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## THE INFLUENCE OF ELECTRIC CURRENT ON BONE REGENERATION IN VIVO\*

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Current research indicates that stress-induced electrical potentials play an important role in directing the architectural and structural integrity of bone. It is felt that this electromechanical phenomenon is due to a classical piezo-electric effect originating in shearing forces on the bone collagen (Fukada 1956, Shamos & Lavine 1963, 1964, 1967).

Because electromechanical effects appear to be vital in explaining much orthopaedic physiology, several groups, first the Japanese (Yasuda, Noguchi & Sata 1955), and then the Americans (Shamos & Lavine, 1963, 1964, 1967, Bassett et al. 1964) have been active in studying their various parameters. In the course of these researches, direct current effects on bone physiology have proved to be of great interest.

There have been attempts to construct an ideal experimental model (Bassett et al. 1964, Minkin et al. 1968, O'Conner et al. 1969) using direct current, with variable results. One model, which is most useful and has been described by our group (Lavine et al. 1969), has been published in the recent literature.

This experimental power unit (Figure 1) consists of a 1.4 V mercury cell connected in series with a 174 K resistor. The leads from the battery pack are copper wire fastened to platinum electrodes with silver epoxy cement. Alligator clips are placed in one of the leads for monitoring. The wire which goes into the bone is insulated with shrinkable rubber tubing.

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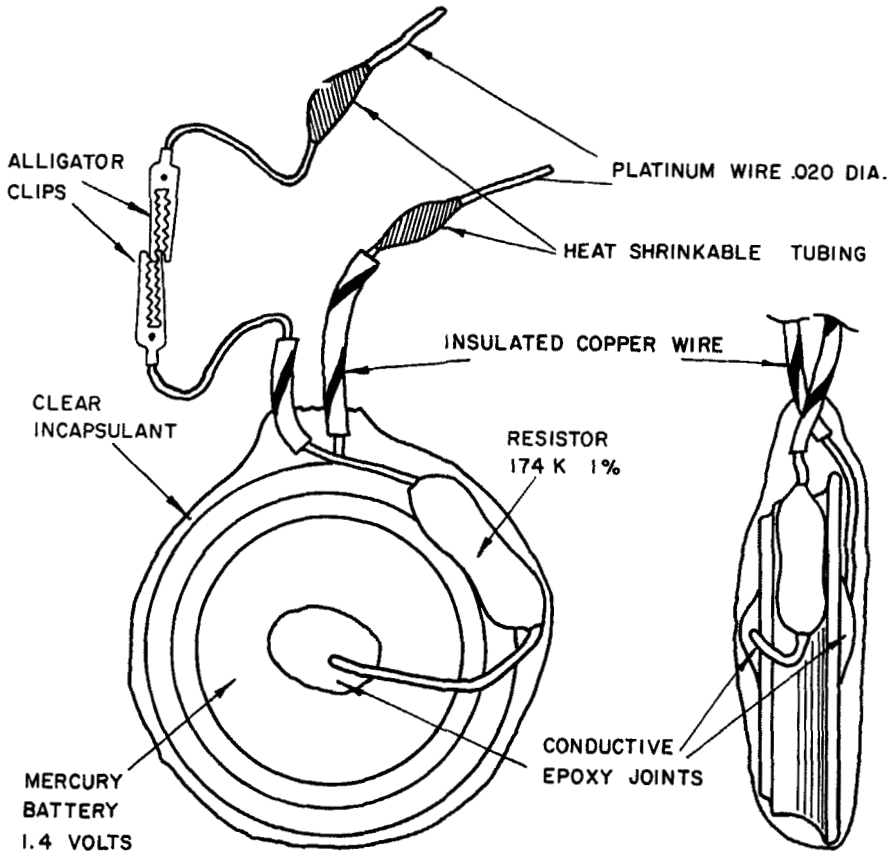
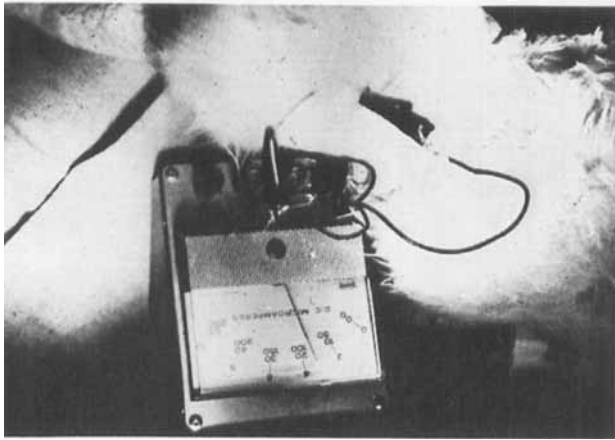


Figure 1. Diagram of experimental unit.

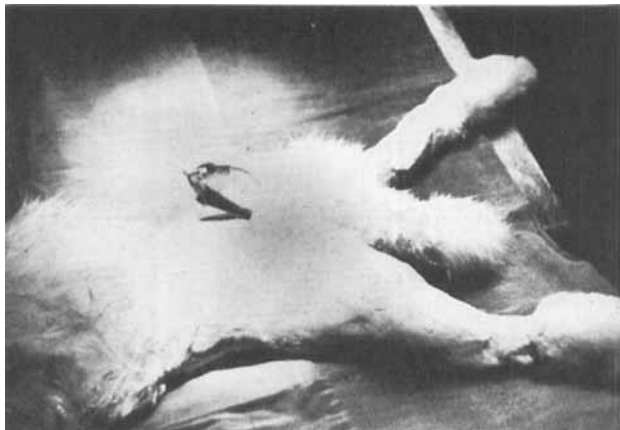
It is the purpose of this paper to describe an *in vivo* study on rabbits using our experimental model, showing the effect of direct current in the range of 2–4 microamperes on a bony defect produced in rabbit femora.

#### MATERIALS

Ninety-one 2–3 kg white Dutch pelted rabbits were anesthetized with intravenous nembutal. The rear extremity was shaved and prepared under sterile conditions. The middle one-third of the femur was exposed and the periosteum stripped from the femur. Two drill holes (1.97 mm) were made through one cortex only, 15 mm apart; a third drill hole (2.77 mm) was produced midway between the two and acted as the “experimental defect”. Platinum electrodes were inserted into the 1.97 mm diameter drill holes. The wires and battery capsule were buried sub-



*Figure 2. Circuit completed through microampere meter; showing method of monitoring current.*



*Figure 3. Animals and electrical apparatus encased in plaster cast for protection. "Alligator" clamps used for monitoring current connected to complete electrical circuit.*

cutaneously. "Alligator" clamps were brought out through an incision in the skin of the back. (These clamps could be connected to a microamperemeter and current readings obtained, Figure 2). The circuit was completed by connecting the two alligator clamps. A spica cast was applied for the protection of the bone and the electrical apparatus (Figure 3).

Two to four microamperes of direct electric current crossed the experimental defect for periods ranging from one to three weeks. Animals were sacrificed at one,

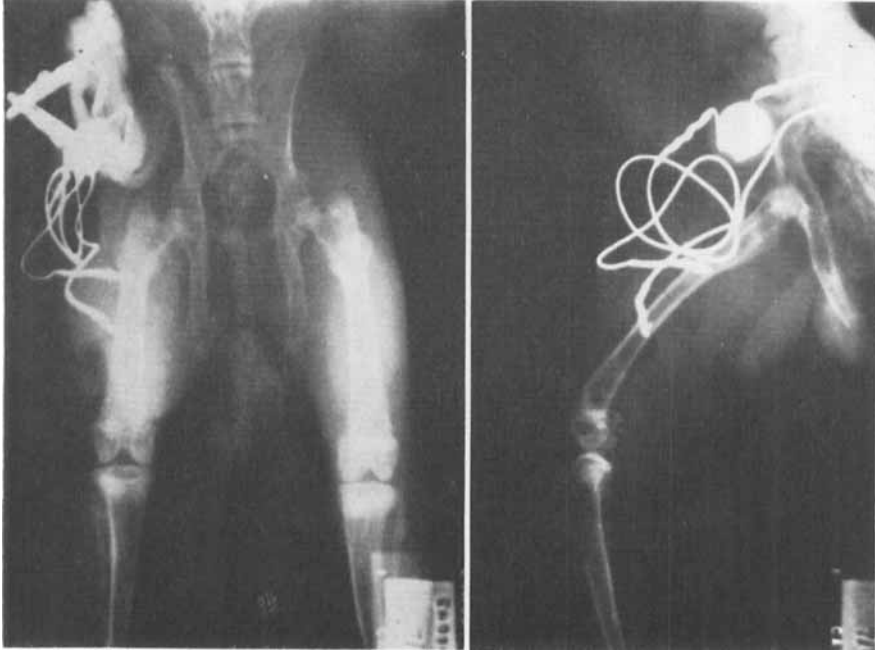
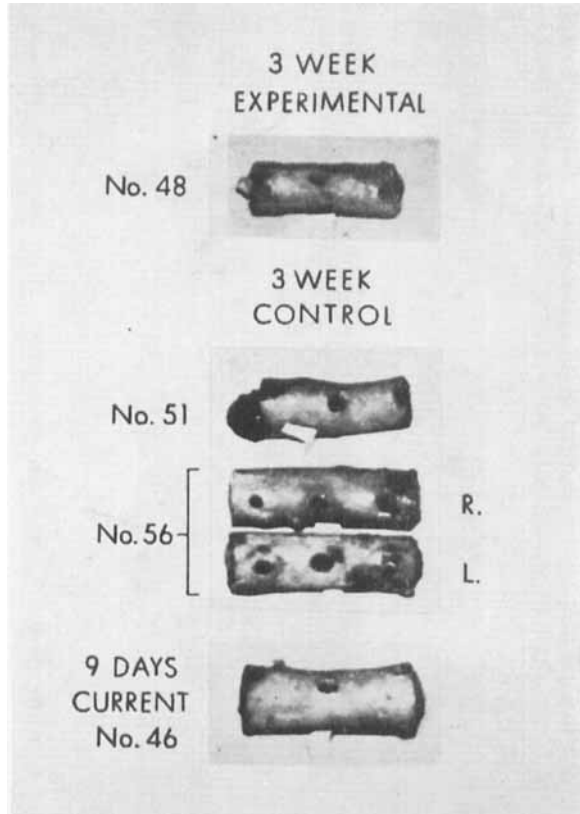


Figure 4. X-ray showing platinum electrodes in situ in the cortex of the femur.

Table 1

Weeks		Mean current in microamperes	Number of animals		
			Healed (Hole >75 % filled)	Partially healed (Hole >75 % filled)	No healing
1	{ Exp.	3.1		1	14
	{ Cont.	-			6
2	{ Exp.	2.2		6	2
	{ Cont.	-			8
3	{ Exp.	2.5	13	5	
	{ Cont.	-		6	17
4	{ Exp.	-			
	{ Cont.	-	1	1	
5	{ Exp.	1.8	1		
	{ Cont.	-			
6	{ Exp.	1.3	1		
	{ Cont.	-	4		

Figure 5. Gross comparison of the "experimental defect" in three-week experimental and control animals.



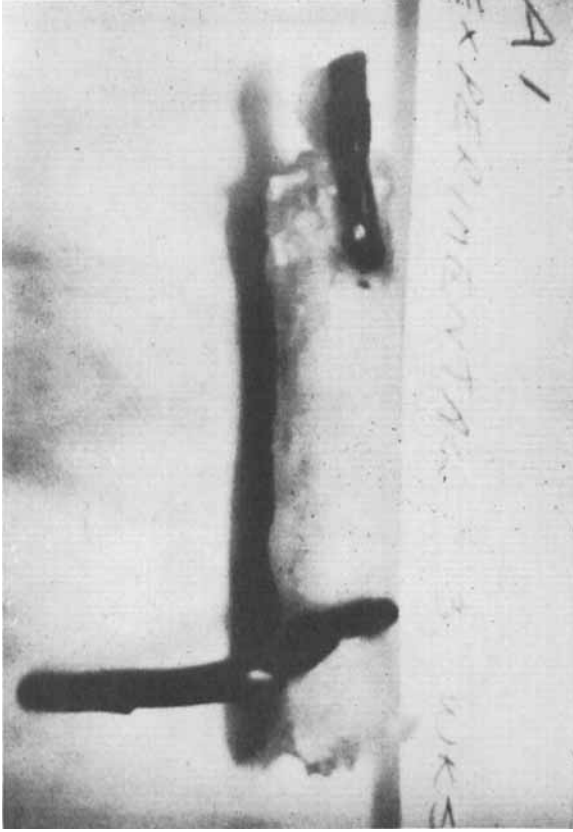
two and three week intervals. The femur was removed and the "experimental defect" was observed grossly and microscopically for new bone formation.

The "experimental group" (animals having constant current passing through the "experimental defect") consisted of 15 animals in the one-week group, 8 animals in the two-week group, 23 animals in the three-week group, and 1 animal each for five and six weeks: a total of 48 animals. The "control group" (animals treated in the identical manner as the "experimental group" except that no electric current passed through the "experimental defect") consisted of 43 animals: 6 rabbits in the one-week group, 8 rabbits in the two-week group, 23 rabbits in the three-week group, 2 rabbits for four weeks, and 4 rabbit for six weeks.

## RESULTS

The results are summarized in Table 1. Our findings indicate that:

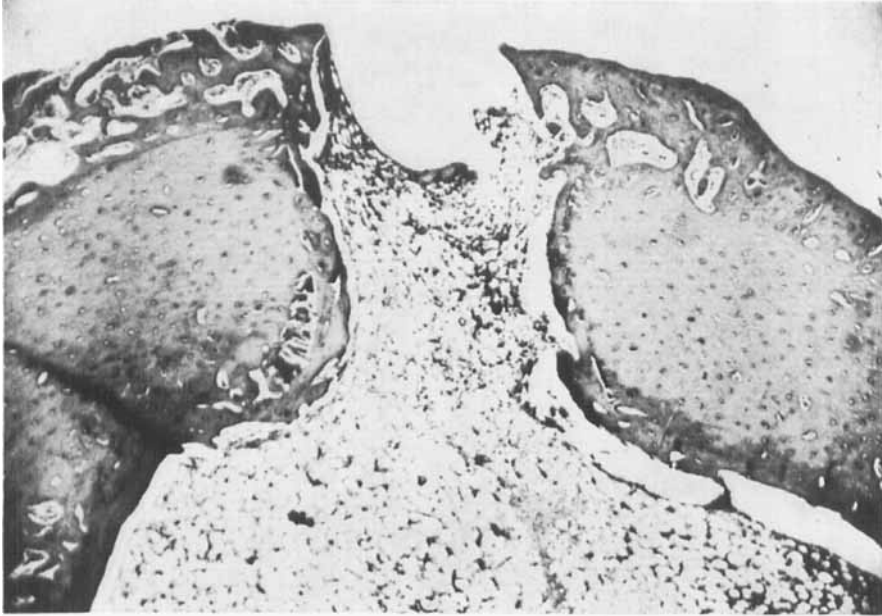
1. Three weeks of current at 2.5-3.5 microamperes is most conducive to the production of new bone formation.



*Figure 6. Grossly completely healed defect in a three-week experimental animal (see Figure 10).*

2. Infestation interferes with healing by direct electric current.
3. Three-week experimental animals showed approximately the same amount of bone formation as six-week controls.
4. Slight variations occurred in the ultimate healing at three weeks in the experimental group. However, as compared to control animals, the changes were conclusive.

Figures 5 and 6 represent the gross appearance of 3-week experimental animals as compared to controls. The gross difference is obvious. The slight variation in healing can be seen by comparing Figure 6 to Figure 5. Figures 7, 8, 9 and 10 represent the microscopic picture seen in three-week experimental and control animals. The variations in healing observed grossly in the experimental group are reconfirmed microscopically.

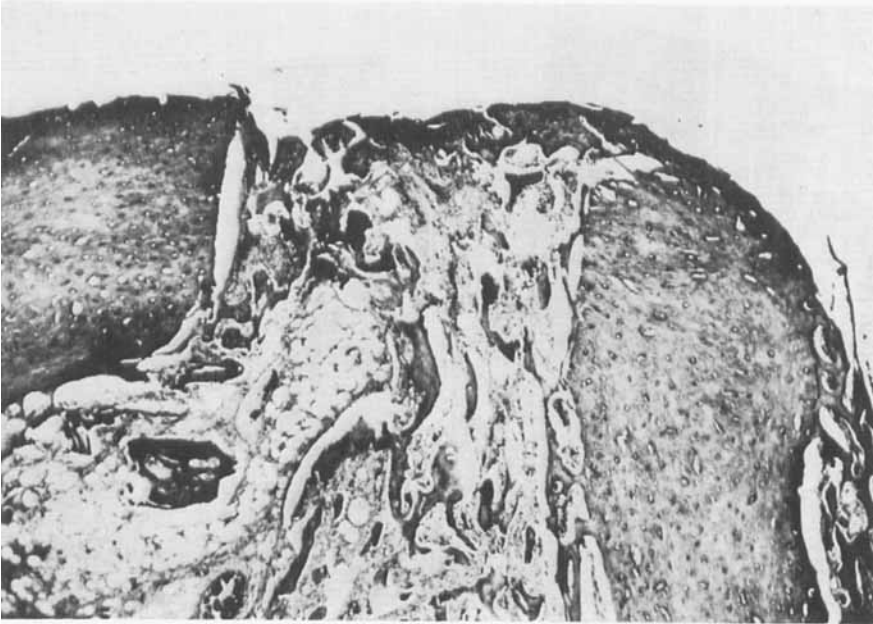


*Figure 7. A control section three weeks postoperative. The lumen of the cavity is filled with a loose tissue, not significantly different from the adjacent medullary tissue. The outer surface of the core shows some evidence of postoperative reactive osteogenesis.*

#### DISCUSSION

The application of electrical currents, as outlined in the experiment, enhances the normal calcification process. How can one account for the mechanism of activation of many different cells by this specific stimulus? Recent experimental evidence indicates that among the control mechanisms involved in bone physiology, electrical effects probably share in the well-known biochemical factors operative at the cellular level.

Transmission of signals from one cell to the next is accomplished by a combination of chemical and electrical means. This transmission is a highly specialized function mediated through a complex of biological and physical factors. It does not seem unreasonable to suppose that the local changes may be effected architecturally by the rapid orientation of the fibrous structures and also through the action of calcium ion. It is known that dissociation of bound calcium can be induced



*Figure 8. This specimen, three weeks experimental, differs from that shown in Figure 7 in that the defect is filled with a mass of trabecular bone which seems to be continuous with similar tissue type found within the medullary cavity. Little reactive bone formation has occurred on either the periosteal or the endosteal surfaces.*

electrically and that the calcium ion has profound effects on cellular and enzyme functions.

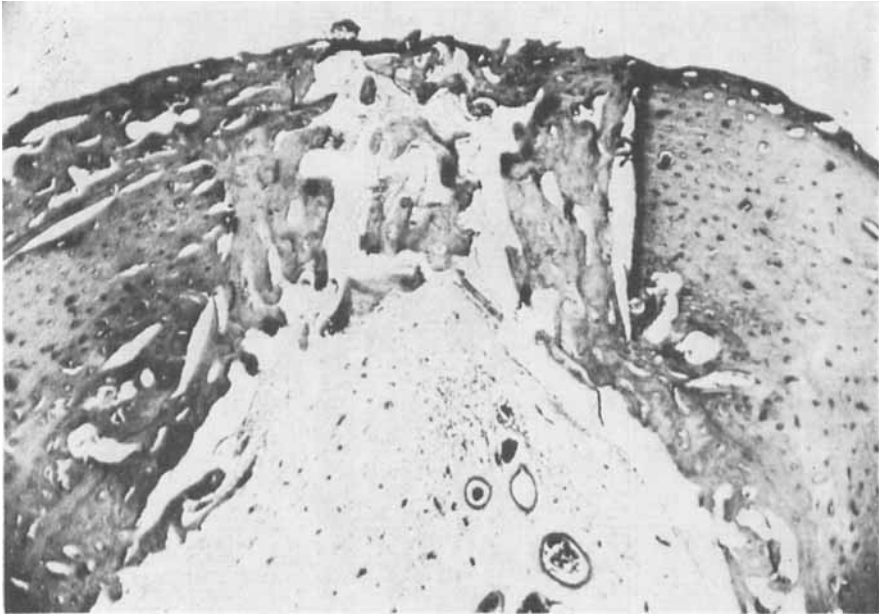
It is important to state that this discussion includes only a few of the key factors responsible for bone healing. There is no question that other physical, chemical and biological factors are involved in bone regeneration.

#### SUMMARY AND CONCLUSIONS

1. Observations have been carried out in 91 rabbits on the effects of controlled amounts of direct electric currents on the healing of an "experimental defect".

2. Direct current in the experimental group increased the normal healing as compared to the control animals by roughly a factor of two.

3. Obvious clinical implications can be inferred from this experi-



*Figure 9. A good degree of osseous repair has filled the experimental cortical defect in this specimen after three weeks of application of direct current. There is a continuity between this tissue and the reactive peri and endosteal formation.*

mental work. The value of electric current on the enhancement of bone healing in congenital pseudoarthrosis of the tibia and long standing non-union of fractures is presently being investigated.

#### ACKNOWLEDGMENTS

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*Figure 10. This specimen, 3 weeks experimental, disclosed a far advanced degree of osseous repair filling the experimental defect (see Figure 6).*

#### REFERENCES

- Bassett, C. A. L., Powluk, R. J. & Becker, R. O. (1964) Effect of electric current on bone *in vivo*. *Nature* **204**, 652.
- Fukuda, E. (1956) *J. Phys. Soc., Jap.* **11**, 1301.
- Lavine, L. S., Lustrin, I. & Shamos, M. H. (1969) Experimental model for studying the effect of electric current on bone *in vivo*. *Nature* **224**, 1112-1113.
- Minkin, C., Poulton, B. R. & Hoover, W. H. (1968) The effect of direct electric current on bone. *Clin. Orthop.* **57**, 303.
- O'Conner, B. T., Charlton, H. M., Carrey, J. D., Kirby, D. R. S. & Woods, C. (1969) Effects of electric current on bone *in vivo*. *Nature* **222**, 162-163.
- Shamos, M. H. & Lavine, L. S. (1964) Physical basis for bioelectric effects in mineralized tissues. *Clin. Orthop.* **35**, 177.
- Shamos, M. H. & Lavine, L. S. (1967) Piezoelectricity as a fundamental property of biological tissues. *Nature* **213**, 267-269.
- Shamos, M. H., Lavine, L. S. & Shamos, M. I. (1963) On the piezoelectric effect in bone. *Nature* **81**, 197.
- Yasuda, I., Noguchi, W. & Sata, T. (1955) Dynamic callous. *J. Bone Jt. Surg.* **37 A**, 1292-1293.