

Current Concepts in Electrotherapy

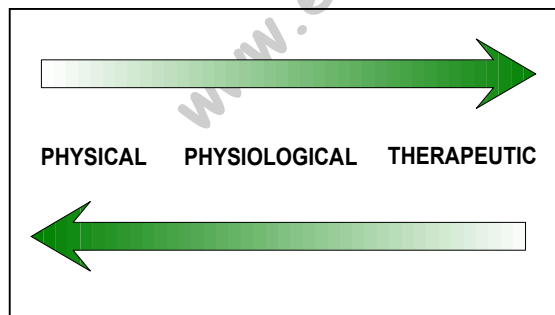
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The Changing Nature of Electrotherapy

Much as electrotherapy has been a component of physiotherapy practice since the early days, its delivery has changed remarkably and continues to do so. The most popular modalities used these days are in many respects quite dissimilar to those of 60 or more years ago.

Modern electrotherapy practice needs to be evidence based and used appropriately. Used at the right place, at the right time for the right reason, it has phenomenal capacity to do good. Used unwisely, it will either do no good at all, or worse still, make matters worse. The skill of electrotherapy is to make the appropriate clinical decision as to which modality to use and when.

A simple, but effective clinical decision making model (represented in the diagram below) can be utilised.



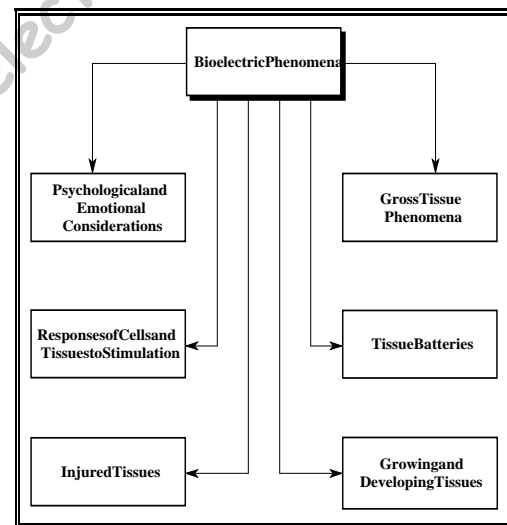
All electrotherapy modalities (with the exception of biofeedback) involve the introduction of some physical energy into the system. This energy brings about one or more physiological changes, which are used for therapeutic benefit. Clinically, it is probably more useful to work the model in reverse - determine first the nature of the problem to be addressed. Then establish the physiological changes that need to take place in order to achieve these effects. Lastly, the modality which is most able to bring about the changes in the tissue(s) concerned should be a relatively straightforward decision.

The Body Bioelectric

The electrical activity of the body has been used for a long time for both diagnostic and monitoring purposes in medicine, largely in connection with the 'excitable' tissues. Examples include ECG, EMG, EEG. More recent developments have begun to look at the tissues which were not regarded as excitable, but in which, endogenous electrical activity has been demonstrated. The endogenous electrical activity of the body arises from a variety of sources, some of which are well documented whilst others remain more obscure in their origins & control mechanisms (Offner 1984, Leonasio and Chen 1987). The relationship between endogenous electrical activity (not exclusively potentials), injury & healing have been researched in several areas of clinical practice.

These investigations appear to follow three main themes:

1) that the endogenous electrical activity of the body can be used as an indicator of a particular pathological



process without necessarily attributing a cause/effect relationship. (Edelberg 1971, 1977 Marino et al. 1989, Woodrough et al. 1975).

2) that the endogenous electrical activity of the body acts as an initiator, control mechanism or modulator of the post embryonic growth & healing processes. (Becker et al. 1962, Becker 1967, 1974, Borgens 1982, Foulds and Barker 1983, Hinkle et al. 1981, Illingworth and Barker 1980, Patel and Poo 1982).

3) that by enhancing the endogenous electrical activity of the damaged tissues, the growth and/or healing processes can be stimulated or enhanced. (Brighton et al. 1981, Brown et al. 1988, Carley and Wainapel 1985, Kincaid 1989, Kloth and Feedar 1988, Reed 1988, Rowley et al. 1974, Wheeler et al. 1969).

The subject of endogenous bioelectricity is somewhat larger than can be detailed here, though what follows may provide a useful overview.

Tissue batteries are found in bone, skin and muscle and nerve, and probably other musculoskeletal tissue. These tissues seem to produce a potential difference between various parts of the tissue, and this potential is different in the injured and non injured situations. Bone exhibits piezoelectric potentials, streaming potentials and steady potentials (Fukada 1984, Pollack et al. 1984, Friedenberg et al. 1973, Borgens 1984, Chakkalakal et al. 1988). In the skin, there are a wealth of bioelectric phenomena, but particularly in this context, Skin Potential Levels, Responses to psychological stimulation and changes associated with injury and pathology (Barker et al. 1982, Edelberg 1968, Foulds and Barker 1983, Christie and Venables 1971, Millington and Wilkinson 1983, Vanable 1989). Similar potentials have been shown in muscle (Betz et al. 1984, 1986) and collagenous based tissues (Anderson and Eriksson 1968, Athenstaedt 1970).

Growing and Developing Tissues exhibit numerous very interesting bioelectric activities. Amphibian limb regeneration studies (Borgens 1982, Becker 1961, Siskin 1983), mammalian partial limb regeneration (Neufeld 1989, Becker 1972) and rabbit ear regeneration (Chang and Snellen 1982, Goss 1981) have been reasonably well investigated. Fingertip amputation and regeneration in children provided the focus for an interesting study (Illingworth and Barker 1980). In addition, there has been considerable work into electric effects in embryology and morphogenesis (Robinson 1989, Jaffe 1981, 1986, Jaffe and Nuccitelli 1977, Nuccitelli and Erickson 1983)

Injured Tissues are reported to be electrically active, and this activity appears to be more than just an epiphenomenon. The exact origin of the injury potential remains debatable (Nordenstrom 1983, Thakor and Webster 1978, Becker 1967, 1974). Tissues which have demonstrable electrical changes on injury include Skin (Barker et al. 1982, Foulds and Barker 1983, Jaffe and Vanable 1984, Vanable 1989), Bone (Friedenberg et al. 1973, Lokietek et al. 1974, Chakkalakal et al. 1988, Borgens 1984), Muscle (Lokietek et al. 1974, Betz et al. 1984), Nerve (Shibib et al. 1988a,b, Borgens and McCaig 1989), Blood vessels (Sawyer et al. 1953) and several others. Ulcers and other skin wounds appear to have electrical links (Carley and Wainapel 1985, Rowley 1985, Griffin et al. 1991, Kloth and Feedar 1988, Reed 1988).

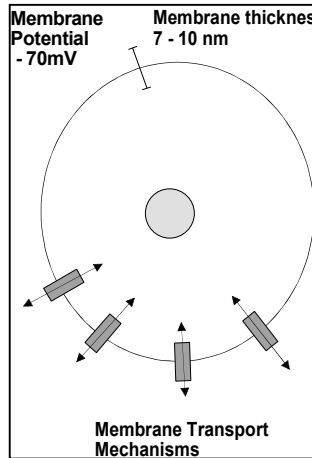
Cells which are electrically responsive include FIBROBLASTS (Vanable 1989, Weiss et al. 1990, Erickson and Nuccitelli 1984, Dunn 1988), EPIDERMAL CELLS (Brown et al. 1988, Brown et al. 1989, Luther and Peng 1983, Robinson 1985, Vanable 1989), MACROPHAGES (Vanable 1989), NEUTROPHILS AND ERYTHROCYTES (Becker and Murray 1967), BONE AND ARTICULAR CARTILAGE (Brighton et al. 1981, Rubinacci and De Loecker 1988, Norton et al. 1977, Okihana et al. 1985), TENDON (Stanish et al. 1985), LIGAMENT (Akai et al. 1988, Frank et al. 1983).

Psychological and Emotional factors include a wide range of electrodermal activity (Edelberg 1968, Edelberg 1971, 1977, Christie 1981), links with hypnosis and sleep (Becker 1974, Leonesio and Chen 1987), electroanalgesia (Becker 1990), some voluntary control may be possible using biofeedback (Nishimura and Nagumo 1985, Volow et al. 1979), and finally, possible links with psychiatric disorders (Venables 1978, Williamson et al. 1985).

The Bioelectric Cell

Every living cell has a membrane potential (of about -70mV), with the inside of the cell being negative relative to its external surface. The cell membrane potential is strongly linked to the cell membrane transport mechanisms in that much of the material that passes across the membrane is ionic (charged particles), thus if the movement of charged particles changes, then it will influence the membrane potential. Conversely, if the membrane potential changes, it will influence the movement of ions.

Relative to the size of the cell, the membrane potential is massive. The membrane is, on average 7-10 nm thick (a nanometre is a thousandth of a millionth of a metre). The equivalent voltage is somewhere in the order of 10 million volts per metre (which is reasonably impressive!).

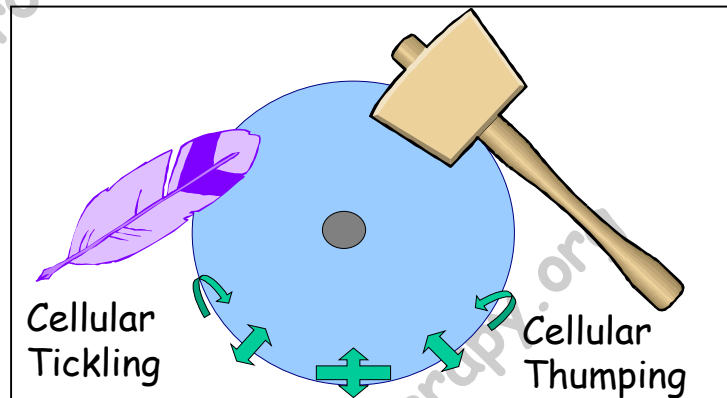


Approaches to Electrotherapy

Given the natural energy systems of the living cell, there are two approaches to the application of electrotherapy modalities. Firstly, one can deliver sufficient energy to overcome the energy of the membrane and thereby force it to change behaviour. Secondly, one can deliver much smaller energy levels, and instead of forcing the membrane to change behaviour, it can be 'tickled'. Low energy membrane tickling produces membrane excitement, and membrane excitement in turn produces cellular excitement. Excited cells do the same job as bored cells, but they do so at a rather harder and faster rate. It is the excited cells which do the work rather than the modality itself.

In addition to considering the endogenous potentials, there are several exciting aspects of this work which are of more direct relevance to physiotherapists and others working in the rehabilitation field. Most obviously is the possible relationship between the endogenous bioelectric activity and the energy inputs (in a variety of forms) by means of electrotherapy treatments.

There has been a general trend over the last few years, for the energy levels applied in electrotherapy to be reduced. Ultrasound treatment doses are significantly lower (in terms of US intensity & pulse ratios) than previously thought to be effective. Pulsed Shortwave employs power levels which are several orders of magnitude lower than those applied during continuous shortwave therapy. Laser therapy is another such example of the clinical application of low energy levels to damaged, irritated or traumatised tissues.



The over-riding principle of these interventions, is that the application of a low power/energy modality can enhance the natural ability of the body to stimulate, direct and control the healing & reparative processes. Instead of 'hitting the cells' with high energy levels, and thereby forcing them to respond, the low energy applications are aiming to tickle the cells, to stimulate them into some higher activity level and thus use the natural resources of the body to do the work.

This philosophy can be applied to many areas of therapy, not exclusively to electrotherapy - though it does marry well with the subject. Several areas are currently being investigated in this respect, including the possibility of using the endogenous bioelectric activity as a feedback mechanism to enable the patient to take (natural) control of their healing, measurement of the physiological effects of a variety of electrotherapy modalities (including Pulsed Shortwave, Interferential), and an initial investigation which considers the relationship between endogenous bioelectric activity and manual/manipulative therapies.

References

- Barker et al. (1982). "The glabrous epidermis of cavies contains a powerful battery." *Am J Physiology* 242: R358-R366.
- Betz et al. (1986). "A steady electric current at the rat neuromuscular synapse." *Progress in Clinical and Biological Research* 210: 205-212.
- Betz et al. (1984). "Physiological basis of a steady endogenous current in rat lumbrical muscle." *J Gen Physiol* 83: 175-192.
- Borgens, R (1984). "Endogenous ionic currents traverse intact and damaged bone." *Science* 225: 478-482.
- Chakkalakal et al. (1988). "Epidermal and endosteal sources of endogenous electricity in injured canine limbs." *IEEE Trans Biomed Eng* 35: 19-29.
- Christie, M. and P. Venables (1971). "Effects on 'Basal' skin potential level of varying the concentration of an external electrolyte." *J Psychosom Res* 15: 343-348.
- Edelberg, R. (1968). "Biopotentials from the skin surface: The hydration effect." *Ann N Y Acad Sci* 148: 252-262.
- Foulds, I and A. Barker (1983). "Human skin battery potentials and their possible role in wound healing." *British Journal of Dermatology* 109: 515-522.
- Friedenberg et al. (1973). "The cellular origin of bioelectric potentials in bone." *Calc Tiss Res* 13: 53-62.
- Fukada, E. (1984). "Piezoelectricity of natural biomaterials." *Ferroelectrics* 60: 285-296.
- Millington, P and R. Wilkinson (1983). *Mechanical, thermal and electrical properties. Skin.* Cambridge, Cambridge University Press. 113-142.
- Pollack et al. (1984). "Streaming potentials in fluid filled bone." *Ferroelectrics* 60: 297-309.
- Vanable, J. (1989). *Integumentary potentials and wound healing. Electric Fields in Vertebrate Repair.* New York, Alan Liss Inc. 171-224.
- Akai et al. (1988). "Electrical stimulation of ligament healing; An experimental study of the patellar ligament of rabbits." *Clin Orthop* 235: 296-301.
- Anderson, J and C. Eriksson (1968). "Electrical properties of wet collagen." *Nature* 218: 166-168.
- Athenstaedt, H. (1970). "Permanent longitudinal electric polarization and pyroelectric behaviour of collagenous structures and nervous tissue in man and other vertebrates." *Nature* 228: 830-834.
- Barker et al. (1982). "The glabrous epidermis of cavies contains a powerful battery." *Am J Physiology* 242: R358-R366.
- Becker, R (1961). "The bioelectric factors in amphibian limb regeneration." *Journal of Bone and Joint Surgery* 43A: 643-656.
- Becker, R (1967). "The electrical control of growth processes." *Medical Times* 95: 657-669.
- Becker, R (1972). "Stimulation of partial limb regeneration in rats." *Nature* 235: 109-111.

- Becker, R (1974). "The basic biological data transmission and control system influenced by electrical forces." *Ann N Y Acad Sci* 238: 236-241.
- Becker, R (1974). "The significance of bioelectric potentials." *Bioelectrochemistry and Bioenergetics* 1: 187-199.
- Becker, R (1990). *Cross Currents*. London, Bloomsbury Publishing.
- Becker et al. (1962). "The direct current control system: A link between environment and organism." *New York State Journal of Medicine* 62: 1169-1176.
- Becker, R and D Murray (1967). "A method for producing cellular dedifferentiation by means of very small electrical currents." *Trans N Y Acad Sci* 29: 606-615.
- Betz et al. (1984). "Physiological basis of a steady endogenous current in rat lumbrical muscle." *J Gen Physiol* 83: 175-192.
- Borgens, R (1982). "What is the role of naturally produced electric current in vertebrate regeneration and healing?" *International Review of Cytology* 76: 245-298.
- Borgens, R (1984). "Endogenous ionic currents traverse intact and damaged bone." *Science* 225: 478-482.
- Borgens, R and C McCaig (1989). *Endogenous currents in nerve repair, regeneration and development. Electric Fields in Vertebrate Repair*. Alan Liss Inc. 77-116.
- Brighton et al. (1981). "A multicenter study of the treatment on non-union with constant direct current." *JBJS* 63A(1): 2-13.
- Brown et al. (1989). "Polarity effects on wound healing using electrical stimulation in rabbits." *Arch Phys Med Rehabil* 70: 624-627.
- Brown et al. (1988). "Electrical stimulation effects on cutaneous wound healing in rabbits." *Physical Therapy* 68(6): 955-960.
- Carley, P and S Wainapel (1985). "Electrotherapy for acceleration of wound healing: Low intensity direct current." *Arch Phys Med Rehabil* 66: 443-446.
- Chakkalakal et al. (1988). "Electrophysiologic basis for prognosis in fracture healing." *Medical Instrumentation* 22(6): 312-322.
- Chang, K and J Snellen (1982). "Bioelectric activity in the rabbit ear regeneration." *J Exp Zool* 221: 193-203.
- Christie, M (1981). "Electrodermal activity in the 1980's; A review." *J Royal Soc Med* 74: 616-622.
- Dunn, M (1988). "Wound healing using collagen matrix: Effect of DC electrical stimulation." *J Biomed Mater Res* 22(A2 Suppl): 191-206.
- Edelberg, R. (1968). "Biopotentials from the skin surface: The hydration effect." *Ann N Y Acad Sci* 148: 252-262.
- Edelberg, R. (1971). *Electrical properties of the skin. Biophysical Properties of the Skin: A Treatise of Skin. Volume 1*. Wiley Interscience.
- Edelberg, R. (1977). "Relation of electrical properties of the skin to structure and physiologic state." *J Invest Dermatol* 69: 324-327.

Erickson, C. and R. Nuccitelli (1984). "Embryonic fibroblast motility and orientation can be influenced by physiological electric fields." *J Cell Biology* 98(1): 296-307.

Foulds, I. and A Barker (1983). "Human skin battery potentials and their possible role in wound healing." *British Journal of Dermatology* 109: 515-522.

Frank et al. (1983). "Electromagnetic stimulation of ligament healing in rabbits." *Clinical Orthopaedics & Related Research* 175: 263-272.

Friedenberg et al. (1973). "The cellular origin of bioelectric potentials in bone." *Calc Tiss Res* 13: 53-62.

Goss, R. (1981). *Tissue interactions in mammalian regeneration. Mechanisms of Growth Control.* Springfield, Illinois, Charles C Thomas. 12-26.

Griffin et al. (1991). "Efficacy of high voltage pulsed current for healing of pressure ulcers in patients with spinal cord injury." *Physical Therapy* 71(6): 433-442.

Hinkle et al. (1981). "The direction of growth of differentiating neurones and myoblasts from frog embryos in an applied electric field." *Journal of Physiology* 314: 121-135.

Illingworth, C and A Barker (1980). "Measurement of electrical currents emerging during the regeneration of amputated finger tips in children." *Clinical Physics and Physiological Measurement* 1(1): 87-89.

Jaffe, L. (1986). "Ionic currents in development: An overview." *Progress in Clinical and Biological Research* 210(Ionic Currents in Development): 351-357.

Jaffe, L (1981). "Control of development by steady ionic currents." *Federation Proceedings* 40(2): 125-127.

Jaffe, L and R Nuccitelli (1977). "Electrical controls of development." *Ann Rev Biophys Bioeng* 6: 445-476.

Jaffe, L and J Vanable (1984). "Electric fields and wound healing." *Clinics in Dermatology* 2(3): 34-44.

Kincaid, C (1989). "Inhibition of bacterial growth in vitro following stimulation with high voltage, monophasic, pulsed current." *Physical Therapy* 69: 651-655.

Kloth, L and J Feedar (1988). "Acceleration of wound healing with high voltage, monophasic pulsed current." *Physical Therapy* 68: 503-508.

Leonesio, R and A Chen (1987). "Nonsudorific skin potential level: Current hypothesis and psychophysiological significance." *Intern J Neuroscience* 32: 783-798.

Lokietek et al. (1974). "Muscle injury potentials: A source of voltage in the undeformed rabbit tibia." *Journal of Bone and Joint Surgery* 56B(2): 361-369.

Luther, P and H Peng (1983). "Changes in cell shape and actin distribution induced by constant electrical fields." *Nature* 303: 61-64.

Marino et al. (1989). "On the relationship between surface electrical potentials and cancer (Abstract)." *J Bioelectricity* 8(2): 279.

Neufeld, D (1989). "Epidermis, basement membrane and connective tissue healing after amputation of mouse digits: Implications for mamalian appendage regeneration." *Anatomical Record* 223: 425-432.

Nishimura, C. and J. Nagumo (1985). "Feedback control of the level of arousal using skin potential as an index." *Ergonomics* 28: 905-913.

Nordenstrom, B (1983). Biologically Closed Electric Circuits: Clinical, experimental and theoretical evidence for an additional circulatory system. Stockholm, Nordic Medical Publications.

Norton et al. (1977). "Epiphyseal cartilage cAMP changes by electrical & mechanical perturbations." *Clinical Orthopaedics and Related Research* 124: 59-68.

Nuccitelli, R. and C. Erickson (1983). "Embryonic cell motility can be guided by physiological electric fields." *Exp Cell Res* 147: 195-201.

Offner, F (1984). "Bioelectric potentials - Their source, recording and significance." *IEEE Trans Biomed Eng BME31*(12): 863-868.

Okihana et al. (1985). Effects of direct current on the cultured growth of cartilage cells. *Bioelectrical Repair and Growth*. 103-108.

Patel, N. and M.-M. Poo (1982). "Orientation of neurite growth by extracellular electric fields." *Journal of Neuroscience* 2(4): 483-496.

Reed, B (1988). "Effect of high voltage pulsed electrical stimulation on microvascular permeability to plasma proteins - A possible mechanism in minimising edema." *Physical Therapy* 68: 491-495.

Robinson, K. (1989). Endogenous and applied electric currents: Their measurement and application. *Electric Fields in Vertebrate Repair*. New York, Alan Liss Inc. 1-25.

Robinson, K (1985). "The responses of cells to electrical fields: A review." *Journal of Cell Biology* 101: 2023-2027.

Rowley, B (1985). Electrical enhancement of healing. Proc IEEE Nat Aerospace & Electronics Conf (NAECON), Dayton, Ohio, IEEE.

Rowley et al. (1974). "The use of low level electrical current for enhancement of tissue healing." *Biomed Sci Instrum* 10: 111-114.

Rubinacci, A. and W. De Loecker (1988). The endogenous transcutaneous potential affects protein synthesis. *Transactions 8th Annual BRAGS*,

Sawyer et al. (1953). "Relations of abnormal injury electric potential differences to intravascular thrombosis." *Am J Physiology* 175: 108-112.

Shibib et al. (1988). "Structural and regenerative changes in deafferented and defferented ulnar nerves." *Surg Neurol* 29: 282-292.

Shibib et al. (1988). "Polarisation of nerve regeneration (Electraxis)." *Surg Neurol* 29: 372-388.

Sisken, B (1983). "Nerve and limb regeneration." *IEEE Engineering in Medicine and Biology* 2: 32-39.

Stanish et al. (1985). The effects of electrical stimulation on tendon healing. *Bioelectrical Repair & Growth*. 311-318.

Thakor, N. and J. Webster (1978). The origin of skin potential and its variations. 31st ACEMB, Atlanta, Georgia, USA,

Vanable, J. (1989). Integumentary potentials and wound healing. *Electric Fields in Vertebrate Repair*. New York, Alan Liss Inc. 171-224.

Venables, P. (1978). "Psychophysiology and psychometrics." *Psychophysiology* 15(4): 302-315.

Volow et al. (1979). "Biofeedback control of skin potential level." *Biofeedback and Self-Regulation* 4(2): 133-143.

Weiss et al. (1990). "Electrical stimulation and wound healing." *Arch Dermatol* 126: 222-225.

Wheeler et al. (1969). Theory of electronic determinism in biologic homeostasis. Proc Int Symp, Graz, Austria, 8-13 Sept 1969,

Williamson et al. (1985). "Electrodermal potential and conductance measurements clinically discriminate between cystic fibrosis and control patients." *Pediatric Research* 19(8): 810-814.

Woodrough et al. (1975). "Electrical potential difference between basal cell carcinoma, benign inflammatory lesions and normal tissue." *British Journal of Dermatology* 92: 1-7.

Personal Publications

Bricknell, R. and T. Watson (1995). "The thermal effects of pulsed shortwave therapy." *Br J Therapy & Rehabilitation* 2(8): 430-434.

Watson, T. (1994). Electrical Stimulation of Wound Healing. *Clayton's Electrotherapy* 10th Edition. S. Bazin & S. Kitchen (Eds), London, WB Saunders.

Watson, T. (1995). Bioelectric Correlates of Musculoskeletal Injury & Repair. *PhD Thesis*, Department of Mechanical Engineering, University of Surrey.

Watson, T. (1996). "Electrical Stimulation for Wound Healing." *Physical Therapy Reviews* 1: 89-103.

Watson, T. (1996). "Electrotherapy research developments and their relevance to womens health." *J Assoc Chartered Physiotherapists in Womens Health* 78: 7-12.

Watson, T. (2000) "Elektrotherapie" in *Angewandte Physiologie Vol 3 : Therapie, Training, Tests*. Ed Frans van den Berg. Thieme, Stuttgart

Watson, T. (2000). "The role of electrotherapy in contemporary physiotherapy practice." *Man Ther* 5(3): 132-41.

Watson, T (2002) "Current concepts in electrotherapy" *Haemophilia* 8:413 – 418

Watson, T (2002) "Ultrasound Dose Calculations" *In Touch*, Autumn 2002 101; 14-17

Watson, T. (2003), *Electrotherapy – A Paradigm Shift?*
14th International Congress of the World Confederation for Physical Therapy, Barcelona, Spain

Watson, T. (2003), *Soft Tissue Healing*. *In Touch* 104;2-9