ELECTRICALLY-INDUCED OSTEOGENESIS IN EXTERNAL FIXATION TREATMENT

by A. CEBALLOS, O. PEREDA, R. ORTEGA and R. BALMASEDA

This animal model experiment is performed to evaluate how bipolar direct current of 20 microamp. affects osteogenesis once external fixation treatment is applied in different forms : stabilization, distraction, and compression.

In all cases a secondary healing, typical of external fixation treatment, was found ; but a more mineralized callus and an increase in osteoprogenitor cell proliferation and differentiation were obtained through the use of electrical stimulation especially in the compression group.

Keywords : osteogenesis ; electrically induced ; external fixation.
Mots-clés : ostéogenèse ; induction électrique ; fixateur externe.

RÉSUMÉ

A. CEBALLOS, O. PEREDA, R. ORTEGA et R. BALMASEDA. Ostéogenèse induite à l'électricité au cours du traitement par fixateur externe.

Ce modèle d'expérimentation animale a été réalisé pour étudier les effets produits par le courant électrique direct bi-polaire de 20 micro-ampères sur l'ostéogénèse, quand ce courant est associé à un fixateur externe placé sur l'os en stabilisation, distraction ou compression.

Dans toutes les séries, on a constaté une consolidation osseuse du type secondaire, la stimulation électrique ayant stimulé la minéralisation et la prolifération des cellules ostéogéniques.

SAMENVATTING

A. CEBALLOS, O. PEREDA, R. ORTEGA en R. BALMASEDA. Electrisch geïnduceerde osteogenese bij behandeling met externe fixatie.

Dit experimenteel model werd gerealiseerd ter evaluatie van de werking van een bipolaire direkte stroom van 20 microamp. op de osteogenese wanneer simultaan een externe fixatie geplaatst is met verschillende modaliteiten : stabilisatie, distractie of compressie.

In de verschillende gevallen werd een secundaire consolidatie gezien, typisch voor externe fixatie ; de electrostimulatie — vooral in de groep met compressie — heeft echter de mineralisatie en de ostengenese bespoedigd.

INTRODUCTION

After the first report of Fukada and Yasuda (10, 11) on electrical phenomena in bones, research has shown that osteogenic effects can be produced by application of different types of electronic current. Various electrodes have been used, including implantable (Friedemberg) (8, 9) and percutaneous (Brighton) (4, 5).

The first to report on the combination of electrical stimulation (E/S) was Jörgensen (16), who applied direct current to the pins of Hoffman's apparatus.

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The aim of the present study is to analyze the osteogenic potential of bipolar direct current in association with external fixation treatment of bone disorders.

MATERIALS AND METHODS

The middle of the shaft of the tibia was exposed in 50 dogs under general anesthesia and a transverse osteotomy was made using an oscillating saw.

The osteotomy was fixed with a circular external fixation device consisting of two connected rings and four Kirschner wires of 2 mm diameter which pass through the bone and cross each other as orthogonally as is anatomically possible. Before closing the wound under direct view, stabilization, displacement (1.5-2 mm wide), or compression were applied, and the dogs grouped accordingly :

Group 1 : Stabilization (Neutralization), 20 dogs
Group 2 : Displacement, 10 dogs
Group 3 : Compression, 20 dogs

The electrical stimulator fed by a 9-volt battery delivered 20 microamperes and less than one volt. The frequency was of 0.5 Hz with the polarity changing every two seconds. Proximal and distal fixation wires were used as electrodes (fig. 1). Half the animals in each group were given stimulation while the other half acted as controls. Postoperatively the animals were allowed to move freely. A fragment of bone, including the osteotomy area, was removed at 15 and 21 days, fixed in 10 percent formalin and placed in a sealed plastic bag. The fragment was then studied by simple X-ray A.P. view, computer tomography (C.T.) Siemens S.F. using the Toposcan (22) to pinpoint the osteotomized area, photon absorption with C.T., using Hounsfield's density units (14) with numerical representation plotted on coordinate lines to obtain curves representing mineralization of tissues. The conventional paraffin-embedding method was used for bone histology, as well as fixation by methacrylate inclusion, for hard cutting.

Samples of bone were stained in hematoxylin and eosin for routine examination, toluidine blue for tissue differentiation, and Von Kossa stain for osteoid (7, 12, 22). The soft tissue close to the wires were also studied under light microscopy.

RESULTS

The dogs tolerated the experiment satisfactorily ; three were excluded from the study owing to wound or pin infection. The statistical results were determined by means of the ANOVA program

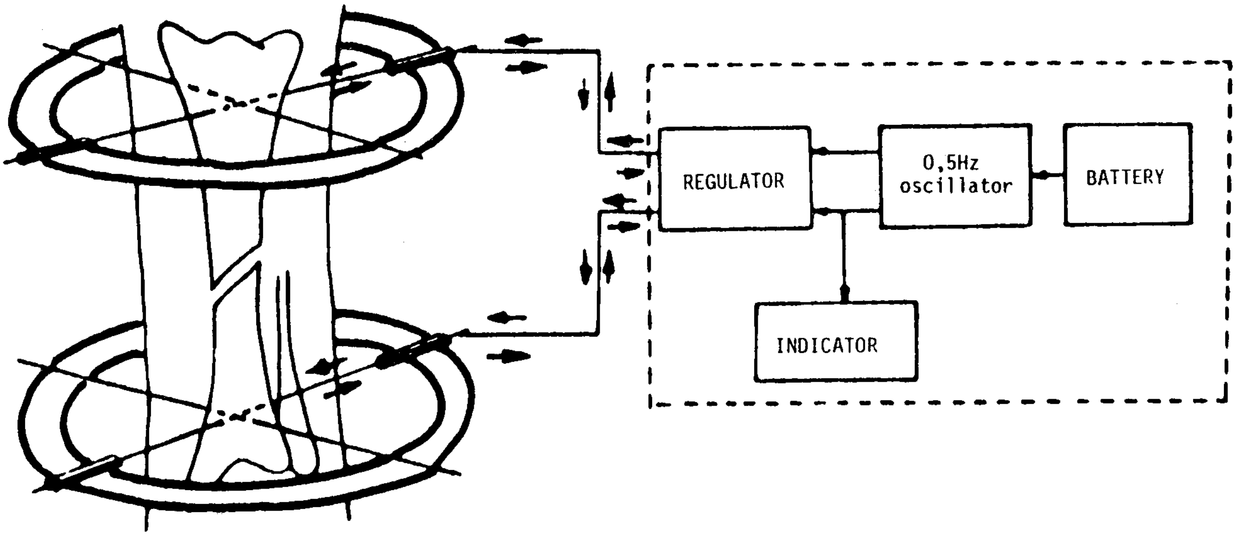


Fig. 1. — Diagram of circuit for electrical stimulation of tibia bone of a dog using a circular external fixation device and four Kirschner wires passing through the bone.

form of variant analysis. In order to establish whether the differences were significant they were compared with the Fisher distribution table. In all the cases where statistical significance was determined, the differences were significant at the 95% confidence level.

X-rays were taken to evaluate fragment opposition and periosteal callus formation (fig. 2). The osteotomy line was visible in all groups. Groups 1 and 2 were characterized by displacement and angulation ; an increase in periosteal callus was noticeable when E/S was used. A good contact at the osteotomy line with improvement of medullary callus was found in Group 3. Various specimens showed periosteal callus due to microinstability ; the increase in density was evident when E/S was applied, particularly at 21-day specimens where a periosteal and endosteal callus was markedly improved compared with the non-stimulated group.

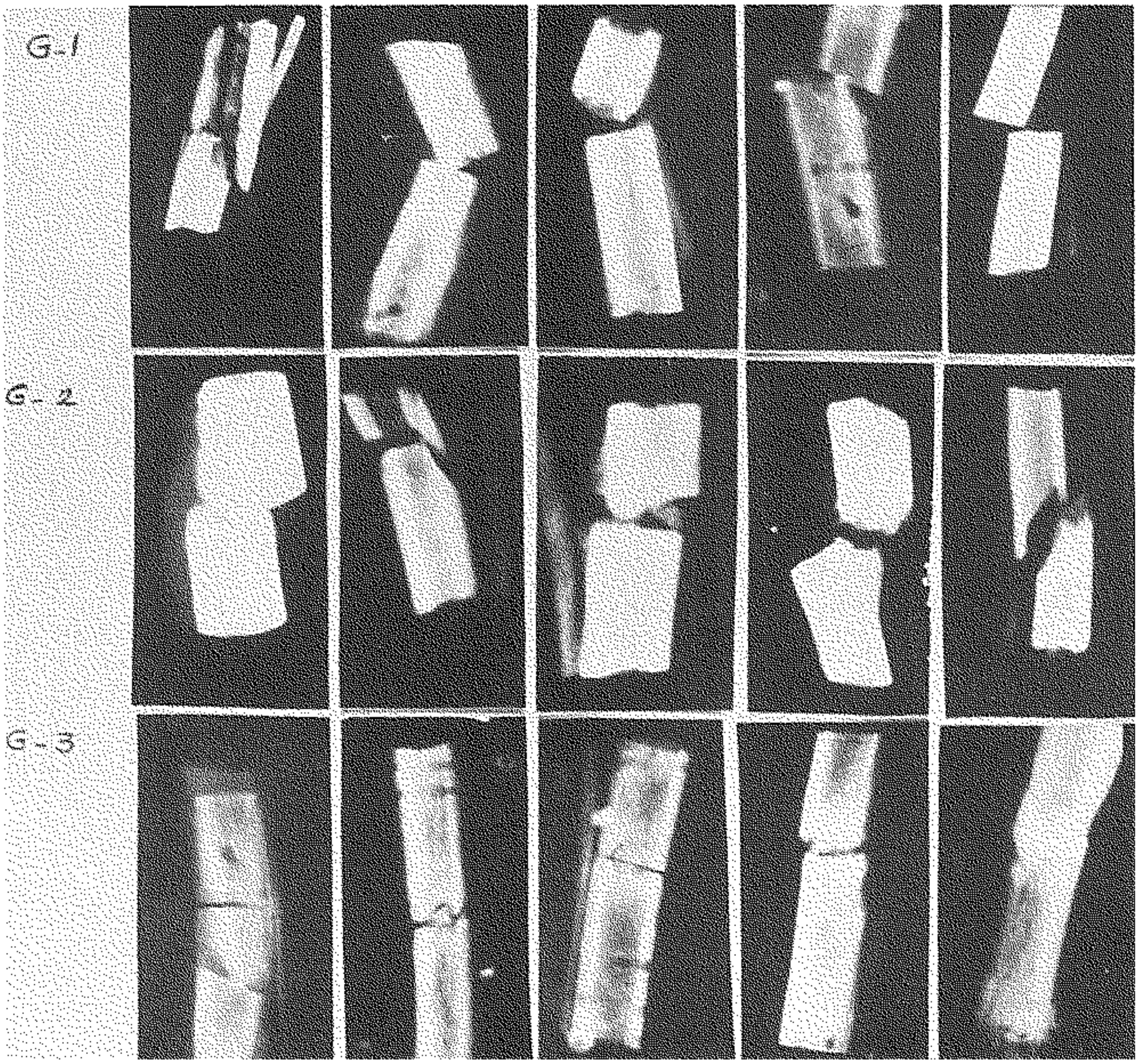


Fig. 2. — X-rays for evaluation of fragment opposition and periosteal callus formation. G-1 & 2 showed displacement and angulation with increased periosteal callus. G-3 showed improvemend of medullary callus.

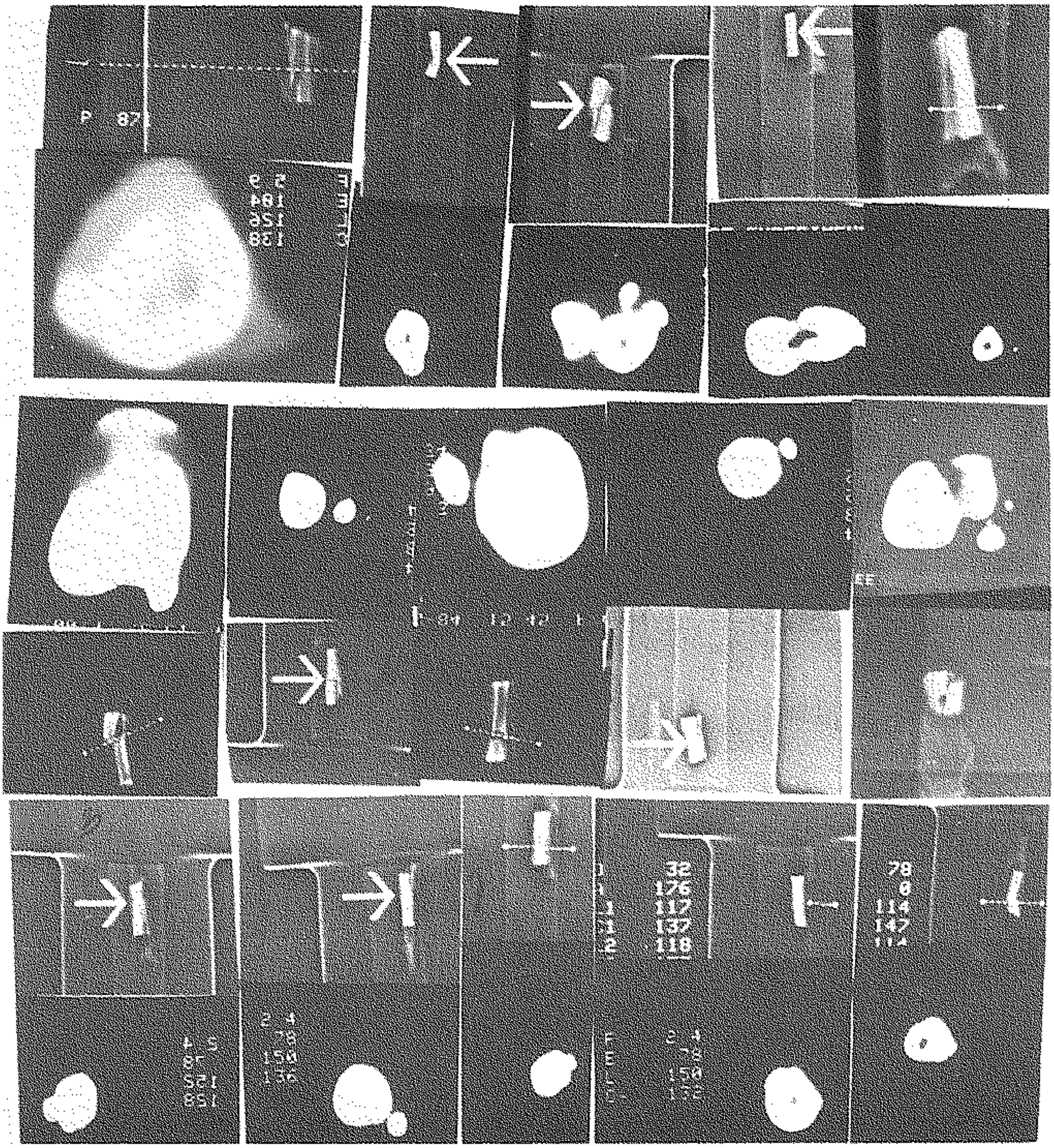


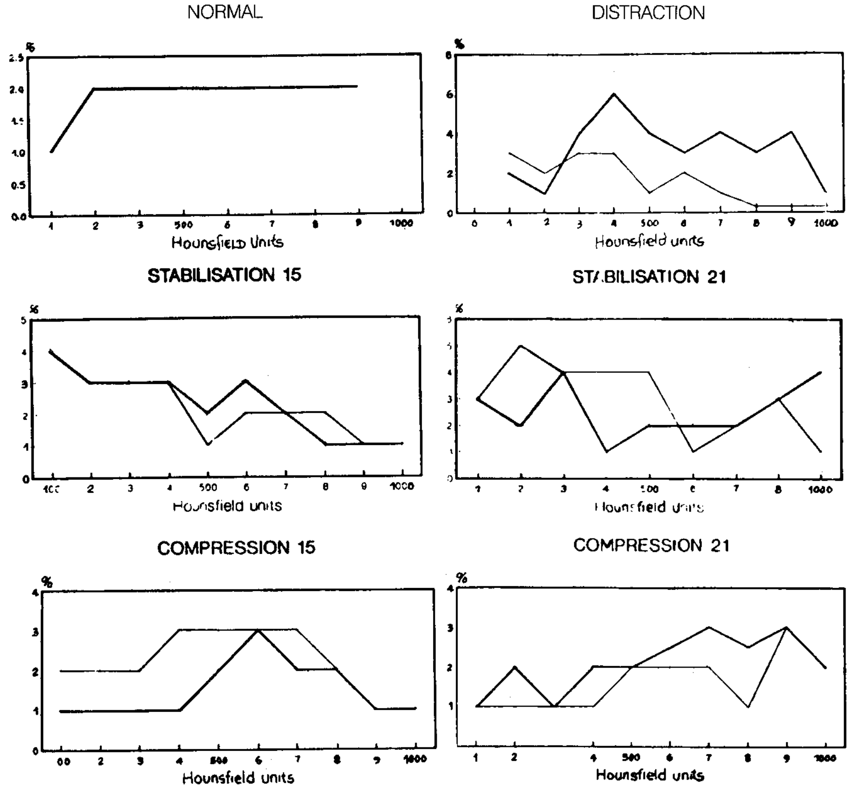
Fig. 3 Evaluation of the progression of medellary callus formation.

C.T. scan imagery permits the evaluation of the progression of medullary callus formation which can occlude the medullary cavity either partially or totally. Usually this cavity shows negative Hounsfield's units, 120 UH according to Kuhn (18) (fig. 3).

In almost all cases of Group 1 the medullary cavity contained no dense masses, considering whether stimulation was used or not.

In Group 2, displacement produced aberrant periosteal callus images due to instability, and the distance between the two fragments, the effect of electrical stimulation, was not evident. Group 3 showed dense masses filling the medullary cavity especially when E/S was used. This fact implies that good stability is necessary for the current to be effective.

In the photon absorption studies, the curves that displayed positive (+ 100 to + 1022) Hounsfield's density units represented the mineralization into callus (fig. 4). Total results of the three groups for 21 days showed significantly higher curves than those of 15 days. The effect of E/S was evident in all groups by the presence of higher curves, especially between + 400 to + 700 units which represented new lamellar bone, with an increase in mineralization and stiffness in the callus formation area.


NORMAL

DISTRACTION

STABILISATION 15

STABILISATION 21

COMPRESSION 15

COMPRESSION 21

Fig. 4 — Curves in photon absorption studies.

HISTOLOGY

Signs of non-union were seen in non-stimulated specimens of Groups 1 and 2 characterized by the increase of poorly vascularized fibrous tissue, areas of cartilage and some periosteal reaction. In stimulated specimens the most distinct change was seen in the periosteum, which showed a marked osteogenic reaction consisting of new lamellar bone formation.

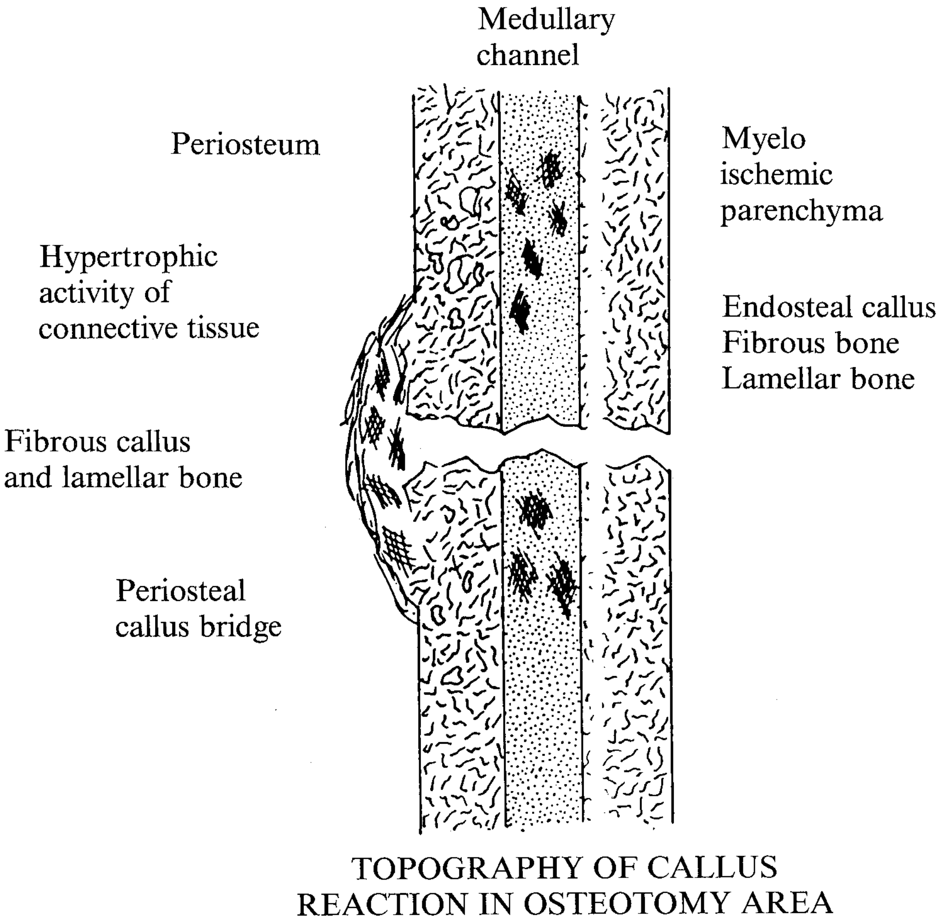


Fig. 5

In Group 3 well-developed external callus with periosteal activation and areas of mineralized osteoid were seen in stimulated animals whereas in non-stimulated specimens only slight bone formation in the same area was found. An increase in lamellar bone due to electrical stimulation was found in this group if the width of the fracture gap was under 1000 micron.

DISCUSSION

External fixation treatment produces secondary bone healing, which depends on the stability of the fragments and on the characteristics of the device (1, 3, 19). It is evident that E/S increases this secondary callus, especially in the periosteal layer.

The action of direct current produces damage in the anode area due to bone resorption and soft tissue necrosis (6, 16). In his second approach to this problem Jörgensen (17) stated that the polarity should be reversed every 24-48 hours. Aro (2) changed polarity every two days and found new bone formation around both electrodes. Our experimental fracture model and it's treatment using the wires as electrodes to apply 20 microamp, with the polarity changing every two seconds, confirms these reports and the clinical experience of Jörgensen (17), Inoue (15) and Von Satzger (24). Thus we conclude that it is unnecessary to expose the fracture area to implant electrodes.

The two new methods to study callus formation with C.T. need a larger number of cases to establish their real value. Our histological results confirm previous works of Friedemberg (8, 9) and

Ohashi (21), which showed that direct current increases cellular proliferation and differentiation, especially the induction of osteoprogenitor cells into osteocytes.

Hinsenkamp (13) has found granules of corroded materials in the soft tissue close to the pins, composed of calcium, phosphorus, iron and chromium. In our experiment we found amorphous masses of calcium salts not harmful to the skin. We feel that this does not contraindicate the use of stainless-steel wires as electrodes.

CONCLUSIONS

The wide variety of available external fixators provides the potential for meeting all requirements in modern orthopedics ; the addition of bipolar direct-current electrical stimulation contributes to the production of more mineralized callus. Stimulation through external fixator pins constitutes a non-invasive method which eliminates the necessity of exposing the fracture area. Better results were obtained applying compression associated with electrical stimulation.

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