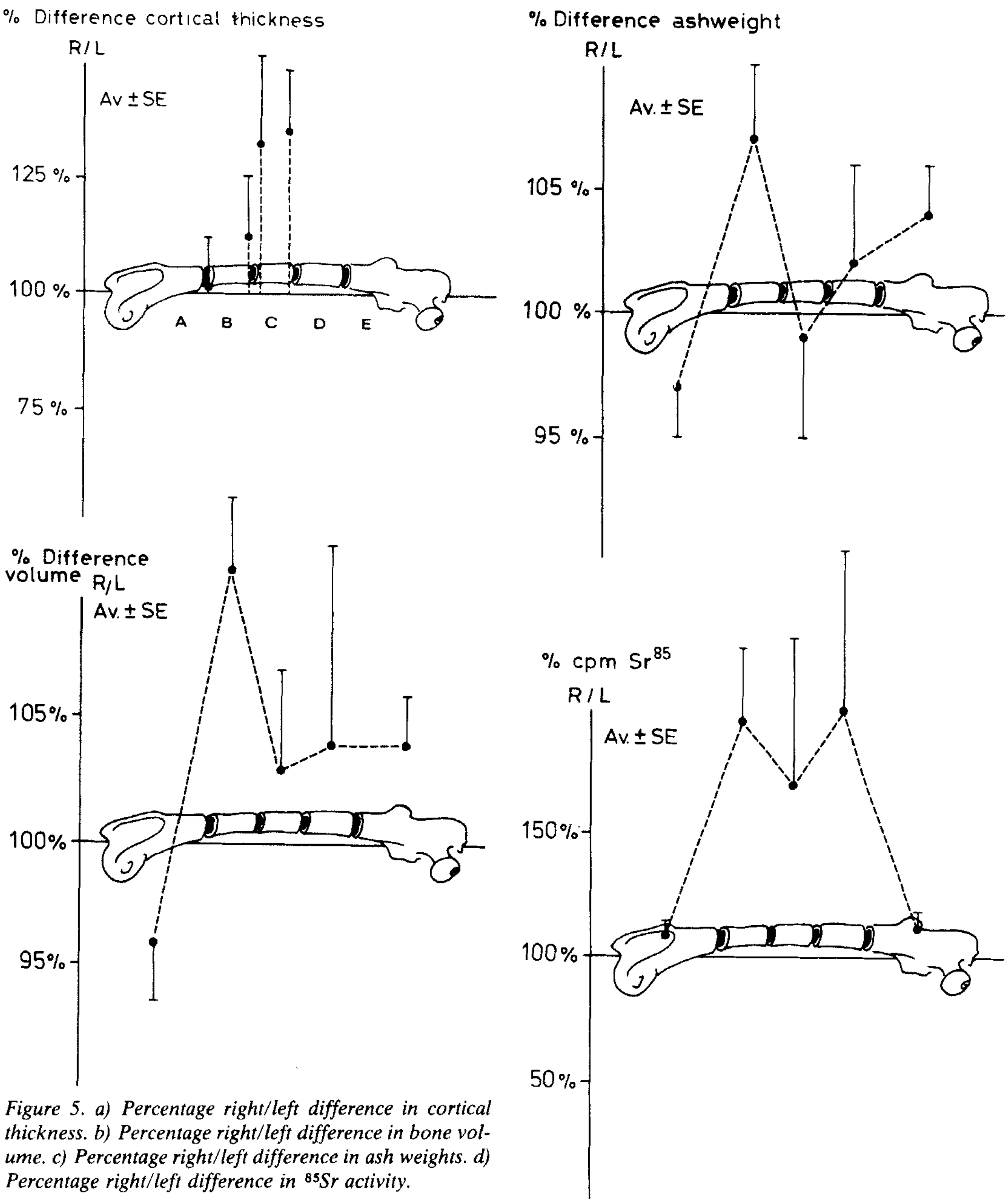

Figure 5. a) Percentage right/left difference in cortical thickness. b) Percentage right/left difference in bone volume. c) Percentage right/left difference in ash weights. d) Percentage right/left difference in ^{85}Sr activity.

femur with both electrodes introduced into the bone. The effect, however, is small and the best way of demonstrating it seems to be with radioisotope uptake measurements.

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