

High-Tech Healing

The evolution of therapeutic electromagnetic fields in plastic surgery

by Brian M. Kinney, MD, FACS, MSME

In the late 1700s Alessandro Volta performed early work on batteries and storage of electrical charge. This was followed in the early 1800s by André-Marie Ampère's work on the attractive and repulsive forces of currents in conductors, which led, in the late 19th century, to the introduction of Morse code, electric lighting and lightbulbs, motors, and a host of other inventions. Did Volta or Ampère ever think that they would be helping today's doctors to provide improved wound care? Probably not—but that is exactly what they did.

Initial Medical Devices, Static Magnets, and PEMF Therapy

Diathermy, the therapeutic use of a high-frequency current to generate heat within tissue, began with a first-generation continuous wave device that used electrical

sue was affected remained in question. Regardless, diathermy became a standard part of physical therapy, ordered for rehabilitation, healing after trauma or surgery, stimulation of blood flow to speed healing and lymphatic flow, therapeutic interventions in the treatment of rheumatoid arthritis, sporting injuries, and other conditions.

The principal of diathermy is the basis of electrocautery devices that utilize high-frequency radio waves to intensely heat tissues in a small area in order to coagulate vessels, cut tissue, and aid with surgery.

In 1957, Hal Mettler introduced the first ultrasonic heating device that used a frequency range of 1–3 MHz in a continuous output. These devices remain in use to this day. This is not to be confused with the use of static, or bar, magnets that have become so popular in recent years.^{1,5} Most investigations have found no objective evidence that they improve pain or swelling in soft tissues. With a static, invariant magnetic field, a beneficial mechanism of action is difficult to postulate. Few studies, other than one performed in 1997 at Baylor University, verify that static magnets have an objective therapeutic effect on tissues.⁶ That study demonstrated a statistically significant relief of musculoskeletal back pain

in post-polio patients.

After decades of use, in 1976 with the signing into law of the act that created the FDA, continuous-wave diathermy devices were “grandfathered” into use from prior clinical experience without the requirement that premarket approval (PMA) be granted. The PMA process necessitates intensive scientific investigation, large-scale clinical trials, and a more laborious regulatory obligation.

Until the early 1990s continuous-wave diathermy devices remained the standard approach to treating wounds. This

remained largely unchanged for more than 50 years.⁷⁻¹² Pulsed electromagnetic field devices (PEMF), also known as electrotherapy devices, were an improvement over ones based on continuous waves.¹³⁻¹⁶ They used less power, had a limited radio-frequency field pattern due to improved antenna and circuit design, and did not interfere with other electrical devices.

Electromagnetic Fields and Health Effects

In the 1990s, after more than a century of electromagnetic usage in wound care, concern about leukemia clusters found in children living near power transmission lines led to a public interest in surveying and analyzing the state of the art in electromagnetic fields and human tissue. The National Institute of Environmental Health Sciences published a Working Group Report, entitled *Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields*. The 523-page document examined both the adverse and beneficial effects (and the broad range of interaction of biological tissues) with electromagnetic fields. Carcinogenicity, noncancer health effects in experimental animals, epidemiology, and laboratory studies in humans. In vitro studies, biophysics, changes in tissues induced by EMF, and physical mechanisms in tissues were examined as well.

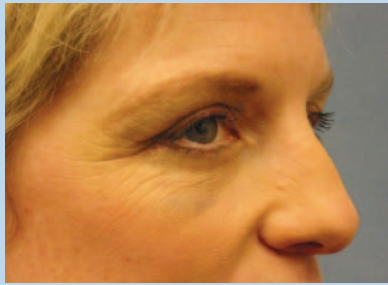
There was “inadequate” evidence for adverse health effects in more than 10 conditions, including Alzheimer's, immune system deficiencies, cardiovascular disease, and amyotrophic lateral sclerosis, among others. The majority of the Working Group found one area with “strong” evidence for a biological effect; bone repair and adaptation, both of which were improved in a variety of settings, including bone lengthening, inhibition of bone resorption, and appositional (surface) bone growth. However, our orthopedic colleagues, concerned largely with the bony

This therapy eliminates major barriers for patients considering plastic surgery by reducing the long recovery time caused by the swelling, pain, and bruising of the incision and surgical dissection.

signals to do just that: generate heat in tissue. This was one of the first electrical devices in medicine. The 1938 *Collier's Year Book* mentions the use of diathermy to generate heat to treat gonococcal infections.

Early devices were essentially broad-frequency broadcasting stations that could be detected miles from the treatment device with a standard radio receiver. With this much power, tissue was bathed in excessive, unfocused, poorly-tuned power whose effects were untested. Decades of use had shown that circulation was increased, but the systematic study of how individual tis-

Before & After



Preoperative blepharoplasty oblique photo.



2 weeks after surgery with makeup.

tissue, did not study the soft tissue between the skin and the bone during almost all of their studies. Therefore, there was a relative paucity of evidence to evaluate in soft tissue. Finally, it was generally agreed that electromagnetic fields could be sensed in the tissue by patients during treatment.

Based on the studies evaluated, 10 Working Group members voted “for moderate” evidence on nervous and nonbone connective tissue repair and adaptation in vertebrate animals, 12 abstained, six voted for “weak” evidence and one voting member was absent. Human studies in soft tissues were quite rare, although radio frequency devices have long been known to increase blood flow and had been in use for decades. Double-blind studies, the gold standard in rigorous medicine, but relatively rare in cosmetic plastic surgery, have provided some guidance for clinical progress in recent years.

Studies of Soft-Tissue Effects

Research studies in the past 20 years uncovered an extremely important finding: the electric field induced in the body could increase blood flow to the tissues without having to heat the tissues. For decades it was thought that the heating effect of the high-energy field in the first-generation device was essential for the increased blood flow, but this does not appear to be the case. Pulsatile devices with a factor of 10 or more appeared to stimulate blood flow by a pulsatile, rapidly peristaltic mechanism on ves-

sel walls, rather than heating action or secondary vasodilatation.

Studies 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.¹⁷⁻¹⁹ In one study endothelial cells responded to PEMF by increased growth rate and angiogenesis and it has been suggested that wound healing in general is improved. In another animal model, spinal fusion was improved while in another study, bone-graft take was improved after a state of nonunion.²⁰

In the early 1980s Nicolle and Bentall wrote in the *Aesthetic Plastic Surgery Journal* of the reduced swelling on clinical exam after blepharoplasty with an older generation electromagnetic field device.²¹ Silver used a device to treat patients postoperatively after capsular contracture release.²² Roland, et. al’s research group reported in *Plastic and Reconstructive Surgery* in April 2000 on a statistically significant difference in capillary sprouting after PEMF treatment compared to controls in a double-blind study laboratory animal model.²³

The Development of Modern Devices and “Nonthermic” Diathermy

Since the 1990s, the second-generation devices advanced the state of the art because

they were “nonthermic” in that they did not heat tissue to any appreciable degree. Unfortunately, while somewhat useful, these machines weighed 40 to 50 lbs, making them difficult to work with. Treatment with the devices required a return trip to the office daily or delivery by truck to the patient’s home for therapy for the first week after surgery.

The device was placed directly over the face about 1 inch from the area of treatment and the patient had to remain quiet for 30 minutes, twice a day—a task often difficult for the immediately postoperative patient.

Practicality limited the compliance with a once- or twice-daily weeklong regimen. In fat injection to the face, the use of these devices became a routine part of the postoperative plan for some surgeons. The angiogenesis effect likely improves autograft take, although this has not been shown under controlled laboratory conditions. The need for a more streamlined, easy-to-use device became apparent.

A new third-generation device, cleared by the FDA 2 years ago for marketing by a 510 (k), resolved some of the major issues with the second-generation device. The electronics were miniaturized onto a printed circuit board, the controls were managed by microchips and the device was now sealed in a flesh-colored, soft outer covering. 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 7–10 days.

The device was applied much as EKG leads with a double-sided adhesive strip directly to 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 device that was used only twice daily at very high, pulsed doses.

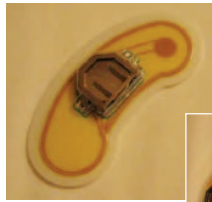


Postoperative photos in recovery room with electromagnetic devices applied.

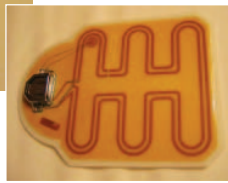


Patient 2 days after surgery.

PHOTOS COURTESY OF BRIAN W. KINNEY, MD, FACS, MSME



Left: Small fourth generation device.
Below: Large fourth generation device.



In March 2004, a fourth-generation device cleared for marketing by the FDA improved on its predecessor in several ways. Notably, the outer seal was made flexible to better follow body contours; the microchips were further miniaturized; the antenna design was made more efficient and created a more enveloping radiated field with better penetration potential. The fourth-generation device had an on-off switch for conservation of the power source and a 30-day life span.

Clinical trials are set to begin shortly and should be completed by the end of the year. The widespread acceptance of PEMF

Research studies in the past 20 years uncovered an extremely important finding: the electric field induced in the body could increase blood flow to the tissues without having to heat the tissues.

devices for physical medicine and rehabilitation, orthopedics, sports injuries, and musculoskeletal conditions belies the fact that other fields of medicine have not investigated them extensively.

Discussion of 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 electrotherapy's mechanism of action and learning that very low power levels, when used over extended periods, can produce equivalent results to the high power, transient treatments associated with cumbersome traditional machines. Lower power levels with efficient antenna designs allow packing the power of electrotherapy into a wearable, affordable patch. This therapy eliminates major barriers for patients considering plastic surgery by reducing the long recovery time caused by the swelling, pain and bruising of the inci-

sion and surgical dissection.

Increasing fluid flow due to its pulsatile action, electrotherapy helps to re-establish 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 RF 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 to the damaged cells. Each signal is pulsed at 1,000 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 compared to 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 re-establish 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 which tight and loose junctions are potentially improved. Nerves may stop receiving pain signals and the inflammatory response may be ameliorated while healing is activated. ■

Brian M. Kinney, MD, FACS, MSME, is a board-certified plastic surgeon with a private practice in Los Angeles. He can be reached at (310) 277-5112.

References

1. Becker R. *Cross Currents: The Promise of Electromedicine, the Perils of Electropollution*. New York, NY: JP Tarcher; 1991.
2. Gerber R. *Vibrational Medicine*. Santa Fe, NM: Bear and Co; 1996.
3. Null G. *Healing with Magnets*. New York, NY: Carroll and Graf; 1998.
4. Polk C, Postow E (eds). *Handbook of Biological*

Effects of Electromagnetic Fields. Boca Raton, Fla: CRC Press; 1996.

5. Selden G, Becker R. *The Body Electric: Electromagnetism and the Foundation of Life*. New York, NY: William Morrow and Co; 1985.
6. Vallbona C, Hazlewood CF, Jurida G. Response of pain to static magnetic fields in postpolio patients: a double blind pilot study. *Arch Phys Med Rehabil*. 1997;78(11):1200-1203.
7. Kaplan EG, Weinstock RE. Clinical evaluation of Diapulse as adjunctive therapy following foot surgery. *J Am Podiatry Assoc*. 1968;58(5):218-221.
8. Constable JD, Scapicchio AP, Opitz B. Studies of the effects of Diapulse treatment of various aspects of wound healing in experimental animals. *J Surg Res*. 1971;11(5):254-257.
9. Pasila M, Visuri T, Sundholm A. Pulsating shortwave diathermy: value in treatment of recent ankle and foot sprains. *Arch Phys Med Rehabil*. 1978;59(8):383-386.
10. Krag C, Taudorf U, Siim E, Bolund S. The effect of pulsed electromagnetic energy (Diapulse) on the survival of experimental skin flaps. a study on rats. *Scand J Plast Reconstr Surg*. 1979;13(3):377-380.
11. Goldin JH, Broadbent NR, Nancarrow JD, Marshall T. The effects of Diapulse on the healing of wounds: a double-blind randomised controlled trial in man. *Br J Plast Surg*. 1981;34(3):267-270.
12. Raji AR, Bowden RE. Effects of high-peak pulsed electromagnetic field on the degeneration and regeneration of the common peroneal nerve in rats. *J Bone Joint Surg Br*. 1983;65(4):478-492.
13. Stiller MJ, Pak GH, Shupack JL, Thaler S, Kenny C, Jondreau L. Portable pulsed electromagnetic field (PEMF) device to enhance healing of recalcitrant venous ulcers: a double-blind, placebo-controlled clinical trial. *Br J Dermatol*. 1992;127(2):147-154.
14. Badea MA, Vasilco R, Sandru D, Paslaru L, Jieanu V, Comorosan S. The effect of pulsed electromagnetic field (diapulse) on cellular systems. *Rom J Physiol*. 1993;30(1-2):65-71.
15. Kanje M, Rusovan A, Siskan B, Lundborg G. Pretreatment of rats with pulsed electromagnetic fields enhances regeneration of the sciatic nerve. *Bioelectromagnetics*. 1993;13(4):353-359.
16. Till M, Gubisch W, Frickert G, Reichert H, Schmidt KH. Postoperative management with pulsed high frequency electromagnetic energy. A clinical study of 38 patients with rhinoseptoplasty [in German]. *Hanchir Mikrochir Plast Chir*. 1993;25(1):26-32.
17. Greenough CG. The effects of pulsed electromagnetic fields on blood vessel growth in the rabbit ear chamber. *J Orthop Res*. 1992;10(2):256-262.
18. Mayrovitz H, Larsen PB. Effects of pulsed electromagnetic fields on skin microvascular blood perfusion. *Wounds*. 1992;4(5):197-202.
19. Mayrovitz H, Larsen PB. A preliminary study to evaluate the effect of pulsed electromagnetic field treatment on lower extremity peri-ulcer skin microcirculation of diabetic patients. *Wounds*. 1995;7(3):90-93.
20. Wilson DH, Jagadeesh P. Experimental regeneration in peripheral nerves and the spinal cord in laboratory animals exposed to a pulsed electromagnetic field. *Paraplegia*. 1976;14(1):12-20.
21. Nicolle FV, Bentall RM. Use of radio frequency pulsed energy in the control of postoperative reaction in blepharoplasty. *Aesth Plast Surg*. 1982;6(3):169-71.
22. Silver H. Reduction of capsular contracture with two-stage augmentation mammoplasty and pulsed electromagnetic energy (Diapulse therapy). *Plast Reconstr Surg*. 1982;69(5):802-808.
23. Roland D, Ferder M, Kothuru R, Faierman T, Strauch B. Effects of pulsed magnetic energy on a microsurgically transferred vessel. *Plast Reconstr Surg*. 2000;105(4):1371-1374.

Pulsed Electromagnetic Field Therapy in Plastic Surgery

Electrotherapy devices, used for decades to reduce pain and swelling following surgery, have undergone significant refinements and have been used successfully in rhytidectomy, liposculpture, laser resurfacing, brow lift, facial fat grafting, rhinoplasty, abdominoplasty, and breast surgery. The devices are currently available as wearable patches. (*Aesthetic Surg J* 2005;25:87-92.)

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



Brian M. Kinney, MD, Los Angeles, CA, is a board-certified plastic surgeon and an ASAPS member.

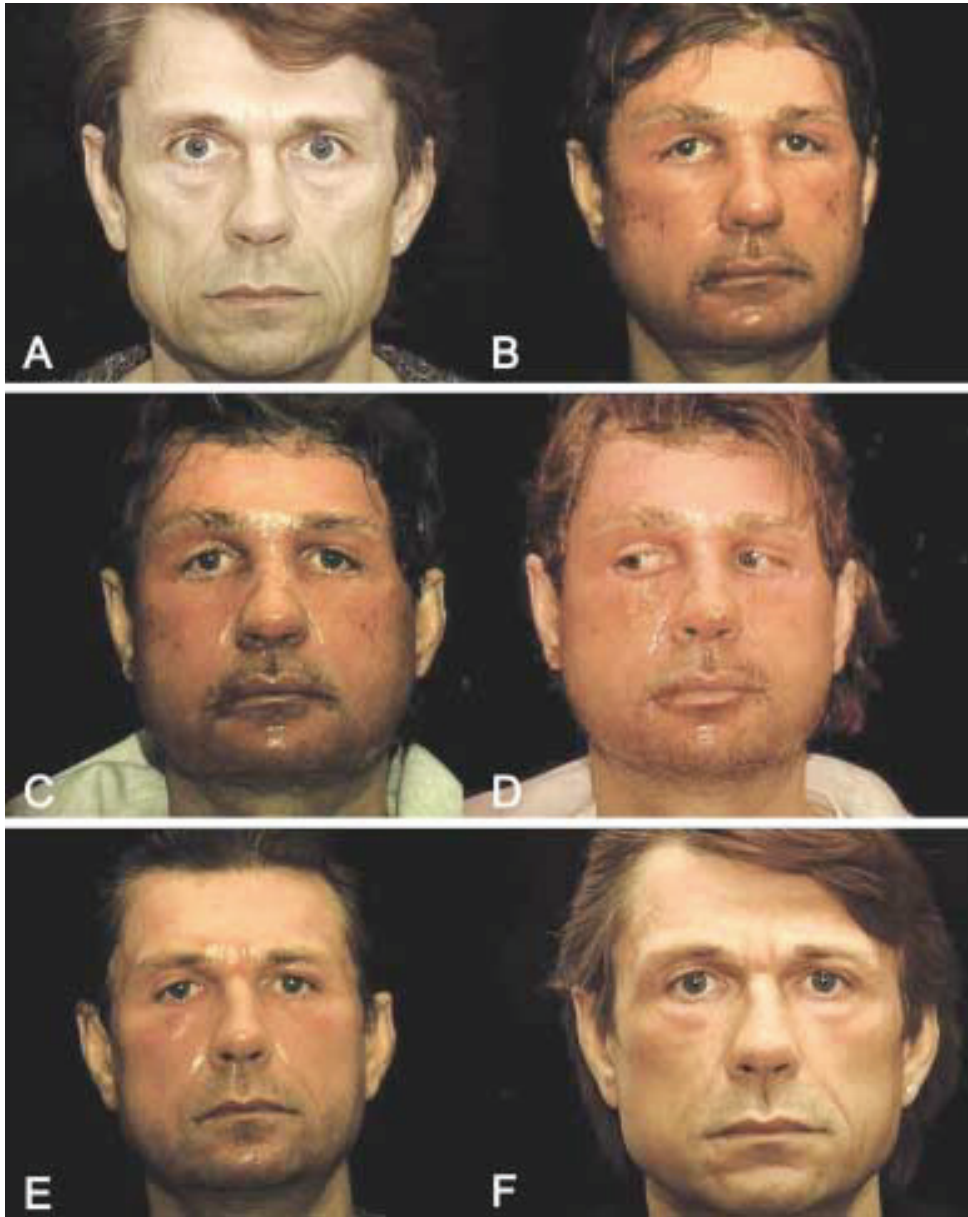


Figure 1. **A**, Preoperative view of a 48-year-old man. **B**, Postoperative view 1 day after full face CO₂ laser resurfacing. Patient was also treated with the SofPulse device administered on the left side of the face only: once preoperatively, once immediately postoperatively, and twice daily on days 1, 2, and 3 after surgery. Opposite side was “treated” with nonfunctioning machine for placebo effect. **C**, Two days after surgery. **D**, Three days after surgery. **E**, Seven days after surgery. **F**, Fourteen days after surgery.

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-



Figure 2. Postoperative view of a 40-year-old woman who has undergone blepharoplasty wearing the 3rd generation ActiPatch on her cheek.

decessor in the following ways: (1) the outer seal was made flexible to better follow body contours, (2) the microchips were further miniaturized, (3) the antenna design was more efficient and created a more enveloping radiated field with better penetration potential, (4) it exhibited an approximate 30-day lifespan, (5) a new crescent shape allowed for following the malar and mandibular contours, and (6) an on-off switch was added for conservation of the power source (Figure 3).

Clinical experience with ActiPatch in ameliorating edema and pain after blepharoplasty, rhytidectomy, abdominoplasty, breast augmentation, and other plastic surgery procedures is accumulating. Numerous personal communications reflect a consistent reduction in edema and a potential reduction in pain with this device. With further study and clinical use, the efficacy of PEMF in plastic surgery may soon become clearer.

Background on Electromagnetic Fields and Health Effects

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*⁴ 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,



Figure 3. Fourth-generation ActiPatch device.

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 vasodilatation. 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.⁵ In another animal model, spinal fusion was improved,⁶ and in another, bone-graft take was improved after a state of non-union.⁷

In the early 1980s, Bental⁸ 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.⁹ In 2000, Roland et al¹⁰ 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.¹¹ Markov et al¹²⁻¹⁴ 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.^{15,16}

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 μ sec 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 (-70mV), 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.¹⁷

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. ■

References

- Vallbona C, Hazlewood CF, Jurida G. Response of pain to static magnetic fields in postpolio patients: a double blind pilot study. *Arch Phys Med Rehabil* 1997;78:1200-1203.
- Kinney B. Electromagnetic Field Stimulation After CO₂ Laser Resurfacing of the Face. Presented at the American Society of Plastic Surgeons Annual Meeting, Los Angeles, CA, October 11, 2000.
- Carraway J, Casas L, DiBernardo B, Coleman S, Dobb R, Garica J. Personal communication.
- National Institute of Environmental Health Sciences, National Institutes of Health Working Group Report: 1998. Portier C, Wolfe M. *Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields*. 1998-3981.
- Yen-Patton GP, Patton WF, Beer DM, Jacobson BS. Endothelial cell response to pulsed electromagnetic fields: Stimulation of growth rate and angiogenesis in vitro. *J Cell Physiol* 1988;134:37.
- Glazer PA, Heilmann MR, Lotz JC, Bradford DS. Use of electromagnetic fields in spinal fusion: A rabbit model. *Spine* 1997;22:2351.
- Bassett CAL, Mitchell SN, Schink MM. Treatment of therapeutically resistant nonunions with bone grafts and pulsing electromagnetic fields. *J Bone Joint Surg Am* 1982;64:1214.
- Frederick VN, Bental RHC. Use of radiofrequency pulsed energy in the control of postoperative reaction in blepharoplasty. *Aesth Plast Surg* 1972;6:169-171.
- Bental RHC. Low-level pulsed radiofrequency fields and the treatment of soft-tissue injuries. *Bioelectrochemistry and Bioenergetics* 1986;16:531-548.
- Roland D, Ferder M, Kothuru R, Faierman T, Strauch B. Effects of pulsed magnetic energy on a microsurgically transferred vessel. *Plast Reconstr Surg* 2000;105:1371-1374.
- Weber RV, Navarro A, Wu JK, Yu HL, Strauch B. Pulsed magnetic fields applied to a transferred arterial loop support the rat groin composite flap. *Plast Reconstr Surg* 2004;114:1185-1189.
- Markov MS, Pilla A. Electromagnetic field stimulation of soft tissues: Pulsed radiofrequency treatment of postoperative pain and edema. *Wounds* 1995;7:143.
- Markov MS. Electric current and electromagnetic field effects on soft tissue: Implications for wound healing. *Wounds* 1995;7:94.
- Itoh M, Montemayor JS, Matsumoto E, Eason A, Lee MHM. Accelerated wound healing of pressure ulcers by pulsed high peak power electromagnetic energy (Diapulse). *Decubitus* 1991;4:24-25, 29-34.
- Callaghan M, Kinnuncan ER, Ceradini DJ, Simon BJ, Gertner GC. Accelerated Wound Healing by Pulsed Electromagnetic Fields. Presented at the American Society of Plastic Surgeons Annual Meeting, Philadelphia, PA, October 13, 2004.
- Strauch B. The Clinical Potential of Pulsed Magnetic Fields. Presented at the American Society of Plastic Surgeons Annual Meeting, Philadelphia, PA, October 8, 2004.
- Sisken BF, Walker J, Orgel M. Prospects on clinical applications of electrical stimulation for nerve regeneration. *J Cell Biochem* 1993;51:404-409.

Bibliography

Cameron MH. Comparison of heat distribution with inductive coil SWD applicator, capacitive plate SWD applicator, microwave diathermy and ultrasound. In: *Physical Agents in Rehabilitation, from Research to*

Practice. Chapter 10, Electromagnetic Radiation. St. Louis: Elsevier Science. 1999. p. 325.

Erdman WJ. Peripheral blood flow measurements during application of pulsed high frequency currents. *Am J Orth* 1960;2:196-197.

Excerpted from Collier's Yearbook 1938, Review of Medicine, in MSN Encarta Encyclopedia 2004.

Excerpted from Collier's Yearbook 1939, Review of Radio, in MSN Encarta Encyclopedia 2004.

Mayrovitz H, Larsen PB. Effects of pulsed electromagnetic fields on skin microvascular blood perfusion. *Wounds* 1992;4:197-202.

Mayrovitz H, Larsen PB. A preliminary study to evaluate the effect of pulsed electromagnetic field treatment on lower extremity periwound skin microcirculation of diabetic patients. *Wounds* 1995;7:90-93.

Mericle RP, et al. Plant Growth Responses. In: *Biological Effects of Magnetic Fields*. New York: Plenum Press; 1964. p. 183-195.

Sharrard WJW. A double-blind trial of pulsed electromagnetic fields for delayed union of tibial fractures. *J Bone Joint Surg* 1990;72B:347-352.

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.

Copyright © 2005 by The American Society for Aesthetic Plastic Surgery, Inc. 1090-820X/\$30.00

doi:10.1016/j.asj.2004.12.001

Volume 25, Number 1