Pulsed Electromagnetic Field Therapy in Plastic Surgery

When the body is heated, increase in cutaneous blood flow is the primary means to dissipate heat. One of the first electrical devices in medicine was a continuous electromagnetic wave device known as *diathermy*, a first-generation device that used an induced electrical field to generate heat in tissues. Then, about 25 years ago, research uncovered an extremely important finding: the electric field induced in the body could increase blood flow to the tissues without the necessity of heating the tissues. As a result, a series of second-, third-, and fourth-generation non-thermic diathermy devices were developed.

Pulsed electromagnetic field devices (PEMF), also known as electrotherapy devices, were an improvement over devices based on continuous waves. The PEMF devices used less power, had a limited radiofrequency radiation pattern due to improved antenna and circuit design, and did not interfere with other electrical devices.

Electrotherapy must not be confused with the static magnets, or bar magnets, that have recently become so popular for pain treatment. With few exceptions, such as the 1997 study by Valbona1 at Baylor University, investigations have found no objective evidence that these magnets improve pain or swelling in soft tissues.

The widespread acceptance of PEMF devices for physical medicine and rehabilitation, orthopedics and sports injuries, and musculoskeletal conditions belies the fact that other branches of medicine have not investigated or applied these devices extensively. With regard to applications in plastic surgery, there is some evidence suggesting benefits in the healing and recovery process.

In 2000, a double-blind, placebo-controlled pilot study with the SofPulse (Electropharmacology, Inc. Pompano Beach, FL [company disbanded]),2 an older second-generation PEMF device, showed that 7 of 7 patients undergoing CO2 laser resurfacing had clinically reduced edema on the treated side based on clinical evaluation (Figure 1).

In more than 5 years using the SofPulse device, I found that it reduced edema after facial plastic surgery procedures such as blepharoplasty, laser resurfacing, and fat grafting; others have noted similar experiences.3 Unfortunately, while somewhat useful, these devices weighed 40 to 50 pounds, resembled an old-fashioned stereo amplifier with an attached desk lamp type arm, were large and bulky, and cumbersome to use. Treatment in the first week after surgery required that patients make a daily trip to the office or have the device trucked home. The device was positioned about 1 inch directly over the skin, or area of treatment, and the patient was asked to remain still for 30 minutes twice a day, a task that is frequently difficult immediately after surgery.

Some surgeons routinely used PEMF as a component of postoperative treatment when injecting fat into the face. It is likely that the angiogenesis effect improves autograft take and decreases failure, although this has not been specifically shown for fat autografts under controlled laboratory conditions. Difficulty of use was an obstacle not only in complying with prescribed therapy but also to widespread acceptance and application in clinical practice.

New third-generation devices, one of which was FDA-approved for marketing in 2002, replaced the second-generation devices and solved some of their major drawbacks (Figure 2). The electronics were miniaturized onto a printed circuit board, the controls were managed by microchips, and the device was sealed in a soft outer covering. Also, the antenna was etched directly onto the circuit board with an electrically efficient design that allowed a small watch battery to power it continuously for 7 to 10

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days. The device was applied in a manner similar to application of EKG leads, with a double-sided adhesive strip placed directly on the wound or onto a bandage that covered the wound itself. Compliance problems were virtually eliminated by incorporation of the device into the standard postoperative dressings immediately after surgery. While the new device weighed only a few ounces and radiated less total power, the total therapeutic dose, delivered gently over 24 hours, was about 2.5 to 3 times that of the large, bulky second-generation devices that were used only twice daily at very high, pulsed doses.

A fourth-generation device called ActiPatch (Bioelectronics Corp, Frederick, MD), approved by the FDA for marketing in March 2004, improved on its pre-
In the 1990s, concern about childhood leukemia clusters found in residents near power transmission lines led to public interest in surveying and analyzing the state of the art in electromagnetic fields and human tissues. The National Institute of Environmental Health Sciences published a 523 page Working Group Report with 63 pages of references encompassing adverse and beneficial effects and the broad range of interaction of biological tissues with electromagnetic fields. The report critically examined subjects such as carcinogenicity, non-cancer health effects in experimental animals, epidemiological and laboratory studies in humans, in vitro studies, biophysics, changes in tissues induced by electromagnetic fields, and physical mechanisms in tissues.

The Report demonstrated “inadequate” evidence for adverse health effects in humans in more than 10 categories including Alzheimer’s, immune system and cardiovascular disease, and amyotrophic lateral sclerosis, and only “weak” evidence in particular categories for experimental animals. Most Working Group participants found one category with strong evidence of a biological effect. Bone repair and adaptation was assessed as improved in terms of bone lengthening, inhibition of bone resorption, and appositional (surface) bone growth. However, the participating orthopedists, primarily concerned with bony tissues, did not, for the most part, examine the soft tissues between the skin and the bone. Therefore, there was relatively little soft tissue evidence to evaluate. Finally, it was generally agreed that during treatment patients could sense electromagnetic fields in the tissues.

Based on their evaluation of interaction of biological tissues with electromagnetic fields in these studies, 10 Working Group participants voted for “moderate” evidence of nervous and non-bone connective tissue repair and adaptation in vertebrate animals, 12 participants abstained, 6 participants voted for “weak” evidence, and one voter was absent.

Studies of the Effects of PEMF on Soft Tissues

For decades it was thought that the heating effect of the high energy field in the first generation diathermy device was essential for the increased blood flow. However, later research showed that pulsatile devices with a factor of 10 or less energy appeared to stimulate blood flow by a pulsatile, rapidly peristaltic mechanism on vessel walls, not heating action or secondary vasodilation. The energy could be measured in watts.

Studies of PEMF treatment have shown improvement...
in microvascular blood perfusion and more rapid healing of ulcers in diabetic patients, increased skin perfusion in the forearm of volunteer experimental human subjects, and improved pedal edema in cardiac patients. In one study, endothelial cells responded to PEMF with increased growth and angiogenesis, and it has been suggested that PEMF generally improves wound healing. In another animal model, spinal fusion was improved, and in another, bone-graft take was improved after a state of non-union.

In the early 1980s, Bental wrote about reduced swelling after blepharoplasty (on clinical examination) with an older-generation electromagnetic field device and about effective treatment of soft-tissue injuries to diminish edema and speed wound healing. In 2000, Roland et al reported a statistically significant increase in capillary sprouting after PEMF treatment, compared with controls, in a double-blind, laboratory animal model of groin wounds. Further studies in animals that underwent ligation of the feeding artery to a groin flap showed improved flap survival compared with controls. Markov et al found decreased edema and improved wound healing in soft tissues treated with PEMF. Accelerated wound healing was recently demonstrated in 2 laboratory models in plastic surgery.

**Potential Electrotherapy Mechanisms**

Electrotherapy has been used for decades to reduce pain and swelling following surgery. In addition, there is clinical and laboratory evidence of its efficacy in significantly inducing capillary growth. Now, new technology is catching up with the clinical evidence and we are reaching a better understanding of the electrotherapy mechanism of action and learning that very low power levels, when used over extended periods, can produce results equivalent to the high power, transient treatments associated with cumbersome traditional machines.

Lower power levels with efficient antenna designs facilitate packing the power of electrotherapy into a miniaturized, wearable, and affordable patch. Such a patch can help to overcome the hesitation of patients considering plastic surgery by potentially reducing postoperative pain and recovery time.

Increasing fluid flow due to its pulsatile action, electrotherapy helps to reestablish cell membrane potential in vitro, reduces edema, seems to relieve pain, and appears to ignite healing in vivo, clinically, by compressing the “inflammatory process.” In one device, electrotherapy, when activated, emits a pulsed radiofrequency signal that is propelled into the body on a 27 MHz frequency wave. These waves introduce an electromagnetic field into the affected tissue that induces a low frequency electrical current in the damaged cells. Each pulse is 100 μsec in duration and the signal is pulsed at 1000 Hz for a duty cycle of 10% (90% off, 10% on per second).

The induced electrical current affects the cells, which have been traumatized and physically separated by intercellular fluids. Each cell stores an electrical capacitance by actively pumping and maintaining many electrolyte gradients across the membrane, including a high concentration of potassium and low concentration of sodium, inside rather than outside of the cell wall. This pumping mechanism and the relative concentration of the electrolytes have been diminished through trauma. Electrotherapy’s applied low-level induced electrical current helps reestablish that electrical capacity. When the cell achieves its normal resting potential (–70 mV), it will emit few chemical pain signals and inflammatory agents (histamines, nitric oxide, prostaglandin E and others).

The induced, time-varying electric field created by electrotherapy excites the lymphatic system and the blood vessels; more quickly pumps the concentration of fluid from the affected area, and induces capillary growth in healing tissues. As a result, the physical separation of cells due to increased extracellular fluid will decrease, and intercellular communications through tight and gap junctions are potentially improved. Nerves may stop receiving pain signals and the inflammatory response may be ameliorated while healing is activated.

**The Future**

The use of PEMF devices preoperatively to induce capillary growth and postoperatively to improve swelling has a scientific underpinning, but efficacy has not been scientifically proven in clinical studies. Use after facial surgery, breast surgery, and abdominoplasty may be most beneficial in reducing edema and, perhaps, pain. Clinical studies indicating decreased use of postoperative analgesics in plastic surgery have not been published, and anecdotal reports must be corroborated in light of effects on nerve endings documented in laboratory studies.

As our knowledge of these technologies improves, many more applications may emerge in treatment of postoperative edema and pain, nerve regeneration, replantation, rehabilitation, hand surgery, microvascular free-tissue transfer, and grafting. Clinical studies are currently planned or underway in podiatry for heel pain, in orthopedics for soft-tissue injuries, in dentistry and oral surgery after major dental and maxillofacial procedures, and other fields. Wound healing, inflammation, edema, capillary growth, nerve regeneration, and pain are almost ubiqui-
tous factors in medicine and numerous applications will be investigated, both within and outside of plastic surgery.

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Note: Dr. Kinney serves on the Board of Directors of the Bioelectronics Corporation, manufacturer of the ActiPatch device, and formerly consulted for Electropharmacology, Inc, before its breakup. Reprint requests: Brian M. Kinney, MD, 2080 Century Park E., Suite 1110, Los Angeles, CA 90067-2009.

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