CHAPTER 15

AN OVERVIEW OF ELECTRICAL STIMULATION OF BONE INCLUDING THE CLINICAL USE OF PEMF

John A. Ruch, D.P.M.

The use of electrical stimulation in the management of bone healing complications has been viewed with both skepticism and enthusiasm over the last 20 years. Clinical applications of the technique in the early 1970s were viewed with a degree of disbelief as individual clinical successes were difficult to duplicate. The instrumentation and devices were quite cumbersome, and the lack of common success did little to promote increased use of the technology.

Over the past 20 years, there has been continued study and many positive clinical trials which strongly suggest that electrical stimulation, either Direct Current (DC) or Pulsed ElectroMagnetic Fields (PEMF), do have a beneficial role in the management of bone healing complications such as delayed union or nonunion.

ELECTROPHYSIOLOGY

Early work by the researchers, Yasuda and Fukada, was based on electrical potentials identified in living bone. Stress of this tissue created electrical potentials with the compression side of the bone becoming electronegative, and the tension side of the bone becoming electropositive. The change in polarity of the bone surfaces was attributed to a process termed "streaming potentials," as ions were carried by the moving fluids of the bone tissue as it was deformed. Later studies by Levine and Shamos coined the term "piezo electric effect."

The theory behind the electrical characteristics of bone is drawn from Wolff's Law. The compression side of living stressed bone shows a buildup or increase in bone density, attributed to the electronegative region of the bone. The Japanese researchers carried this theory into the lab by inserting anode and cathode electrodes into living bone tissue. An increase in bone production or density was consistently noted in the region of the electronegative pole.

Similar results were independently reported by Bassett, Brighton, and Patterson utilizing a variety of different techniques including direct current, pulsed electromagnetic field, and semi-invasive and totally invasive techniques of direct current applications.

The theoretical effects of electrical potential on bone forming tissue were attributed to the following: 1. Increased pH promoting bone formation. 2. Decrease in pO_2 enhancing calcium deposition in osteoid matrix. 3. Desensitization of the osteoclast to parathyroid hormone, promoting a shift in balance favoring osteoblastic cells and bone formation. 4. Activation of cyclic AMP to further promote transport of calcium through the cell membrane and into osteoid matrix.

A variety of clinical studies were performed through the 1970s and 1980s utilizing direct current and pulsed electromagnetic fields. Original research by Bassett demonstrated a 73% effectiveness of pulsed electromagnetic fields in healing congenital pseudoarthrosis. Brighton and Bassett reported similar success rates in dealing with nonunion and delayed unions. Bassett reported a 93% success rate in healing of delayed unions and nonunions by combining pulsed electromagnetic field and autogenous bone grafting techniques. A significant double blind study was performed by Sharrard in 1988, which identified only a 12% incidence of healing after 12 weeks of application with the control, and a dramatic increase of 45% in the pulsed electromagnetic field group.

MECHANICAL BASIS FOR SUCCESSFUL ELECTRICAL STIMULATION OF BONE HEALING

While the effects of electrical stimulation have been clearly identified, the use of electrical stimulation does not guarantee successful bone healing. Bassett's fundamental work in 1982 identified the need for mechanical control of the fracture or nonunion site to allow electrical stimulation to have a positive influence on bone healing.

Uncontrolled motion at the fracture site produces an interposing fibrous tissue which is not capable of converting to osteoid matrix or bone tissue. Absence or control of motion creates an interposing tissue of fibrocartilage or osteoid matrix, which readily incorporates calcium and is converted into woven bone. Bassett's work stated that motion across the fracture site must be limited to no more than 5 degrees to allow formation of appropriate fibrocartilage for fracture healing.

CLINICAL EFFICACY

Not every delayed union or nonunion is amendable to successful healing with the application of electrical stimulation techniques. Standard measures for evaluation of these complications must be utilized before determining that electrical stimulation should be incorporated in the management of any case.

A primary consideration in evaluation of bone healing complications is the nature of interposing tissue between fracture surfaces. A long-standing nonunion with considerable motion at the fracture site is likely to be interposed with fibrous tissue or scar. The age of the nonunion, as well as the degree of motion available across the fracture area, play a significant role in the formula of evaluation. Long-standing nonunions with extreme hypermobility are unlikely candidates for electrical stimulation, as the interposing tissue commonly creates the clinical condition of pseudoarthrosis, and a condition that is unresponsive to electrical stimulation.

A variety of clinical techniques may be employed in the evaluation of the nonunion, including standard radiographs, stress fluoroscopy, technetium-99m scans, CT, and MRI studies.

The commonly accepted indications for the use of electrical stimulation include: 1. Congenital pseudoarthrosis 2. Delayed union 3. Nonunion 4. Complex bone grafting 5. Complex open reduction and internal fixation (ORIF) 6. Infected nonunions (Pulsed electromagnetic field technology or noninvasive techniques are the only methods indicated for the infected nonunion) Primary contraindications for the use of electrical stimulation include: 1. Synovial pseudoarthrosis 2. Uncontrolled fracture motion 3. A fracture greater than 1 cm or 1/2 the diameter of the bone substance 4. Pregnancy (relative contraindication) 5. Invasive techniques in osteomyelitis (relative contraindication).

Two case studies will demonstrate the success of fracture healing with the application of pulsing electromagnetic fields.

CASE 1

Case 1 involves a 33-year-old female who was involved in an automobile accident, suffering a supination external rotation fracture of her fibular malleolus. Treatment consisted of the application of a short leg cast for approximately 12 weeks.

The patient was involved in another motor vehicle accident approximately four months after the original injury, and a third injury occurred approximately 11 months after the original injury. The patient continued to experience pain, and a nonunion was determined after radiographs were taken at approximately 14 months (Fig. 1). The clinical picture included pain and swelling over the lateral malleolus of the right ankle. Treatment initiated at this point included the application of a short leg cast and PEMF therapy.

Three months after the initiation of PEMF therapy, consolidation of the fracture was evident (Fig. 2). Cortical changes indicated bone healing activity along with endosteal healing across the fracture line.

Six months after initiation of PEMF therapy, and 23 months after the original ankle fracture, radiographs demonstrated complete union of the fibular fracture (Fig. 3). Cortical remodeling had occurred, along with complete obliteration of the original fracture line and nonunion site. Resolution of the clinical symptoms of edema and pain were accomplished with this conservative, non-surgical treatment.

Figure 1. Radiograph of a non-healed SER II fracture of the fibular malleolus.

Figure 2. Three months after the initiation of PEMF therapy, fracture consolidation is evident.

Figure 3. Radiograph six months after initition of PEMF therapy, and 23 months after the original ankle fracture.

CASE 2

The patient was a 44-year-old female who underwent correction of a hallux valgus deformity of the right foot by McBride-type hallux valgus repair and oblique base wedge osteotomy. The six-week postoperative radiograph showed no significant change in the osteotomy as compared to the immediate postoperative films (Fig. 4). Normally, this is a positive indicator when reviewing a fracture or osteotomy which has been rigidly fixated. The absence of bone callus or significant shift or displacement is usually associated with satisfactory primary bone healing. The patient was allowed to begin weight bearing at this point.

Following a troublesome postoperative course, the radiograph at 3 1/2 months postoperative indicated delayed union of the first metatarsal osteotomy (Fig. 5). There was migration of the proximal screw along with bone callus activity, and lysis or reabsorption of bone across the osteotomy site. Clinical signs included focal edema around the osteotomy, temperature increase and pain at the surgical site. The complication was identified at approximately eight weeks, and subsequent treatment included additional casting and non-weight bearing. Upon resumption of weight bearing, the osteotomy continued to show evidence of instability, and at 14 weeks the migrating screw was removed and the remaining fixation tightened. No bone graft was used and the patient was placed in a non-weight-bearing, short-leg cast. A PEMF stimulation device was used at this time.

At five months postoperative, and approximately six weeks following initiation of PEMF therapy, there was radiographic evidence of consolidation at the osteotomy site (Fig. 6). There was a general decrease in edema and induration, and evidence of endosteal healing, as well as cortical remodeling. Surgical alignment and the length of the metatarsal had been maintained. Guarded weight bearing was resumed at approximately five months postoperative.

At eight months postoperative, and approximately 4 1/2 months following initiation of PEMF therapy, the osteotomy had solidly healed (Fig. 7). There had been total healing across the osteotomy surface and recontouring of the cortical margins of the metatarsal. The patient had no functional complication such as shortening or elevation of the metatarsal osteotomy.

A long-term follow-up radiograph at approximately 2 1/2 years demonstrated mature remodeling of the first metatarsal osteotomy site (Fig. 8). There had been a permanent long-term correction of the hallux valgus deformity with a congruous joint alignment and excellent joint space. PEMF therapy contributed positively to this patient's recovery. The use of electrical stimulation in the management of complicated nonunions and other complex osseus procedures has been proven to be a positive adjunct in modern therapy.

Figure 4. Six week postoperative view of hallux valgus repair of the right foot.

Figure 5. Radiograph demonstrates delayed union of the first metatarsal osteotomy.

Figure 6. Approximately six weeks following initiation of PEMF therapy, radiographic evidence of consolidation is visible at the osteotomy site.

Figure 8. Radiograph at 2.5 years demonstrates mature remodeling of the first metatarsal osteotomy site.

Figure 7. The osteotomy has healed approximately 4 1/2 months following initiation of PEMF therapy.

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