ACCELERATION OF BONE HEALING BY ELECTRICAL STIMULATION

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Stimulation of bone and soft tissue healing by means of artificial application of electrical energy is a research frontier offering promise of major progress in orthopedic and rehabilitation treatment. Advances in this field could give the clinician a measure of direct control over the processes of healing.

Attempts to stimulate bone healing with electrical energy are based on certain observations concerning inherent electrical activity in bone. Many investigators have shown that bone generates an electrical potential in response to mechanical stress, and that application of specific types of small electric currents can stimulate bone formation; under appropriate conditions bone will be formed around a cathode extending into the medullary canal.

Although limited clinical studies are in progress in several centers, development of electrical stimulation of bone as a treatment modality is in its infancy; the problem remains to convert a laboratory phenomenon into a practical tool to produce clinically significant amounts of new bone.

The purpose of this project is to develop techniques by which electric currents may be utilized to stimulate deposition of a significant amount of new bone in nonunions and large defects in bone, clinical problems of special interest to the Veterans Administration. Before this goal can be achieved, detailed laboratory studies are necessary to develop appropriate electrical parameters and to observe effects on healing of potential and established nonunions. The first year of the project was spent in standardizing a suitable animal model for this application, and in developing the necessary stimulator and electrode implants in association with Avery Laboratories.

The experimental model is a bone defect created surgically in mature dogs by excising a segment of distal ulna extraperiosteally; it results in a permanent defect in the ulna. To apply electrical currents to this defect, a special array of platinum electrodes on a fixed bracket was devised. Leads are run subcutaneously to the axillary region where a self-contained battery-powered stimulating unit is implanted.

Several stimulation modes are being tested, including continuous d.c. and various configurations of pulsed current. In this series, each animal serves as its own control. A precisely similar procedure is carried out on the opposite limb, but electrode leads are connected to a dummy stimulator with high resistance representing the active unit. As the radius is left intact, the animals resume normal activities almost immediately.

Effects in stimulated and control defects in each dog are compared by X-ray, histological, and radioactive tracer techniques. This experimental model offers an excellent opportunity to answer many vital questions concerning bone stimulation which must be clarified before one can hope to achieve success in clinical applications.

Results in the first year were limited due to a variety of mechanical and electronic problems with the commercially constructed electrodes and stimulators. For the second year, the entire implant system was redesigned; no significant technical problems are being encountered, and promising results are being seen.

In another area, a major success was achieved the first year of this project. In selecting a mode of electrical stimulation, it is desirable to know the nature of the normal pattern of stress generated electrical potentials in bone so that they may be duplicated. While many measurements of these potentials in bone have been made, the true dynamic pattern in vivo has never been delineated. To answer this question, a method was developed to study the potentials generated in long bones in animals during normal walking and to correlate the electrical activity directly with mechanical strain.

Utilizing these new techniques, electric potentials and mechanical strain were recorded simultaneously directly from the bone during normal walking of the dog 10 days postoperatively. Excellent correlation between mechanical strain and electrical activity was noted (Fig. 1 and 2). Additional experiments involving controlled manual bending of the leg demonstrated a pattern of electrical activity similar to that known to be generated by moist bone in vitro (Fig. 3). These manual tests confirmed that the normal result of strain caused by weight-bearing is not potentials of equal magnitude and opposite polarity; rather, the potentials are unequal, suggesting that net unidirectional current flow exists. This correlates with observations that pulsed unidirectional currents are most efficient in promoting bone formation. After further experiments are completed, this type of data will help to determine the most effective specifications for electrical stimulation in terms of frequency, pulse duration, and waveform.

It is hoped that this project will lead to significant advances in the rehabilitation of patients with bone nonunions or large defects in bone.

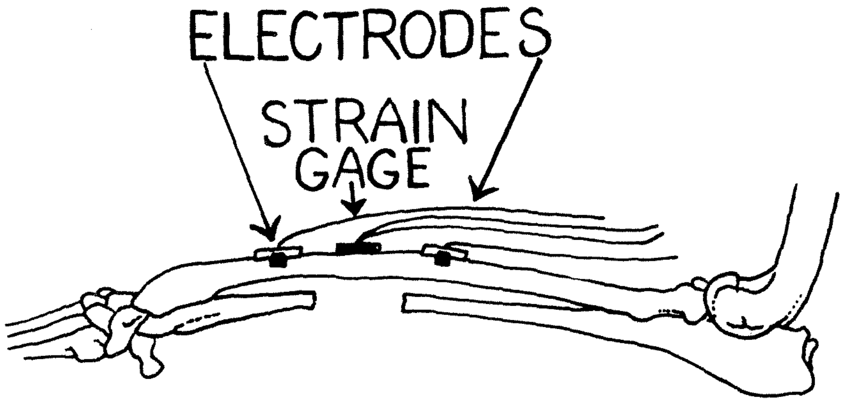

FIGURE 1.—Diagram of electrode and strain gage configuration utilized in a dog for recording of electric potentials and mechanical strain from bone during walking. The defect in the ulna facilitates recording by increasing strain levels in the ulna.

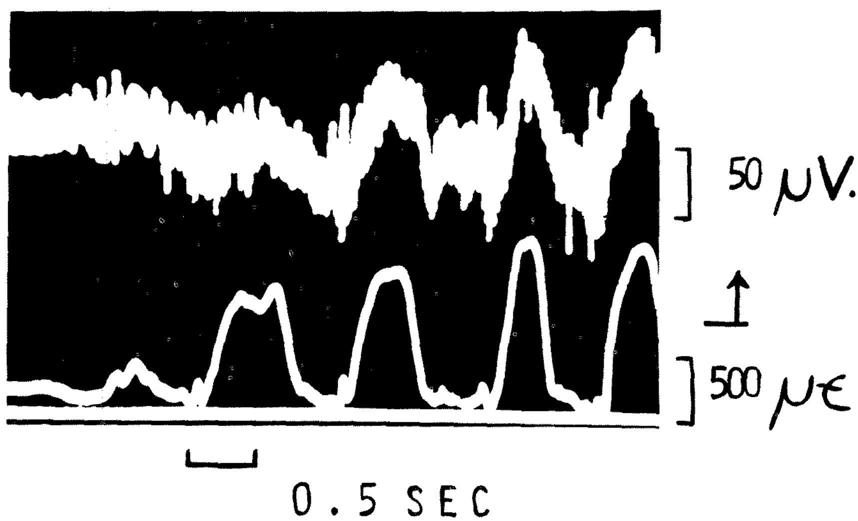

FIGURE 2.—Recording of electromechanical events during walking from preparation diagramed in Figure 1. Electric potentials (top) correlate with mechanical strain (bottom).

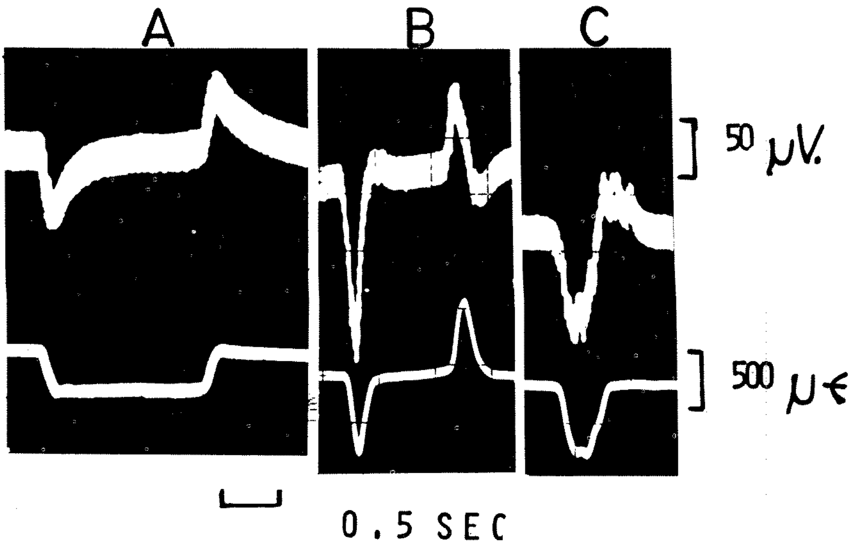

FIGURE 3.—Recording of electromechanical events from canine radius during controlled manual bending of the forelimb: (top) electric potentials. (bottom) mechanical strain. A. symmetrical positive and negative voltage waveforms developed by rapid onset, maintenance, and release of deformation. B. Reversal of polarity with reversal of strain. C. Asymmetrical voltage waveform developed in response to strain input simulating weight-bearing.