EXPERIENCE WITH LOW-CURRENT/SILVER ELECTRODE TREATMENT OF NONUNION

R. O. BECKER* AND J. A. SPADARO**
*Orthopaedic Surgery
Veterans Administration Hospital
and
S. U. N. Y. Upstate Medical Center

**Biophysics
Veterans Administration Hospital
and
Orthopaedic Surgery
S. U. N. Y. Upstate Medical Center
Syracuse, New York

ABSTRACT

Our experience with the clinical use of electrical bone stimulation has involved constant direct current (0.3 to 1.1 microamperes) applied to pure silver cathodes. These have been installed using an invasive, but conservative, surgical technique directly into the nonunion site without bone graft. Results on a limited sample of 18 fractures (20 attempts) are encouraging, with a success rate of 72 per cent. The median duration of the nonunions was 2.0 years and the mean followup time was 21 months.

A distinct advantage of the silver electrode system is the ability to render it bacteriostatic at will by the application of a few microamperes of anodic current preceding cathodic stimulation in cases compromised by infection.

Brief experience with noninvasive, pulsed magnetic fields was disappointing, although this technique remains an intriguing biophysical tool. Three nonunions treated with pulsed magnetic fields for one, two, and five months showed no sign of healing.

Experience with Low-Current/Silver Electrode Treatment of Nonunion

Since 1973 we have used cathodic electrical direct current (DC) stimulation to enhance the healing of nonunited fractures of long bones. This study evolved from the previous observations of the effects of small DC currents in animal tissues (3,4), the clinical observations of Friedenberg, Brighton, and others (7), and the need for an alternative treatment for certain patients for whom conventional therapies had failed. At present, 18 nonunions in 16 patients have been treated with low-current silver cathode method. The success rate has been equivalent to that reported by others (8), although the number of cases is small.

In this report we present a summary of the techniques and the results obtained. Recommendations are made about limitations to the use of electrical osteogenesis and the need for further research into the basic mechanisms involved.

METHODS

The electrical system has been described in some detail earlier (6). The cathode was a 0.64 mm diameter solid silver wire (99.99 per cent pure) insulated with heat-shrinkable Teflon (TFE), except for the terminal portion. The anode was a carbon-filled silicone rubber pad placed on the skin with a mild electrode paste. The source of current was a battery driven circuit box, with appropriate current and voltage test jacks.

The level of current delivered was selected originally on the basis of bioelectric potentials seen in animals in response to injury and on experiments with cellular dedifferentiation. A level of 0.1 microamperes per cm of electrode length was selected and has been found effective, although twice this value has been used on two patients, also with success. The geometric current density applied is therefore 0.005 microamperes/mm^2 at the electrode. This is 30 to 100 times lower than currents found effective by several other investigators with different electrodes. A typical patient electrode has been five cm (uninsulated), requiring a current of 0.5 microampere and showing interelectrode potentials of 0.3 to 0.8 volts.

The selection of silver was based on *in vitro* electrical measurements which showed a characteristically low to moderate net electrode impedance. Fortuitously, other studies in our laboratory had demonstrated the usefulness of silver as an antibacterial agent when operated anodically (1,5,9). This property was later incorporated into the clinical trials whenever a history of infection or mild osteomyelitis was present at the nonunion site. The silver electrode was run anodically at one microampere/cm length for 24 hours preceding the start of cathodic treatment.

After minor debridement and exposure of the medullary canal to the nonunion site, the electrode was inserted into the site through a drill hole in one shoulder of the cortex so that the insulation was firmly caught (Figure 1).

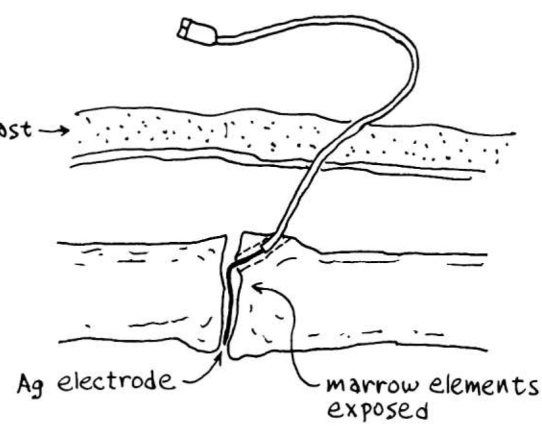

Figure 1. A sketch of a typical placement of the single wire DC cathode into the nonunion site. After minor debridement, if necessary, and exposure of marrow elements to the fracture site, the electrode is inserted via a small drill hole in the shoulder of the cortex. The insulation is snugly held in this hole and the remaining lead is led through the soft tissue, the skin, and the cast.

The remainder was led out through a stab incision in the skin and held by the cast. Current was applied continuously for four to eight weeks except for two cases in which the electrodes broke at three weeks. No bone grafts were used in this series. The patients were casted and treated as for other fractures and followed radiographically (Figure 2).

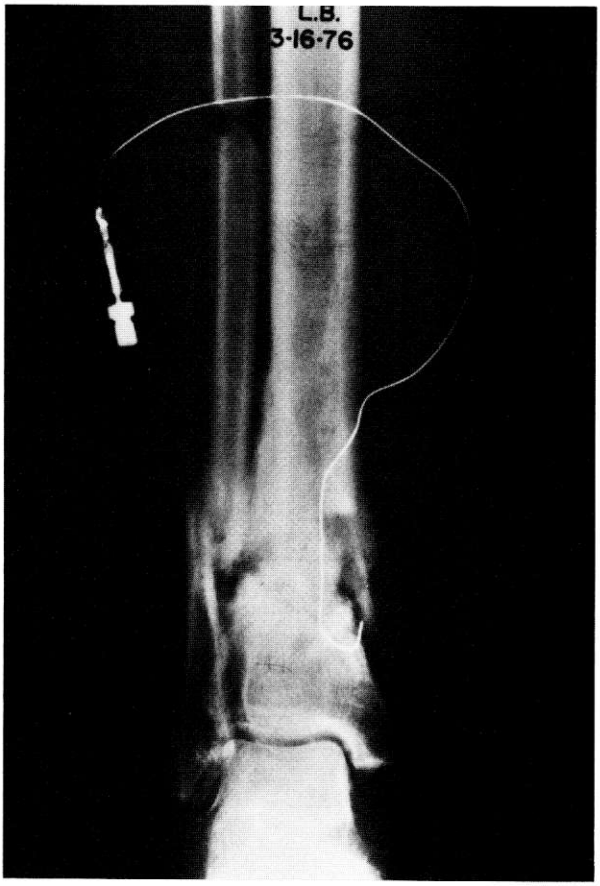

Figure 2. A radiograph after placement of a silver cathode into a tibial nonunion. The clear area in the proximal side is due to a slot that was made in the cortex to gain access to the site.

RESULTS

The patients chosen for these experiments had, with one exception, long standing nonunited fractures, unresponsive to conventional surgical procedures. One patient underwent a Charnley knee fusion in an attempt to resolve a severe and long standing pyarthrosis. Cathodic stimulation was used in this case to give an added measure of assistance to the already severely compromised joint (6). Seventeen nonunions and one knee fusion were treated with cathodic DC stimulation in 16 patients with a mean age of 42.9 years and range of 22 to 77 years. Two fractures were treated twice because of failure to obtain union. The median duration of the nonunions (Figure 3) was two years, with the newest (other than the knee fusion) being eight months and the longest 22 years. The mean followup time was 21 months posttreatment.

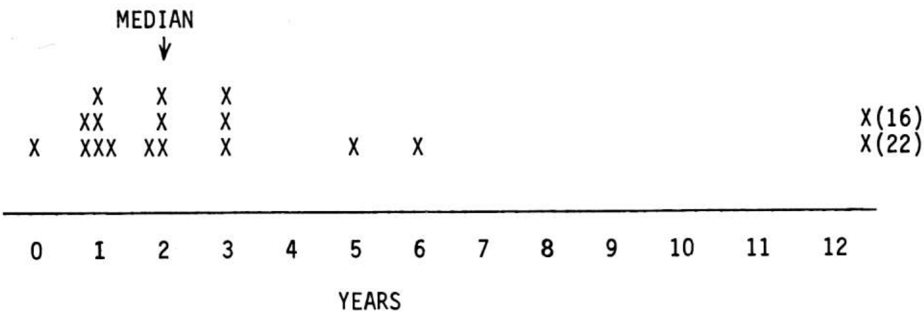

Figure 3. Nonunion age--18 fractures. The distribution of nonunion age in this study. In all cases, one or several conventional procedures had been tried previously. The case at "0" is the electrically assisted fusion in a pyarthritic knee, cited in the text.

Fracture healing was judged by full ambulation, radiographic fusion, and examination. Of the 20 treatment trials, 13 healed, giving a success of 65 per cent. Based on the number of fractures finally brought to union, the success rate was 72 per cent (Table 1).

TABLE 1

Summary of Results: Electrical Treatment of Nonunited Fractures

	Infected	Non-Infected	Total
Nonunions	8	10	18
Treatment Attempts	8	12	20
Treatments	Ag(+)/Ag(-)	AG(-)	
Healed	5	8	13
Failed	3	2	5
Per cent Healed	62%	80%	72%

One of the five ultimate failures was in a forearm fracture of 22 years duration. One was in a 77-year-old syphilitic, and three were in cases with chronic osteomyelitis, two of which obtained fibrous union with no drainage at 16 months. In the infected group, in which anodic current preceded cathodic treatment, the success rate was 5/8 or 62 per cent.

DISCUSSION

As had been noted previously (6), cases in which more than 0.6 joules of energy were applied resulted in healing of the nonunion. With total energies below this vale, healing was not achieved. There were two exceptions to this. In one case, the energy determination was confused by the application of two electrodes simultaneously and, in the other, infection returned to reverse the progress after completion of electrical treatment. The significance of this observation and its dependence on the more fundamental parameters of time and current density needs to be determined.

With regard to mechanism, clinical effectiveness is stimulated by either (1) the effect of electric field or charge at the cellular level, or (2) the effect of specific electrochemical products (produced or removed) in the environment of the mesenchymal tissue. It is unlikely, with the technique described above, that nonspecific inflammation has a major role. This latter may, in fact, be the case with other electrode systems or with currents and potentials causing significant hydrogen evolution and pH shifts.

Although not part of the present series, we wish to note that three patients were treated with the pulsed magnetic field regime of Bassett, Pilla, et al. (2). The effect of this surgically noninvasive technique is to induce small eddy currents within the limb, with an asymmetric waveform.

Two patients, one with a nonunion of the femur and one with a nonunion of the distal ulna and radius, were treated with 300 microsecond pulses at 66 Hz for two months and one month, respectively. Treatment was continuous for at least 17 hours each day. A third patient with a long standing tibial nonunion received three and one-half months of treatment as above, followed by one and one-half months with a modified waveform consisting of groups of 3.5 microsecond pulse spikes, in bursts of 5 ms duration, repeated 5 times/second. All three patients failed to respond to this therapy in our hands. The distal forearm fracture had also failed to respond to two attempts with low-current cathode treatment.

Finally, we can summarize with four points:

1) The low-current silver cathode system seems as effective as other methods, judged from this small group of cases.
2) The silver electrode offers the advantage of becoming a locally bacteriostatic agent when operated anodically with small currents. This property seems to be unique to silver and can be used when a previously quiescent infection might become active in the region of the electrode.
3) The fact that widely different current levels and materials could be equally effective points to the need for more basic studies of the mechanisms of action so that the safety and efficacy can be maximized.
4) Because of the poorly understood nature of the cathode stimulation process, we recommend that this procedure be limited in application to cases of established nonunion, etc., for which the risk/benefit ratio is reasonably low. In fresh fractures, the possible benefit is merely faster consolidation, and the risk of interference with an active cellular growth process is unknown. It would seem that applications here should await further understanding and testing.

ACKNOWLEDGEMENT

This work is supported by the Veterans Administration R. E. R. D. Service, Grant #098-14-7718-01.

REFERENCES

1. Barranco,S.D., Spadaro,J.A., Berger,T.J., and Becker, R.O., *In vitro* effect of weak direct current on *S. aureus*, Clin. Ortho. Rel. Res.,100:250, 1974
2. Bassett,C.A.L., Pilla,A.A., and Pawluk,R.J., A nonoperative salvage of surgically resistant pseudarthrosis and nonunions by pulsing electromagnetic fields, Clin. Ortho. Rel. Res.,124:128, 1977
3. Becker,R.O., and Murray,D.G., A method of producing cellular dedifferentiation by means of very small electrical currents, Trans. N. Y. Acad. Sci.,29:606, 1967
4. Becker,R.O., and Spadaro,J.A., Electrical stimulation of partial limb regeneration in mammals, Bull. N. Y. Acad. Med.,48:627, 1972

5. Becker,R.O., and Spadaro,J.A., Treatment of chronic osteomyelitis with silver ions, J. Bone Joint Surg., In press
6. Becker,R.O., Spadaro,J.A., and Marino,J.A., Clinical experiences with low intensity direct current stimulation of bone growth, Clin. Ortho. Rel. Res.,124:75, 1977
7. Friedenberg,Z.B., Harlow,M.C., and Brighton,C.T., Healing of nonunion of the medial malleolus by means of direct current, J.Trauma,11:883, 1971
8. Spadaro,J.A., Electrically stimulated bone growth in animals and man, Clin. Ortho. Rel. Res.,122:325, 1977
9. Spadaro,J.A., et al., Antibacterial effects of silver electrodes with weak direct current, Antimicrob. Agents and Chemother.,6:637, 1974