Pulsed electromagnetic (short-wave) energy therapy

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Therapy using pulsed electromagnetic energy is now used widely in the UK and many claims are made regarding its clinical effectiveness. The technique developed about 40 years ago from that of continuous short-wave diathermy, to which it is similar in many respects. There are, however, certain important differences between these therapies that influence significantly their clinical application.

Continuous short-wave diathermy (SWD) is described fully elsewhere[1-4] and relies principally for its therapeutic effect upon the pattern of heating generated deep within the tissues of the patient by a strong oscillating electromagnetic field. Heat is generated by the movement of ions and distortion of molecules and crystal lattices within the field, and by eddy currents induced within the tissues. The electromagnetic field oscillates at a frequency of 27.12 MHz. More energy enters the tissue than is transported away in the circulation and tissue easily achieves temperatures within the therapeutic range of 40–45°C[3]. This technique is thus accurately described as diathermy.

Pulsed electromagnetic energy therapy (PEMET) cannot correctly be called a diathermy because little or no heating of the tissue occurs. The apparatus operates at the same frequency as continuous SWD but the output is delivered as a train of pulses[5]. The intense electromagnetic field is thus established only briefly, and during the subsequent period of nil output, any heat produced is dissipated by the circulation[6].

This technique allows the use of a very high peak power output without the risk of an undesirable increase in tissue temperature. Peak power output appears to be more significant biologically than mean output[7]. The therapeutic effects of PEMET appear to depend more upon subtle interactions between the electric and magnetic field and biological tissue than upon heating. These processes are as yet poorly understood, although investigations are continuing.

This paper will attempt to describe the apparatus, biophysics and physiological and therapeutic effects of PEMET with reference to the types of condition encountered frequently in sports medicine.

Apparatus

Many short-wave diathermy units are capable of delivering either a pulsed or continuous output, although some are manufactured to fulfil only one role. The specifications of units producing a pulsed output currently used widely in the UK[8] appear in *Table 1*. The design of continuous SWD units is discussed elsewhere[1,3], thus it is only the modifications required for pulsed operation that will be considered here.

A signal generator, operating at 27.12 MHz, is constructed to deliver brief pulses of energy. These pulses usually have a duration of 20–400 μs. Some machines are capable of generating pulses of various lengths whilst others operate at a single pulse duration. Pulse frequency is similarly variable, usually within the range 100–600 pulses per second. This signal is then amplified and fed to the tissues of the patient via a tuned circuit and applicators. The applicators designed for use with continous SWD units may all be used safely to deliver a pulsed output, although certain machines are constructed to accept only the 'monode' type of applicator. This is essentially a coil encased within a cylindrical housing as seen in *Figure 1*.

Biophysics

Although the oscillating electric and magnetic fields are usually pulsed to allow sufficient time for the circulation to dissipate the energy applied, thus preventing a cumulative heating effect, one should remember that at a high output intensity, with a long duration pulse and rapid repetition rate, heating may occur[6]. This is most likely in those tissues poorly supplied with blood vessels or receiving a circulation that is otherwise impaired.

The maximum mean output of most PEMET units is usually in the region of 40 W (compared to 400–450 W maximum output for continuous short-wave diathermy), although the pulsing regime allows a peak output that often approaches 1 KW. The facility to apply a very strong electromagnetic field without the risk of a burn enhances those therapeutic processes mentioned earlier that are not a function of heating[6,7,9].

Some authors suggest that PEMET causes a redistribution of ions across the cell membrane, thus modifying resting membrane potential and certain cellular metabolic processes, especially those active during inflammation[10]. Neurons may be depolarised directly, or as a result of neurotransmitters moving in the electromagnetic field[7].

Others observe that ATPases are capable of absorbing energy from oscillating electric fields of defined frequency and amplitude and using this to perform chemical work[11]. Blood vessels may act as conductors within the time-varying magnetic field and thus have induced within them a weak electric current.

0306-3674/89/040213-04 $03.00

Table 1. Specifications of pulsed output short-wave therapy units

Manufacturer	Model	Mode of Operation	Pulse length (μs)	Pulse Frequency (pulses. s^{-1})	Maximum Pulsed Power Output (W)	Coupling	Applicators
EMS (Greenham) Ltd.	Megapulse	Pulsed	20, 40, 65 100, 200, 400	100, 200, 400, 600, 800	125	Manual	Cable in drum case
Enraf-Nonius Delft	Curapulse 419	Pulsed/Continuous	400	15–200 (10 steps)	1000	Automatic	Rigid plates Flexible plates Free cable Cable in drum case Cable in hinged case
Siemens Ltd.	Ultratherm 808i	Pulsed/Continuous	400	20–180	900	Automatic	Rigid plates Flexible plates Free cable Cable in drum case Cable in hinged case
Diapulse	Diapulse DS104A	Pulsed	65	80, 160, 300 400, 500, 600	975	Manual	Cable in drum case

Some propose that these currents can initiate and co-ordinate repair processes, influence the rhythm of electrical activity in the brain, and alter directly vascular muscle tone[12]. This direct effect of pulsing electromagnetic fields upon blood vessels was seen experimentally when muscle, treated with PEMET at a mean output of 40 W, showed an increase of 308 per cent in the rate of blood flow in the absence of measurable heating[13]. This may, however, be a reflex phenomenon. PEMET treatment of the epigastrum using a Diapulse unit delivering a mean power output of 16 W caused an increase in blood flow to the lower limb with no increase in rectal temperature[14]. The author proposes that this mechanism be harnessed in the treatment of peripheral vascular disease.

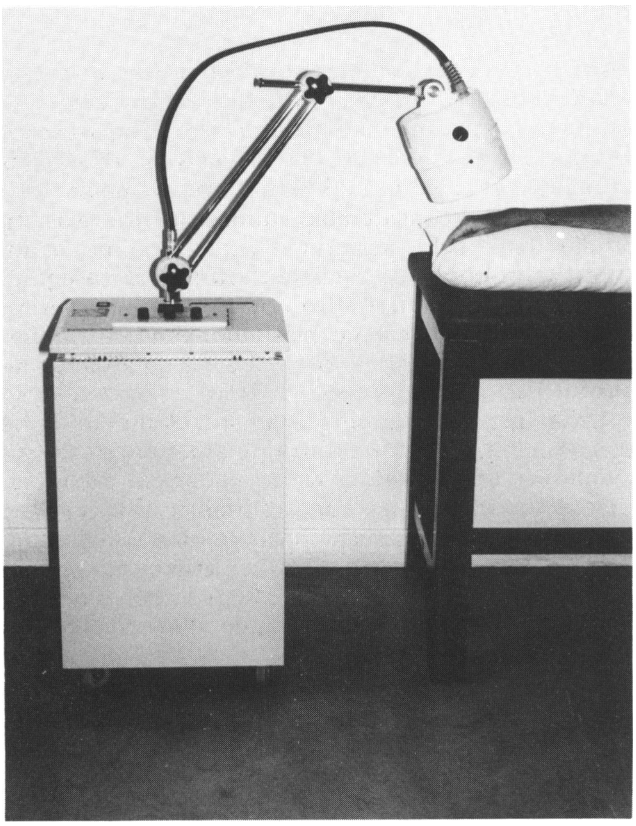

Figure 1. Pulsed electromagnetic energy therapy unit

Further explanation of these complex interactions is beyond the scope of this work, and the interested reader is directed, in the first instance, to more specialized reviews[7,15,16]. Much research is currently devoted to the investigation of frequencies other than 27.12 MHz.

Physiological and therapeutic effects

Pain

Several manufacturers claim that PEMET is capable of reducing pain[17]. Research substantiating this is described with injuries to the hand[18], vascular disorders[19], foot surgery[20], and ankle sprains[21]. Other investigations have, however, failed to support these findings[22,23], although a study of the effect of PEMET on post-surgical pain following repair herniae, in which no difference between treatment and control groups was reported[24], used a machine that emitted a weak electromagnetic field (1 W mean power output).

Soft tissue injury

Inversion injuries of the ankle have been treated using PEMET with varying degrees of success. Sprains receiving therapy within 36 hours of injury using Diapulse (38 W mean power output) for one hour daily on three successive days and graded subsequently for swelling, pain and disability are reported much improved[25,26]. However, similar treatment and assessment criteria used by others failed to show any beneficial effect[23] as have studies investigating PEMET at lower field intensities of 10 mW[22] and 19.6 W[21]. This last investigation does, however, claim some improvement of swelling, pain and time taken to achieve full weight bearing, although these improvements were not statistically significant.

Trials using Diapulse to treat various lesions of the lower limb in a mixed population of subjects (38 W mean power output) report considerable therapeutic success, particularly for conditions in which ischaemia was a major factor[19]. Hand injuries treated with PEMET within 36 hours of injury for 30 minutes twice daily (30 W mean power output) responded well with a marked reduction in swelling and some improvement in pain and disability[18].

Experiments using animal models suggest that rabbit muscle injured artificially by the injection of a toxic agent and treated subsequently for 20 minutes twice daily for eight or 16 days (38 W mean power output initially rising to 143 W by the end of the experiment) was little improved by PEMET[27]. Haematomata induced experimentally in rabbits exposed subsequently to PEMET for 30 minutes twice daily (25 W mean power output) showed a statistically significant acceleration of the rate of healing after the sixth day of a nine day treatment period[28]. Arthritis induced artificially in the joints of rats by intra-articular injection of formaldehyde and treated using a Diapulse unit once prior to damage and twice on the following day (25 W mean power output) were markedly less swollen than those of the untreated control group[29].

Wound healing

Studies of the effect of PEMET on the rate of wound healing have generally given encouraging results[30]. A double blind randomized trial in man studying the healing of medium thickness split-skin grafts, evaluated the effect of a 30 minute preoperative exposure to PEMET followed by four 30 minute treatments daily for seven days (25 W mean power output). The state of healing of the grafts at the end of this period was considerably advanced in the treated group when compared with those in the control[31]. Similar studies on rat tissue failed to identify a beneficial therapeutic effect, although in this study the period of exposure to the electromagnetic field (25 W mean power output) was only 10 minutes twice daily[32].

The healing of surgical incisions was investigated in a mixed population of patients undergoing surgery and found to be influenced favourably by PEMET treatment using Diapulse. Treatments were given twice daily (25 W mean output power) over a four day period and lasted 20 minutes[33]. This was combined with a coincidental application to the liver. The rationale given for this approach was based upon the hypothesis that this would elevate the level of haemopoitic activity. The acute lesions responded particularly well to PEMET.

A similar double-blind study of patients receiving surgery to the foot also incorporated a subsidiary treatment to the liver, although the main treatment was directed at the surgical incision for 15 minutes twice daily (38 W mean power output). Swelling reduced markedly in the treated group, which also benefited from an improvement in pain and erythema[20].

Other clinical studies have shown that the amount of analgesia required by postoperative surgical patients, and subsequent length of stay in hospital, were both reduced by Diapulse treatment[34]. The paralytic ileus that often complicates abdominal surgery did not respond favourably to PEMET[35].

Nerve repair

There is growing evidence that PEMET assists the repair of both the peripheral and central nervous systems. When the median ulnar nerve of rats was sectioned surgically and treated using a Diapulse unit for 15 minutes within two hours of surgery, and then daily for 15 minutes (11 W mean power output), the treated wounds healed more quickly than those in the control group. Nerve conduction studies indicated that function was restored to normal after 45 days in treated group compared to the 60 days that elapsed before the untreated nerves recovered[36].

Furthermore, sectioning of the common peroneal nerve in rats, followed by a 15 minute treatment with PEMET within one hour of surgery, and then daily for up to eight days (15.5 W mean power output), demonstrated that healthy nerves were unaffected and that animals in the treated group recovered function in the damaged limb more quickly. A statistically significant acceleration of the rate of degeneration, regeneration and maturation of myelinated axons also occurred[37,38].

A most interesting observation follows from experiments with cats in which the animals suffered surgical hemicordectomy in the upper lumber region and were then treated using PEMET for 30 minutes daily for 30 days (50 $mW.cm^{-2}$)[39]. After a three month postoperative interval, the spinal cords were examined histologically. Those in the treated group showed less extensive scarring and a greater number of regenerating neurons crossing the site of the lesion than control animals.

Conclusion

Pulsed electromagnetic energy therapy is a widely used technique for which there exists considerable industrial and paramedical enthusiasm. The research supporting the clinical effectiveness of PEMET is growing steadily although much work remains to be completed. A considerable number of the existing studies have been performed with the direct or indirect sponsorship of the manufacturers of the equipment, notably the Diapulse Corporation of America, and whilst I suggest no bias, independent studies would increase confidence in the information available.

Other factors militating against a definitive summary include the lack of experimental rigour that is evident in much previous work, and a failure to measure or report details such as intensity of the electromagnetic field applied to the tissues. Meaningful comparison between studies is sometimes difficult.

The mechanisms responsible for the action of PEMET have yet to be elucidated fully or reported adequately in the West. A considerable amount of work has been done in the Eastern bloc countries to which we have as yet limited access. I anticipate that the minimal heating effects produced by this equipment will be shown to exert only a marginal influence when compared to the direct effects of the interaction between the electromagnetic field and biological tissue.

Certain conclusions may be drawn from the existing literature. Laboratory experiments and clinical studies indicate clearly that acute lesions in soft tissues, caused by accidental trauma or surgery, can be induced to heal more rapidly by the use of PEMET. The effects upon the skin and nervous system would appear particularly useful. Chronic lesions respond less well. Pulsed electromagentic energy therapy should be regarded as a useful therapeutic tool likely to become more effective clinically as further research identifies the conditions under which it is used most appropriately.

References

1 Goats, G.C. Continuous short-wave (radio-frequency) diathermy *Br J Sports Med* 1989, **23**, 123–127

2 Kloth, L. Short-wave and microwave diathermy In: 'Thermal Agents in Rehabilitation' Michlovitz, S.L. and Wolf, S.L. (Eds.). Chapter 8, 177–216 F.A. Davis Company, 1986, Philadelphia

3 Lehmann, J.F., DeLateur, B.J. Therapeutic heat In 'Therapeutic Heat and Cold' Lehmann, J.F. (Ed.) 3rd Edition. Chapter 10, 404–562, Williams and Wilkins, 1982, Baltimore

4 Scott, B.O. Short-wave diathermy In: 'Therapeutic Heat and Cold' Litch, S. (Ed.) 2nd Edition. Chapter 11, 279–309 Waverley Press, 1965, Baltimore

5 Oliver, D.E. Pulsed electromagnetic energy—what is it? *Physiotherapy* 1984, **70**(12), 458–459

6 Low, J.L. The nature and effects of pulsed electromagnetic radiations. *New Zealand J Physiotherapy* 1978, 18–22

7 Frey, A.H. Differential biologic effects of pulsed and continuous electromagnetic fields and mechanisms of effect *Ann New York Acad Sci* 1974, **238**, 273–279

8 Anonymous. Evaluation of short-wave therapy units *Health Equipment Information 170* 1987 Leftwich, G. (Series Ed.) Department of Health and Social Security, London

9 Hayne, C.R. Pulsed high frequency energy—its place in physiotherapy *Physiotherapy* 1984, **70**(12), 459–466

10 Sanseverino, E.R. Membrane phenomena and cellular processes under the action of pulsating magnetic fields Proceedings of the 2nd International Congress for Magneto-medicine 1980, Rome

11 Tsong, T.Y. Deciphering the language of cells *TIBS* 1989, **14**, 89–92

12 Nagelschmidt, K.F. Specific effects of high-frequency currents and magnetotherapy. *Br J Phys Med* 1940, 201–207

13 Jenrich, W. Pulsed short-wave therapy: Mechanism and applications *Electromedica* 1985, **53**(4), 165–168

14 Erdmann, W.J. Peripheral blood flow measurements during application of pulsed high-frequency currents *Am J Orthop* 1960, **2**, 196–197

15 Blank, M. and Findl, E. (Eds.) 'Mechanistic Approaches to Interactions of Electric and Electromagnetic Fields with Living Systems 1987, Plenum Press, UK

16 Frank, C.B. and Szeto, A.Y.J. A review of electromagnetically enhanced soft tissue healing *IEEE Eng Med Biol Mag* 1983, 27–32

17 Van Den Bouwhuijsen, F., Maassen, V., Meijer, M. and Van Zutphen, H. 'Pulsed and continuous short-wave therapy' B.V. Enraf-Nonius, 1985, Delft

18 Barclay, V., Collier, R.J. and Jones, A. Treatment of various hand injuries by pulsed electromagnetic energy (Diapulse) *Physiotherapy* 1983, **69**(6), 186–188

19 Steinberg, M.D. Diapulse therapy in general podiatry practice: A preliminary report *J Am Podiatr Assoc* 1964, **54**(12), 849–852

20 Kaplan, E.G. and Weinstock, R.E. Clinical evaluation of Diapulse as adjunctive therapy following foot surgery *J Am Podiatr Assoc* 1968, **58**(5), 218–221

21 McGill, S.N. The effects of pulsed short-wave therapy on lateral ligament sprain of the ankle *New Zealand J Physiotherapy* 1988, 21–24

22 Barker, A.T., Barlow, P.S., Porter, J., Smith, M.E., Clifton, S., Andrews, L. and O'Dowd, W.J. A double-blind clinical trial of low power pulsed short-wave therapy in the treatment of a soft tissue injury *Physiotherapy* 1985, **71**(12), 500–504

23 Pasila, M., Visuri, T. and Sundholm, A. Pulsating short-wave diathermy: Value in treatment of recent ankle and foot sprains *Arch Phys Med Rehabil* 1978, **59**, 383–386

24 Reed, M.W.R., Bickerstaff, D.R., Hayne, C.R., Wyman, A. and Davies, J. Pain relief after inguinal herniorrhaphy: Ineffectiveness of pulsed electromagnetic energy *Br J Clin Pract* 1987, **41**(6), 782–784

25 Wilson, D.H. Treatment of soft tissue injuries by pulsed electrical energy *Br Med J* 1972, **2**, 269–270

26 Wilson, D.H. Comparison of short-wave diathermy and pulsed electromagnetic energy in treatment of soft tissue injuries *Physiotherapy* 1974, **60**(10), 309–310

27 Brown, M. and Baker, R.D. Effect of pulsed short-wave diathermy on skeletal muscle injury in rabbits *Phys Ther* 1987, **67**(2), 208–214

28 Fenn, J.E. Effect of pulsed electromagnetic energy (Diapulse) on experimental haematoma *J Can Med Assoc* 1969, **100**, 251–254

29 Nadasdi, M. Inhibition of experimental arthritis by athermic pulsating short-waves in rats *Am J Orthop* 1960, **2**, 105–107

30 Cameron, B.M. Experimental acceleration of wound healing *Am J Orthop* 1961, **3**, 336–343

31 Goldin, J.H., Broadbent, N.R.G., Nancarrow, J.D. and 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**, 267–270

32 Krag, C., Taudorf, U., Siim, E. and Bolund, S. The effect of pulsed electromagnetic energy (Diapulse) on the survival of experimental skin flaps *Scand J Plast Reconstr Surg Hand Surg* 1979, **13**, 377–380

33 Cameron, B.M. A three phase evaluation of pulsed high frequency radio short-waves (Diapulse). 646 patients *Am J Orthop* 1964, **6**, 72–78

34 Santiesteban, A.J. and Grant, C. Post-surgical effect of pulsed short-wave therapy *J Am Podiatr Med Assoc* 1985, **75**(6), 306–309

35 Barker, P., Allcutt, D. and McCollum, C.N. Pulsed electromagnetic energy fails to prevent postoperative ileus *J R Coll Surg Edin* 1984, **29**(3), 147–150

36 Wilson, D.H. and Jagadeesh, P. The effects of pulsed electromagnetic energy on peripheral nerve regeneration *Ann New York Acad Sci* 1974, **238**, 575–585

37 Raji, A.R.M. An experimental study of the effects of pulsed electromagnetic field (Diapulse) on nerve repair *J Hand Surg 1984*, **9B**, 105–112

38 Raji, A.R.M. and Bowden, R.E.M. Effects of high peak pulsed electromagnetic field on the degeneration and regeneration of the common peroneal nerve in rats *J Bone Joint Surg* 1983, **65B**(4), 478–492

39 Wilson, D.H., Jagadeesh, P. Experimental regeneration in peripheral nerves and the spinal cord in laboratory animals exposed to a pulsed electromagnetic field *Paraplegia* 1976, **14**, 12–20