

Inside The NIEHS EMF-RAPID Program: Making Bad Sausage Badly

Andrew A. Marino, PhD, JD
Department of Orthopaedic Surgery
LSU Medical School
Shreveport, Louisiana
1999

Introduction

In 1992, the Congress passed a law requiring the NIEHS to determine whether exposure to the electromagnetic fields (EMFs) from high-voltage powerlines could cause cancer (1). Over the next five years, NIEHS spent sixty-five million dollars on a prospective research project called RAPID, ostensibly designed to answer the question. A half-million of those dollars was granted to me. Working at LSU, I built and validated an electromagnetic-field exposure system for laboratory animals, and over a four-year period conducted four controlled experiments to test my hypothesis that the EMFs could cause cancer by impairing the immune surveillance function of natural killer cells in the blood.

I exposed mice to simulated powerline EMFs, recovered the cells in their immune systems, and measured immune function. I planned to interpret any evidence that the immune system had been affected by EMF exposure as support for my hypothesis. I found such data and sent it to Christopher Portier, the head of the RAPID program, telling him I was preparing to disclose it in four publications. He told me the work was unhelpful because I did not identify the biophysical basis by which the EMFs interacted with the mouse tissues to produce immunosuppression, and I did not prove the immunosuppression caused cancer.

That was when I learned the clever boy had changed the mission of RAPID from the search for evidence that EMFs *could* cause cancer—which is technically possible in the mindset of biomedicine—to a search for evidence that EMFs *did* cause cancer—which is essentially impossible in the mindset of physics. Alas, Portier had the mindset of physics.

By 1998, it became clear that the approximately one hundred other RAPID investigators, almost of whom were economically bonded to the US or European power industry as employees or contractors or consultants, had also produced unhelpful results. But even ignoring their obvious bias and self-interest, those investigators were fated to fail by the NIEHS because it funded only experiments designed within the physics mindset.

Inevitably the EMF-RAPID program degenerated into an aporia, the details of which had to be reviewed publicly because the Congress had required the NIEHS submit a final report. The public review process NIEHS conducted consisted of three symposia. In April 1998, Portier invited me to participate the third of three symposia, *Clinical and In Vivo Laboratory Findings*. My contemporaneous thoughts and impressions regarding what I saw at the symposium are recounted below.

I came away impressed with how easy it was for the NIEHS to waste money and mislead the Congress when that was their intention.

April 6, 1998

Portier is a statistician who specializes in analyzing data to assess risks from environmental pollutants. From a public-relations point of view, he seems well-suited for his job of deciding whether EMFs cause cancer. He projects an aura of keen interest in his task, someone who would listen attentively to the various points of view, but someone who would not act imprudently or allow himself to be seen as a champion of one or other viewpoint. He is small and thin, with a ring of thick brown curly hair that girds his head like a halo. He looks like a balding Leonardo diCaprio. The default position on his face is a mild smirk, mediated by a slight curve of his mouth on the left side.

He has a small staff to help carry out his inquiry, including several people from outside NIEHS but inside the federal government. I think the staff was formed for logistical and political purposes, and that it has no significant responsibility regarding the EMF-cancer issue.

He divided the EMF studies into about 30 areas. In this symposium we will debate studies involving breast cancer, electromagnetic hypersensitivity, immunotoxicology, neurobiology, brain cancer, dosimetry, other cancers, reproduction and development, cancer promotion in rats, melatonin, physical theory, and the healing of bone and nerve. All the scientists here were invited by Portier, and he paid their travel and accommodation expenses. The other participants—lawyers and employees of consulting firms—are here at their own expense.

Portier formed subcommittees to evaluate the research, and assigned about 20 scientists to each subcommittee. I have been assigned to the subcommittees on immunotoxicology, reproduction and development, and bone and nerve healing.

Prior to beginning the subcommittee meetings, Portier asked us all to assemble in an auditorium to listen to his lecture about how we should go about forming our opinions concerning a link between EMFs and cancer. He said, "Experiments don't speak for themselves, we have to interpret them," and explained how he wanted this

interpretation carried out. He listed what he called “key scientific components to hazard evaluation,” which he said were the “quality” of the data, the “magnitude of the effect,” and its “consistency,” “specificity,” and “clarity.” I was struck by the incredible subjectivity of these terms. He repeated his “key scientific components” speech three times during his presentation. This is a bad sign.

At one point he said it was crucial to understand the mechanism by which EMFs could cause biological effects. A little later he said we should try to keep an open mind to the possibility that EMFs cause effects even though we don’t understand the mechanism. But near the end of his talk he cut his own tow rope saying, “Finding statistically significant biological effects is not enough, the effects have to be something you believe.”

Immunotoxicology is my first subcommittee meeting; it will begin at 1:30 p.m. The seating is a square arrangement of tables, with the subcommittee members assigned to specific locations. The chair is a young woman from Switzerland named Meike Mevissen. She is flanked by two subcommittee members whom Portier chose to make notes of the meeting; he calls them “rapporteurs.” They are being paid \$150, which is in addition to the \$39 he is paying the rest of us. Unfortunately, both rapporteurs work for the power companies. This is another sign that things will go badly here.

Each subcommittee member’s seat is marked with a placard containing his name, affiliation, and the logo of the NIEHS. The information can be read by everybody, regardless of where they are sitting, because it is written on both sides of the placard. Colored dots on each participant’s name badge correspond to colors posted on the wall outside the rooms where the subcommittees meet. The meeting rooms all have names, but the participants who can’t read English need only follow the colors. I’m pink and gray. Coffee, cokes, tea, and bottled water are available without limit, but the supply of muffins and cookies is quite limited.

Including Portier, there are 22 people on the subcommittee. With the exception of Louis Slesin, the others are apparently all scientists; most are associated one way or the other with the power industry. Because of his newsletter, Slesin is the only person here who can publicize what’s happening. Wherever Slesin goes, Portier is not far behind.

Portier gave us fourteen studies (2–15) and more or less said that our job was to decide whether they conclusively proved that powerline EMFs were toxic to the immune system. I found the studies dreadfully poor and irrelevant. They included papers by House, Mandeville, and Mevissen. I am the only member of the subcommittee who received RAPID money to perform studies dealing directly with the immunotoxicology of powerlines EMFs, but Portier didn’t mention or circulate any of the data I sent him.

I feel like I'm a student in my wife's elementary-school class. Whenever Portier speaks, we all listen. When he wants something written down, the rapporteurs write it down. When he wants to discuss something in detail, we talk about it endlessly. When he is finished, we are finished. The discussions are superficial. "Did they measure such-and-such?" one member asked another member. "Yes, but there was no effect." "Okay, write down 'no effect'," Portier said, and we moved on. There is no proportion between the seriousness of our endeavor and the process by which it is being carried out.

It is easy to understand why a sense of obsequiousness pervades the room. Who is here? People from his staff. People from other federal agencies. Foreign scientists. Industry scientists. And people like me, NIEHS grantees. Portier is in a position to get exactly what he wants from the meeting. If he wants us to take a stand against beer in cans, we will do so.

The most pathetic people here are the foreign scientists, particularly Mevissen and Mandeville. I can imagine how thrilled they must have been to have received money from the NIEHS to perform laboratory studies, and how excited they must have been to be asked to come to the United States and participate in the symposium.

Portier is full of contradictions and inconsistencies. He says he doesn't want the sub-committees to be a consensus-seeking committee, but rather a committee that provides him with a full range of opinions. Nevertheless, every signal he sends is that he wants a consensus.

I asked Portier, "Suppose we had two studies, one of which showed that the measured parameter was statistically significantly increased due to EMF exposure, and a second independent replicate that showed the opposite result (statistically significant decrease). Are those results inconsistent?" Yes, to me those results are inconsistent," he said. "Well," I said, "suppose my hypothesis was that EMFs affected the parameter, and that I had no hypothesis whatsoever regarding the direction of the effect? That is, my idea is that EMFs will be transduced and that, because the system is nonlinear, the dependent variable may be increased or decreased (because of sensitivity to initial conditions commonly found in nonlinear systems). Wouldn't you agree that, with this model and this hypothesis, if the postulated results were observed, then the results should properly be labeled 'consistent'?" He thought for a few moments and said, "Let's put Andy's concern aside and go on."

He said my question was "too theoretical." But it wasn't theoretical, what I described happens all the time. After gassing about the studies for more than four hours, Portier made a motion to conclude, "The studies lack consistency, and include only a limited number of assay endpoints. For this reason, it is not possible at present to draw firm conclusions regarding the potential effect of EMF exposure on either short-term or long-term human health." Portier had obviously done nothing more than discover hot water.

Before we voted, I pressed Portier to explain what he meant by “firm conclusions.” “How does anybody know whether a conclusion is firm? What do you want us to understand by that term?” He replied, “Andy, firm is firm.” The resolution was approved unanimously.

April 7, 1998

Today is the meeting of the reproduction/development subcommittee. There were twenty-three symposium participants on this subcommittee. Slesin was assigned to a cancer subcommittee, and Portier followed him over there, leaving four people in charge of this subcommittee. There is a guy from Finland named Juutilainen, who is clearly having a good time. In several ways he is like all of the foreign scientists at this symposium. In their home countries, nobody takes seriously the possibility that powerline EMFs could cause cancer, so he talks about the studies more or less as if everything here is a big game.

As best I can tell, there are fewer power company people on this subcommittee. Unfortunately, two of them, Mary Ellen O’Connor and Bernadette Ryan, are in charge of the subcommittee. The fourth leader is a guy named Neil Chernoff, who works for the Environmental Protection Agency. I like him. He really seems honest. The problem is that his method for deciding whether something causes adverse effects on reproduction and development is pathetically insensitive. Mostly he works with pesticides. It’s ridiculous to use those methods to evaluate EMFs, but that’s what he is doing. That’s all he knows. I suppose that’s why he’s here.

Although Portier isn’t here, his fingerprints are all over the meeting. He provided twenty papers (16–45) for us to discuss, most written by power-company scientists. Without exception the work is incomplete and/or rigged by the power industry which paid for it. No papers that would point to a potential problem will even be considered. Not surprisingly, none of my papers involving reproduction and development were included.

Effects were “definite” or there were no effects. Nothing in between. At one point Portier appeared and called for a vote on whether the Project Henhouse studies showed that EMFs “could probably affect skeletal development in eggs.” I asked Portier to clarify whether he meant “probably definite” or “definitely probable.” Everybody laughed, but I wasn’t trying to be funny. The motion that passed said that the subcommittee evaluated the studies and considered them to be “equivocal.” I couldn’t get anyone to define “equivocal.”

Chernoff, however, speaking as if he were a schoolboy or a layman, said “definite” was the sort of thing that was easy to understand. If, for example, a pesticide level is too high then the frogs and fish are abnormal. If the frogs and fish are normal, then the pesticide level is safe. He said, in effect, “It’s that simple.”

Chernoff strikes me as the kind of guy you'd like to have for a neighbor. He would come over and help you move a refrigerator. He would attend your mother's funeral even though he never knew her, simply because you were his friend. He would share with you the tomatoes in his garden. He doesn't kick his dog. His TV isn't too loud. His kids don't have pierced tongues or pink hair. It's not that he isn't a nice guy. He simply isn't qualified.

No one has a clue about how the results of groups of studies should be generalized to draw an overall conclusion. Some subcommittee members are sensitive, thoughtful persons; I think their views regarding scientific reasoning can be shot down, nevertheless they hold these views sincerely and with an open mind. Real dialogue, however, never occurs because it seems impolite to disagree with someone.

Should investigators search for EMF bioeffects under the assumption that if they occur they can be imputed to human beings, and taken as evidence of risk? The power-company spokesmen argue that the committee should look for biological effects in animals and that, if they are found, determine which of those effects are abnormal, and which of those could be imputed to people, and which of those constitute evidence of risk. The word "abnormal" is used a lot. It seems at first glance to have a specific meaning, but no one can define the term.

There was much confusion regarding what it means to say that an observed effect was "small." Committee members always seem to avoid defining terms that have decisional impact. Terms like "robust," or "equivocal," or "controversial," or "inconsistent," or "cause," were never defined, despite their enormous importance in conveying the committee's conclusions.

Like good little soldiers, we voted unanimously that EMFs had not been "conclusively" shown to cause skeletal abnormalities in chick eggs. We then voted unanimously that EMFs had not been "conclusively" proven to cause birth defects in animals. Most of the committee members voted to say that the results were "equivocal."

April 8, 1998

Today is the meeting of the tissue-healing subcommittee. Slesin was assigned to this committee, and Portier is back as a member. This is the strangest of the three committees. The power companies are represented, but Portier put an orthopaedic surgeon named Roy Aaron, and a laboratory scientist named Ken McLeod in charge of the meeting. My impression is that, like most of us, he has contempt for the research done by the Electric Power Research Institute. Even so, the law that created RAPID requires that the NIEHS cooperate with the power industry in seeking the truth about

health hazards of EMFs. Consequently, Portier's hands are tied, and the industry is inside the tent.

Of the twenty papers (46–65) Portier gave us to debate, Aaron and McLeod have written five; none of the 20 papers I published on the topic were included. I am not surprised.

Portier said that he “wants to capture diversity of opinion,” but how do you do that when you choose who is attending the meeting, tell them what to consider, and arrange for the people who will write the history? What you get from that process, I think, is what you want.

The meeting was relatively brief. McLeod and Portier steered the committee toward the conclusion that the use of EMFs for treating bone disease was a well-established clinical procedure approved by the FDA, but that those EMFs had nothing to do with powerline EMFs. How absurd!

Reflections While Flying Home

Portier must have known there was a political history regarding the EMF issue, and regarding why the Congress had passed the EMF law. If he had looked at the reasons for the failures of the other blue-ribbon committees, he might have remedied at least some of them.

What could he have done? First, recognize that there will be winners and losers when the question whether EMFs affect human health is finally answered. An affirmative answer will cost the power companies money. A negative answer will mean that some of the people who live beside powerlines will get sick and die because of the powerlines.

There needs to be some procedure whereby people on each side of an issue can challenge the reasoning of the other guys. The alternative to an adversarial process is a consensus process, and we already know that consensus processes don't work in the EMF area — that's why Congress passed the EMF law. What did Portier do? He brought together a handful of scientists and forced the process toward a consensus, which guaranteed that the power companies would win.

As I sat in the meeting, I thought why the hell should I talk? This guy doesn't want to hear what I've got to say. All of the papers he assigned me to read were crap. It simply doesn't matter what is in Portier's final report. He could exonerate EMFs, indict them, or take any other position. The point is that the process by which he has decided is fatally flawed. Decisions affecting the public interest ought not be made by one man. No one is that good.

What will be the final result of the RAPID program? A poorly documented, diffuse, vague, wishy-washy report in which terms are not defined, procedures are not specified, and Portier's *ipse dixit* is presented as fact. Congress' attempt to resolve the question of health risks of powerlines by assigning the question to the NIEHS is doomed to fail. NIEHS will never make a decision that is adverse to the power industry.

References

In my opinion, essentially all the publications in this list are worthless or irrelevant or worse, and those are the reasons Portier selected them.

1. The National Institute for Environmental Health Sciences (NIEHS) and the Department of Energy coordinated the implementation of the Electric and Magnetic Fields (EMF) Research and Public Information Dissemination (RAPID) Program. EMF-RAPID was established by the 1992 Energy Policy Act, Section 2118 for Public Law 102-486, which was signed by the President in October 1992.
2. Conti, P. *et al.* A role for Ca^{2+} in the effect of very low frequency electromagnetic field on the blastogenesis of human lymphocytes. *FEBS Lett.* 181:28–32, 1985.
3. Conti, P., Gigante, G.E., Alesse, E., Cifone, M.G., Fieschi, C., Reale, M. and Angeletti, P.U. Reduced mitogenic stimulation of human lymphocytes by extremely low frequency electromagnetic fields. *FEBS Lett.* 162:156–160, 1983.
4. de Seze, R., Bouthet, C., Tuffet, S., Deschaux, P., Caristan, A., Moreau, J.M. and Veyret, B. Effects of time-varying uniform magnetic fields on natural killer cell activity and antibody response in mice. *Bioelectromagnetics* 14:405–412, 1993.
5. House, R.V., Ratazczak, H.V., Gauger, J.R., Johnson, T.R., Thomas, P.T. and McCormick, D.L. Immune function and host defense in rodents exposed to 60-Hz magnetic fields. *Fund. Appl. Toxicol.* 34:228–239, 1996.
6. Lee, J.M., Stormshak, F., Thompson, J., Hess, D.L. and Hefeneider, S. Studies of melatonin, cortisol, progesterone, and interleukin-1 in sheep exposed to EMF from a 500-KV transmission line, in *The Melatonin Hypothesis: Breast Cancer and the Use of Electric Power*, R.G. Stevens, B.W. Wilson, and L.E. Anderson, Editors. Battelle Press: Columbus, OH. pp. 391–427.
7. McLean, J.R., Stuchley, M.A., Mitchell, R.E., Wilkinson, D., Yang, H., Goddard, M., Lecuyer, D.W., Schunk, M., Callary, E. and Morrison, D. Cancer promotion in a mouse-skin model by a 60-Hz magnetic field: II. Tumor development and immune response. *Bioelectromagnetics* 12:273–287, 1991.
8. Mevissen, M., Häussler, M., Szamel, M., Emmendörffer, A., Thun-Battersby, S. and

- Löscher, W. Complex effects of long-term 50 Hz magnetic field exposure *in vivo* on immune functions in female Sprague-Dawley rats depend on duration of exposure. *Bioelectromagnetics* 19:259–270, 1998.
9. Mevissen, M., Lerchl, A., Szamel, M. and Löscher, W. Exposure of DMBA-treated female rats in a 50-Hz micro tesla magnetic field: effects on mammary tumor growth, melatonin levels, and T-lymphocyte activation. *Carcinogenesis* 17:903–910, 1996.
 10. Morandi, M.A., Del Rio, J.A., Caren, R.P. and Caren, L.D. Effects of short-term exposure to 60 Hz electromagnetic fields on interleukin 1 and interleukin 6 production by peritoneal exudate cells. *Life Sci.* 54:731–738, 1994.
 11. Murthy, K.K., Rogers, W.R. and Smith, H.D. Initial studies of the effects of combined 60-Hz electric and magnetic field exposure on the immune system of non-human primates. *Bioelectromagnetics Suppl.* 3:93–102, 1995.
 12. Ramoni, C., Dupuis, M.L., Vecchia, P., Polichetti, A., Petrini, C., Bersani, F., Capri, M., Cossarizza, A., Franceschi, C. and Grandolfo, M. Human natural killer cytotoxic activity is not affected by *in vitro* exposure to 50 Hz sinusoidal magnetic fields. *Int. J. Radiat. Biol.* 68:693–705, 1995.
 13. Selmaoui, B., Bogdan, A., Auzeby, A., Lambrozo, J. and Touitou, Y. Acute exposure to 50-Hz magnetic field does not affect hematologic or immunologic functions in healthy young men: A circadian study. *Bioelectromagnetics* 17:364–372, 1996.
 14. Tenforde, T.S. and Shifrine, M. Assessment of the immune responsiveness of mice exposed to a 1.5 Tesla stationary magnetic field. *Bioelectromagnetics* 5:443–446, 1984.
 15. Tremblay, L., Houde, M., Mercier, G., Gagnon, J. and Mandeville, R. Differential modulation of natural and adaptive immunity in Fischer rats exposed for 6 weeks to a 60 Hz linear sinusoidal continuous-wave magnetic field. *Bioelectromagnetics* 17:373–383, 1996.
 16. Berman, E., Chacon, L., House, D., Koch, B.A., Koch, W.E., Leal, J., Løvtrup, S., Mantiply, E., Martin, A.H., Martucci, G.I., Mild, K.H., Monahan, J.C., Sandström, M., Shamsaifar, K., Tell, R., Trillo, M.A., Ubeda, A. and Wagner, P. Development of chicken embryos in a pulsed magnetic field. *Bioelectromagnetics* 11:169–187, 1990.
 17. Brent, R.L., Gordon, W.E., W.R., Bennett and D.A., Beckman. Reproductive and teratologic effects of electromagnetic fields. *Reprod. Toxicol.* 7:535–580, 1993.
 18. Chernoff, N., Rogers, J.M. and Kavet, R. A review of the literature on potential reproductive and developmental toxicity of electric and magnetic fields. *Toxicology* 74:91–126, 1992.

19. Cox, C.F., Brewer, L.J., Raeman, C.H., Schryver, C.A., Child, S.Z. and Carstensen, E.L. A test for teratological effects of power frequency magnetic fields on chick embryos. *IEEE Trans. Biomed Eng.* 40:605–610, 1993.
20. Frolen, H., Svedenstal, B.M. and Paulsson, L.E. Effects of pulsed magnetic fields on the developing mouse embryo. *Bioelectromagnetics*. 14:197–204, 1993.
21. Handcock, M.S. and Kolassa, J.E. Statistical review of the henhouse experiments: The effects of a pulsed magnetic field on chick embryos. *Bioelectromagnetics* 13:429–433, 1992.
22. Huuskonen, J., Juutilainen, J. and Komulainen, H. Effects of low-frequency magnetic fields on fetal development in rats. *Bioelectromagnetics* 14:205–213, 1993.
23. Huuskonen, H., Lindbohm, M.L and Juutilainen, J. Teratogenic and reproductive effects of low-frequency magnetic fields. *Mutat. Res.* 410:167–181, 1998.
24. Juutilainen, J., Huuskonen, H. and Komulainen, H. Increased resorptions in CBA mice exposed to low-frequency magnetic fields: an attempt to replicate earlier observations. *Bioelectromagnetics* 18:410–417, 1997.
25. Kowalczyk, C.I., Robbins, L., Thomas, J.M., Butland, B.K. and Saunders, R.D. Effects of prenatal exposure to 50 Hz magnetic fields on development in mice: I. Implantation rate and fetal development. *Bioelectromagnetics* 15:349–361, 1994.
26. Mevissen, M., Buntenkötter, S. and Löscher, W. Effects of static and time-varying (50 Hz) magnetic fields on reproduction and fetal development in fetal rats. *Teratology* 50:229–237, 1994.
27. Rommereim, D.N., Rommereim, R.L., Sikov, M.R., Buschbom, R.L. and Anderson, L.E. Reproduction, growth, and development of rats during chronic exposure to multiple field strengths of 60 Hz electric fields. *Fund. Appl. Toxicol.* 14:608–621, 1990.
28. Rommereim, D.N., Rommereim, R.L., Miller, D.L., Buschbom, R.L. and Anderson, L.E. Developmental toxicology evaluation of 60 Hz horizontal magnetic field in rats. *Appl. Occup. Environ. Hygiene* 11:307–312, 1996.
29. Ryan, B.M., Mallett, E., Johnson, T.R., Gauger, J.R. and McCormick, D.L. Developmental toxicity study of 60 Hz (power frequency) magnetic field in rats. *Teratology* 54:73–83, 1996.
30. Sienkiewicz, Z.J., Robbins, L., Haylock, R.G. and Saunders, R.D. Effects of prenatal exposure to 50 Hz magnetic fields on development in mice: II. Postnatal development and behavior. *Bioelectromagnetics* 54:363–375, 1994.

31. Stuchly, M.A., Ruddick, J., Villeneuve, D., Robinson, K., Reed, B., Lecuyer, D.W., Tan, K. and Wong, J. Teratological assessment of exposure to time-varying magnetic field. *Teratology* 38:461–466, 1988.
32. Ubeda, A., Trillo, M.A., Chacón, L., Blanco, M.J. and Leal, J. Chick embryo development can be irreversibly altered by early exposure to weak extremely-low-frequency magnetic fields. *Bioelectromagnetics* 15:385–398, 1994.
33. Wiley, M.J., Corey, P., Kavet, R., Charry, J., Harvey, S., Agnew, D. and Walsh, M. The effects of continuous exposure to 20-kHz sawtooth magnetic fields on the litters of CD-1 mice. *Teratology* 46:391–398, 1992.
34. Zusman, I., Yaffe, P., Pinåus, H. and Ornoy, A. Effects of pulsing electromagnetic fields on the prenatal and postnatal development in mice and rats: *in vivo* and *in vitro* studies. *Teratology* 42:157–170, 1990.
35. Anisimov, V.N., Zabezhinskiĭ, M.A., Muratov, E.I., Popovich, I.G., Arutiunian, A.V., Oparina, T.I. and Prokopenko, V.M. [Effect of irradiation from a personal computer video terminal on estrus function, melatonin level, and free radical processes in laboratory rodents] (in Russian). *Biofizika* 43:165–170, 1998.
36. Aaron, R.K. and Ciombor, D.M. Acceleration of experimental endochondral ossification by biophysical stimulation of the progenitor cell pool. *J. Orthop. Res.* 14:582–589, 1996.
37. Aaron, R.K., Ciombor, D.McK., Keeping, H. and Polk, C. Power frequency field effects on cell differentiation coincident with an increase in TGFbeta expression. *Trans. BEMS*, 1998.
38. Buch, F., Jonsson, B., Mallmin, H. and Kalebo, P. The quantification of bone tissue regeneration after electromagnetic stimulation. *Arch. Orthop. Trauma Surg.* 112:75–78, 1993.
39. Borsalino, G., Bagnacani, M., Bettati, E., Fornaciari, F., Rocchi, R., Uluhogian, S., Ceccherelli, G., Cadossi, R. and Traina, G.C. Electrical stimulation of human femoral intertrochanteric osteotomies. *Clin. Orthop. Rel. Res.* 237:256–263, 1988.
40. Eyres, K.S., Saleh, M. and Kanis, J.A. Effects of pulsed electromagnetic fields on bone formation and bone loss during limb strengthening. *Bone* 18:505–509, 1996.
41. Greenough, C.P. The effect of pulsed electromagnetic fields on blood vessel growth in the rabbit ear chamber. *J. Orthop. Res.* 10:256–262, 1992.
42. Ieran, M., Zaffuto, S., Bagnacani, M., Annovi, M., Moratti, A. and Cadossi, R. Effect of low frequency pulsing electromagnetic fields on skin ulcers of venous origin

- in humans: A double-blind study. *J. Orthop. Res.* 8:276–282, 1990.
43. Kanje, M., Rusovan, A., Sisken, B. and Lundborg, G. Pretreatment of rats with pulsed electromagnetic fields enhances regeneration of the sciatic nerve. *Bioelectromagnetics* 14:353–359, 1993.
 44. Mammi, G.I., Rocchi, R., Cadossi, R., Massari, L. and Traina, G.C. The electrical stimulation of tibial osteotomies. Double-blind study. *Clin. Orthop. Rel. Res.* 288:246–253, 1993.
 45. Martin, R.G. and Gutman, W. The effect of electric fields on osteoporosis of disuse. *Calc. Tiss. Res.* 25:23–27, 1978.
 46. McLeod, K.J. and Rubin, C.T. Frequency specific modulation of bone adaptation by induced electric fields. *J. Theor. Biol.* 145:385–396, 1990.
 47. McLeod, K.J. and Rubin, C.T. The effect of low-frequency electrical fields on osteogenesis. *J. Bone Joint Surg.* 74:920–929, 1992.
 48. McLeod, K.J. and Rubin, C.T. *In vivo* sensitivity of bone tissue to electromagnetic field exposure. *Science*. Submitted, 1998.
 49. O'Brien, W.J., Murray, H.M. and Orgel, M.G. Effects of pulsing electromagnetic fields on nerve regeneration correlation of electrophysiologic and histochemical parameters. *J. Bioelectricity.* 3:33–40, 1984.
 50. Ottani, V., DePasquale, V., Govoni, P., Franchi, M., Zaniol, P. and Ruggeri, A. Effects of pulsed extremely-low-frequency magnetic fields on skin wounds in the rat. *Bioelectromagnetics.* 9:53–62, 1988.
 51. Pienkowski, D., Pollack, S.R., Brighton, C.T. and Briffith, N.J. Low-power electromagnetic stimulation of osteotomized rabbit fibulae: A randomized, blinded study. *J. Bone Joint Surg.* 76:489–501, 1994.
 52. Rusovan, A., Kanje, M. and Mild, K.H. The stimulatory effect of magnetic fields on regeneration of the rat sciatic nerve is frequency dependent. *Exp. Neurol.* 117:81–84, 1992.
 53. Sharrard, W.J.W. A double-blind trial of pulsed electromagnetic fields for delayed union of tibial fractures. *J. Bone Joint Surg.* 72:347–355, 1990.
 54. Sisken, B.F., Kanje, M., Lundborg, G., Herbst, E. and Kurtz, W. Stimulation of rat sciatic nerve regeneration with pulsed electromagnetic fields. *Brain Res.* 485:309–316, 1989.
 55. Stiller, M.J., Grace, H.P., Shupak, J.H., Thaler, S., Kenny, C. and Jondreau, L. A portable pulsed electromagnetic field (PEMF) device to enhance healing of

recalcitrant venous ulcers: A double-blind, placebo-controlled clinical trial. *Br. J. Dermatol.* 127:147-154, 1992.