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THERAPIES & MODALITIES

Stimulating Treatment

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The application of electrical current has been proven successful in the promotion of bone growth response in the treatment of nonunions, delayed unions, and stress fractures.

The physiologic basis of fracture healing has long been attributed to Wolff's Law, which states "bone adapts its structure to mechanical loading conditions." Bone has the inherent capacity to heal (form new bone) and remodel based on not only mechanical, but also electrical and magnetic conditions. Yasuda and Fukada in Japan in the early 1950s are believed to be the first to recognize electrical potentials in bone (a phenomenon termed piezoelectricity).1 Bassett and coworkers subsequently demonstrated that stress applied to bone causes the concave (bone growth or osteogenic) side to become electronegative, while the convex (bone resorption) side becomes electropositive. For the last 30 years, surgeons have extensively studied the use of electrical current for the treatment of difficult fractures, including nonunions, delayed unions, and stress fractures.

The Methods

Bone Growth Stimulators—A broad industry offering various electrical and magnetic appliances known as "bone growth stimulators" has developed in an attempt to apply the proper amount of electrical energy to bone to provide maximum healing potential. These devices may employ direct current (DC), pulsed electromagnetic fields (PEMF), combined magnetic fields (CMF), alternating current (AC), or capacitive coupling (CC) to provide electrical stimulation to a fracture site. Varying amounts of initial energy are applied at the electrode (skin pads or implanted wires) to generate 10-20 μa of energy at the fracture site for maximum bone growth. The amount of energy delivered is thought to be critical, in that less than 5 μa produces no bone reaction, while current greater than 20 μa may cause bone death and absorption. The end result of "bone stimulating" is an enhanced osteogenic environment with calcification and mineralization of the fibrocartilage repair tissue (bone growth) at the fracture site and increased vascularity. Stimulators are commonly used for hard-to-treat fractures, nonunions, and poorly healing stress fractures of the scaphoid, distal tibia, femur, humerus, and fifth metatarsal shaft (Jones fracture). Implantable stimulators are also used as an adjunct to bone grafting in spinal fusion surgery. Each method of energy transfer has inherent benefits and potential drawbacks based on individual component specifications such as size, weight, tolerability, patient compliance, and cost. The actual amount of energy applied at the target site may also vary with some models based on tissue depth and resistance. Bone growth response is thought to be dose-dependent, so patient compliance is essential and "more use is better."

Direct Current—DC stimulators consist of surgically implanted wire leads of various lengths placed directly at the fracture or fusion site. These stimulators are most commonly used in the initial surgical procedure for spinal fusion to optimize bone incorporation rates, but may also be implanted during surgical treatment and bone grafting of fracture nonunion or stress fractures. The implanted wire leads are connected to a small lithium battery power generator that is implanted subcutaneously. The system applies 20 µA of direct current to the target area for up to 6 months. Removal of the power generator may be performed during a second surgical procedure at the completion of treatment, but the wire leads remain imbedded at the fusion site.

Direct current stimulators provide constant uniform current at the target site during the entire battery life, eliminating concerns about patient compliance and energy transfer due to tissue resistance. Hospital cost and patient morbidity are both higher than with external units because of the necessity for one or two surgical procedures.

Capacitive Coupling—CC uses an external 9-V battery source for power generation through two wire leads attached to skin electrodes. This unit delivers a 5-V peak-to-peak sine wave at 60 kHz that applies 5-10 mA at the skin and 15-20 µA at the target site. The skin electrodes are applied at the fracture site, and the battery pack is worn externally like a pager. The unit may be operated for 24 hours each day and the 9-V battery is changed daily.

The major advantage of CC, patient compliance, is optimized by the ease of application of dermal electrodes, and the small size and weight of the unit. Transverse application of the electrodes also allows for a relatively broad area of bone growth stimulation. Disadvantages of CC include possible skin irritation from dermal electrodes, and the necessity of frequent battery replacement. Capacitive coupling units may be applied to the fracture site under cast immobilization, or the cast may be windowed for electrode placement.

Pulsed Electromagnetic Fields—An externally applied coil that may be sized on the basis of the fracture location powers PEMF stimulators. The patient wears a battery pack and control unit for up to 10 hours of recommended use per day. The coils may be worn directly under a cast on the skin or on the outside of the cast. The PEMF unit was the initial mechanism for external stimulation and has a fairly long track record; however, the units are often heavy and larger than other options, making patient compliance a concern.

Combined Magnetic Field—Combined magnetic field (CMF) stimulators use an external coil system with a combination of direct and alternating current to produce both static and alternating magnetic fields. The CMF units are available in different sizes and coil designs to accommodate various fracture locations. The size and bulk of CMF technology coils may affect patient compliance, but the units are recommended for only 30 minutes of use per day.

Pulsed Ultrasound—Pulsed ultrasound units are also worn externally and consist of a battery power pack and transducer head. The unit may be applied directly to the skin overlying the fracture site, or by windowing a cast if necessary. Pulsed ultrasound units are somewhat large and bulky, but manufacturers boast the shortest duration of treatment dose at 20 minutes per day.

Treatment Results

Efficacy studies are available in the peer-reviewed literature for each method of bone stimulation. Brighton and Pollack reported excellent results with capacitive coupling used to treat 22 previously treated recalcitrant nonunions. The average pretreatment duration of nonunion was 3.3 years and

17 of 22 (77%) healed with CC stimulation after an average of 22 weeks.2 Scott and King showed significant improvement in healing rates for established nonunions treated with CC stimulation (6 of 10 healed) compared to a placebo control (0 of 11 healed).3 Benazzo and colleagues reported an 88% success rate in treatment of stress fractures of the lower extremity in 25 athletes with electrical bone stimulation for an average of 52 days.4

Figure 1: Radiograph demonstrates a stress fracture of the proximal fifth metatarsal shaft (Jones fracture).

Several authors have noted the importance of dose-dependent therapy, with some controversy concerning the optimal amount of treatment. Brighton and colleagues have suggested that the response to electrical stimulation probably involves several cell types in multiple stages of the cell cycle. Therefore, to provide maximum bone stimulation, they recommend maximum use of the electrical system when applying electrical stimulation to a fracture or fusion site.

A Case Example

A 16-year-old high school basketball player presented with an acute injury to the right foot during a basketball game. The patient noted a 5-month history of lateral foot pain prior to the acute injury. Radiographs demonstrated a stress fracture of the fifth metatarsal shaft (Jones fracture) (Figure 1). He was counseled concerning the uncertain natural history of fracture healing, with the possible need for surgical fixation. The patient elected to attempt nonsurgical treatment and was placed in a non-weight-bearing cast with capacitive coupling electrical bone stimulation. Repeat radiographs after 14 weeks of electrical treatment demonstrated successful treatment with a healed fracture (Figure 2), and the patient returned to full activity without pain.

Figure 2: Repeat radiograph after 14 weeks of capacitive coupling electrical stimulation demonstrates fracture union.

Conclusion

Electrical stimulation has been documented to be useful for the treatment of difficult fractures, delayed, and nonunions, and stress fractures in athletes. Several methods of applying electrical current to the target site are available. Direct current units are invasive (implanted at the target site), but alleviate concerns about patient compliance. The physician may choose external, noninvasive units based on fracture treatment site, unit size and stimulation method, and patient compliance. As a general rule, with electrical bone stimulation “more is better.”

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