16/8/83

ELECTRICAL STIMULATION AND OSTEOGENESIS

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A THESIS SUBMITTED TO THE UNIVERSITY OF ADELAIDE FOR

THE DEGREE OF DOCTOR OF MEDICINE

March 1982

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SUMMARY

While electrical stimulation of nonunion of the tibia was first reported by Hartshorne (1841), Lente (1850) and Garrett (1861), interest in the electrical and electromechanical properties of bone has only occurred over the past 25 years.

In 1955, the Japanese workers Yasuda, Noguchi and Sata described stress-generated piezoelectric potentials in bone and demonstrated that a one microampere direct current, administered for three weeks, produced new bone growth in rabbit femora. In the United States of America, Bassett and Becker and then Shamos and Lavine, and Friedenberg and Brighton independently reported that (1) bone when stressed developed an electric potential, piezoelectricity, (2) areas under compression became negatively charged and, (3) when an electric current was passed through live bone, new bone formed at the negative electrode.

Much animal work with electrical stimulation followed during the 1960s and interest in its use in human clinical situations has followed. Friedenberg and Brighton in 1971 first reported successful healing of nonunion of the medial malleolus by a semi-invasive technique. Bassett, meanwhile, was evaluating and developing a non-invasive technique using pulsing electromagnetic fields. Dwyer in Sydney,

Australia was using a totally implanted stimulator for long standing ununited fractures of long bones and failed posterior spinal fusions. Many surgeons and workers remained sceptics. Clearly this new device had to be used responsibly or the same fate as befell electrical stimulation in the 19th century might occur. It was considered that, before the implanted bone growth stimulator Osteostim S12 was widely used, its ability to produce osteogenesis in at least delayed union of the tibia in adult dogs should be established.

This thesis describes research, both basic and clinical, with the Osteostim since 1973. It details a sequence of animal and clinical work from the development of a successful model of delayed union of the tibia in dogs (Chapter 2), to the study of the effect of an electrical bone growth stimulator utilising that model (Chapter 3), and the clinical trial in Australia utilising electrical stimulation as a means of treating delayed union and nonunion of bone and congenital pseudarthrosis of the tibia in childhood (Chapters 4 and 5). There follows further studies in animals designed to elucidate the effects of varying current levels of electrical stimulation (Chapter 6), and relationship between bone formation and impedance of electrical current flow (Chapter 7). Finally, the study investigated and designed a titanium cathode for use in implant surgery (Chapter 8).

The findings of this sequence of experimental and clinical studies are summarised below.

A consistently successful model of delayed union of the tibia was eventually developed and was used to determine the effect of the Osteostim in a controlled double blind trial using active and inactive generators. Independent qualitative assessments were made by radiography, gamma imaging, clinical assessment and histopathology. Statistically, there was a significant association between the active stimulator and superiority of bone healing ($p \leq 0.02$). The conclusion was that this commercially available direct current stimulator produced significant osteogenesis at four weeks in the experimental model.

As a result, a controlled clinical trial was carried out in Australia from 1976-1978. Strict criteria were used for case selection for this trial. Two surgical techniques were developed and used in all cases. Fracture healing both clinically and radiologically was achieved in 72 of 84 patients (86%). Further, union was achieved in 83% after previous failure with one or more cancellous bone graft operations and in 86% of chronically infected tibial nonunions. These results compared more than favourably with other standard forms of treatment and had similar success rates to the other techniques of electrical stimulation. Similar successes followed its use in ununited fractures of the scaphoid and failed posterior spinal fusions. An attempt was also made to assess the ability of serial nuclear scan studies, using technetium 99m methylene diphosphonate, to differentiate between normal and delayed union following fracture of the tibia. This study did not reveal any significant difference.

Perhaps the most spectacular clinical success in the clinical trial has been with congenital pseudarthrosis of the tibia. A surgical technique of management was developed. It has been reported that there were 6 successes out of 7 cases. These results are superior to other reports especially when it is realized that the incidence of amputation in the literature varies from 11% to 40%.

Different current levels have been used experimentally and clinically. No attempt has been made to ascertain the optimum current level in a situation of delayed healing of a long bone and many authors have expressed concern about this. A modified model of delayed union of the tibia of adult dogs was developed. Histological, nuclear scan and biochemical assays established in a preliminary study that bone activity had largely subsided after 4-6 weeks and that the maximum histological difference between normal unstimulated and stimulated bone healing occurred after three weeks stimulation. While many studies have confirmed that a current level of 20μA produced significant new bone, this study subsequently failed to detect any difference in bone formation with a 20 μA current let alone detect any difference between different current levels. The model, despite a preliminary study, proved to be unsatisfactory. However, the biochemical assays of serum calcium, phosphorus and alkaline phosphatase showed a pattern of responses normally seen in trauma.

A further study was designed to firstly test the hypothesis that, as a result of bone growth stimulation in the vicinity of a titanium cathode, there would be a temporal relationship between bone formation and the impedance to current flow to the cathode and secondly, to evaluate both quantitatively and qualitatively the use of titanium as a cathode. The study revealed that the impedance to current flow to an electrically stimulated titanium cathode did not change appreciably over a 12 week measurement period. Quantitative assessments established that osteogenesis significantly resulted from electrical stimulation using a titanium cathode and that no adverse reactions were observed to the titanium.

After nearly two decades of experience with total joint arthroplasties, many complications have become apparent, particularly loosening of the implant/ methylmethacrylate junction. Increasing efforts are being made to design implant prostheses, particularly porous coated prostheses to enable living bone to be in direct permanent contact with large areas of the surface of the implant, thereby anchoring the prosthesis to the bony cortex. It would be a major advance to avoid the use of cement and, even more so, if bone formation could be enhanced by electrical stimulation.

A preliminary study has been carried out in adult dogs and sheep to try and determine the aperture size for maximum bone growth, both extramedullary and intramedullary. Variable amounts of bone grew into the apertures in titanium metal plates placed on the cortical surface of the femur but significant bone grew around and into a titanium mesh placed in the intramedullary cavity of the upper femur. A titanium mesh cathode can now be designed and incorporated around the stem of a porous coated prosthesis. Future research will try and determine if there is any significant advantage in electrically stimulating such porous coated prostheses.

Electrical stimulation clearly augments osteogenesis and is potentially an important advance in orthopaedic surgery. In addition to possible use in replacement joint surgery, there is evidence of beneficial effects in the treatment of osteomyelitis, healing of skin ulcers and wounds, and of articular cartilage regeneration.

The long term effects of electrical stimulation are not known. Many questions remain unanswered. Its future use is exciting if it is used responsibly and with care.