LITERATURE REVIEW

Review of Shortwave Diathermy Continuous and Pulsed Patterns

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Key Words
Shortwave diathermy, continuous pattern; shortwave diathermy, pulsed pattern; physiological effects; clinical efficacy; hazards.

Summary
Both continuous and pulsed forms of shortwave diathermy (SWD) are used by physiotherapists in the treatment of a range of conditions including soft tissue lesions and the arthritises. The known physiological effects, clinical efficacy and hazards associated with the use of these two forms of SWD are considered and the need for further research both in the field of basic science and clinical application is highlighted.

Introduction

Continuous shortwave diathermy has been used in the treatment of many conditions for a considerable period of time by physiotherapists. Some evaluation of the technique was undertaken during the sixties and seventies, but this work included relatively little evaluation of its efficacy in the clinical situation. Since then a limited number of papers have appeared in the literature, looking at this aspect. Pulsed shortwave diathermy, often referred to as pulsed electromagnetic energy (PEME), pulsed electromagnetic field (PEMF) or pulsed electromagnetic energy treatment (PEMET), was first introduced in the early 1950s; it has become very popular with clinical therapists but research into its effects and clinical efficacy are conspicuous by their scarcity. A liking for this particular modality appears to have arisen without any underlying scientific evidence for its efficacy.

Background

Shortwave electromagnetic radiations range in frequency from ten to 100 MHz; commonly known as radio frequency waves, the shortest wave band is used in therapeutic diathermy. Short radio waves lie between microwaves and medium radio waves on the electromagnetic spectrum. Radio waves can be used in the medical context to heat tissues, to stimulate tissue repair, to destroy carcinogenic tissue and in tissue imaging. Those most commonly used by therapists to heat or treat tissue are of the frequency of 27.12 MHz (Delpizzo and Joyner, 1987; Low and Reed, 1990) and are commonly termed shortwave diathermy (SWD).

Shortwave energy can be delivered in either a continuous or pulsed mode. Continuous shortwave diathermy can be delivered through either the capacitive or inductive methods. It is an alternating current, normally of a frequency of 27.12 MHz, and is used primarily for its heating capacity.

Pulsed shortwave diathermy is of the same frequency but is delivered to the subject in the form of a train of pulses. The pulse lengths normally vary from 25 to 400 microseconds and the number of pulses lie between 15 and 800 per second. Thus the length of the rest periods depends on the relationship between the pulse frequency and length and time, normally considered in seconds. The parameters most frequently quoted are the pulse duration and the number of pulses per second. Both the electromagnetic and electrostatic fields may be used in treatment.

The pulsing of shortwave diathermy results in the need to report both peak and average power values; it is possible for the peak power delivered to tissue to be high while the average power is low, due to short pulse lengths and/or few pulses. Pulsed SWD can be given at levels sufficient to produce heating of the tissues but is more commonly used in clinical practice at levels which are claimed to have minimal heating effects and may, it is suggested, possibly have athermal effects.

In order to clarify the type of treatment which is being given to the subject, parameters should be fully described. These should include frequency (normally 27.12 MHz), average power, time of irradiation and method of application for continuous wave therapy; the type of field used should also be indicated. Peak power, average power, pulsed length, and rest period or number of pulses per second should be added for pulsed therapy.

In clinical practice, however, it seems heating levels are commonly determined by the thermal reaction of the individual subject, owing to the difficulty of establishing precise energy levels. Pulsed therapy parameters should however be clearly noted.

Many authors, particularly in earlier work, describe pulsed shortwave diathermy by referring to the manufacturer's name for a piece of equipment rather than by defining the parameters used; others refer to dosage levels by quoting 'levels' marked on the machine, such as penetration levels 1–6 on the Diapulse machine. This is not a satisfactory practice as inadequate documentation of the parameters results, making it difficult to compare data or even know exactly what dosages have been given. A number of machines available on the market have been described in detail by Hayne (1984) and Low and Read (1990) and the Department of Health (Evaluation Report, 1987) has published evaluations of some equipment. It is very important to note that not all shortwave diathermy machines exhibit similar dosage characteristics; for example, the maximum power output from machines of different makes may differ. Inadequate description of parameters can thus result in apparently similar dosages actually being quite different. When they are known, details of physical parameters will be provided throughout the rest of this text.

Physiological Effects of SWD

The physiological effects of SWD can be divided into thermal and athermal effects. Continuous SWD is normally considered to have thermal effects only, whereas pulsed SWD may have both thermal and athermal effects. There is considerable debate surrounding the area of athermal effects, some workers considering that any effect produced by the energy is due at least in part to low levels of thermal change, and others suggesting that the pulsed nature of the energy may activate certain tissue mechanisms. Adey (1981) points out that any absorption of electromagnetic energy will result in an increase in thermal energy; what matters in physiological terms is whether an adequate increase, in the region of a couple of degrees, is generated which could facilitate some of the responses seen to occur in experimental organisms. Much work has been undertaken in the last ten years on the effects of electromagnetic fields on cellular activity (Frohlich, 1988; Adey, 1988), some of which may shed light on the effects of pulsed, low level shortwave diathermy.

Thermal Mechanisms

Electromagnetic waves of the high frequency of SWD are unable to depolarise either nerve or muscle and cause heating through the conversion of electromagnetic energy to thermal energy. Delpizzo and Joyner (1987) describe heat as being produced through three mechanisms:

- Orientation of electrical dipoles pre-existent in tissue.
- Polarisation of atoms and molecules to produce electric dipoles.
- Displacement or drift of conduction electrons and ions.

The first two involve friction associated with movement and the last, displacement and collision. Heating can only be produced by internal electrical fields, but both the electric and the magnetic fields of SWD can produce heating as the magnetic fields result in the production of eddy currents within the tissue.

The level of heating developed is dependent on tissue properties, known as the 'complex permittivity' of the tissue. This represents the dielectric constant and the heat loss factor of the tissue. Complex permittivity is frequency dependent and therefore the propagation and attenuation of electromagnetic waves is also frequency dependent (Schwan, 1970). Patterns of heating produced in various tissue structures are discussed by Guy (1982), who consider the biophysical effects of SWD currents on tissues. Not all devices are equally effective in heating underlying muscle; Lehman *et al* (1983) evaluated a number of commercially available applicators and found that the heating patterns generated varied greatly between the different models; they noted that some of the commercially available models were inferior to the experimental models, tending to heat surface fat rather than underlying muscle.

Alterations in tissue temperature due to the application of continuous SWD in normal human subjects has been examined by a number of workers. The condenser field method has been evaluated by Verrier *et al* (1977), Hansen and Kristensen (1973) and Abramson *et al* (1960). All measured the cutaneous and intramuscular temperatures, the latter at a depth of 1 cm. A comparison of the results obtained by these three groups of workers is given in table 1.

Table 1: Alterations in tissue temperature

Authors	Area treated	Dosage	Duration of treatment (minutes)	Cutaneous temperature (°C)	Intra-muscular temperature at 1 cm depth (°C)
Verrier *et al* (1977)	Calf	Maximum subject could tolerate	20	3.28	2.24
Hansen and Kristensen (1973)	Calf	'1 watt ... a pleasant warmth'	5	5.13	4.00
Abramson *et al* (1960)	Fore-arm	Governed by thermal comfort 'an arbitrary setting of 25 on the output volt meter'	30	1.30	1.90

The differing experimental protocols can be seen to result in very different tissue temperatures. Abramson *et al* (1960) also highlight the close link between temperatures developed and blood flow — higher temperatures resulting in increased flow. Thus it appears that increased flow may result in lower tissue temperatures, heat being removed as a result of the increase in circulation. Time appears to be a factor in the development of tissue temperature and circulatory changes; the very low temperatures, following a longer period of irradiation, noted by Abramson *et al* (1960), constrast with the higher temperatures recorded by Jansen and Kristensen (1973) who irradiated the part for a short period of time. Other factors which may affect the results include body structure, the vascularity of the area affecting the final temperature, and the dosage, which in these instances is not fully defined.

Temperatures resulting from the use of the inductothermy method have also been examined; Lehmann *et al* (1969) demonstrated temperature rises of 9.50°C at a depth of 1 cm in the human thigh and Verrier *et al* (1977) recorded mean temperature rises of 5.05°C (cutaneous) and 4.40°C (intramuscular depth of 1 cm) in the human calf at a mean dose of 3.44 amperes. Minimal and maximal doses of each form of SWD were compared by Verrier *et al* (1977); energy applied by the inductothermy method produce some degree of heating of muscle at both extremes of dosage. It was, however, impossible to detect any temperature alterations when applying a minimal dose of SWD using the condenser field method.

Both the condenser field and inductothermy methods of administering SWD give results which vary; Verrier *et al* (1977) note that tissue heating is not selective, both the skin and the intramuscular values being within similar bounds. There is an interesting difference, however, between the temperatures achieved through use of the condenser field and inductothermy methods. Despite the varied parameters, these data suggest that the inductothermy method gives rise to greater tissue temperature rises than the condenser field method; this is shown clearly by Verrier *et al* (1977) who compared the two, using similar doses of 3.44 and 3.39 amperes respectively. This result may partially reflect the work of Guy *et al* (1974) which suggested that the majority of capacitor electrode heating arrangements recommended by manufacturers are likely to produce maximum heating in the superficial fat layer of the part, and not the skin and muscles.

Pulsed SWD can also produce temperature changes; the temperatures developed appear to be dependent on the total average power delivered, high peak power and high frequency leading to greater increases in temperature. Erdman (1960) demonstrated increases in skin temperature of 0.5 °C and 1.5 °C respectively for peak powers of 410 watts (frequency: 400 pulses per second) and 1,025 watts (frequency: 600 pulses per second) over the epigastric region in the human subject. An associated increase in temperature in the foot occurred, averaging 2 °C. Morrissey (1966) and Silverman and Pendleton (1968) demonstrated temperature increase at doses of 80 watts and 65 watts average power respectively. The latter noted similar heating levels with both continuous and pulsed SWD at similar average powers. Lower levels of energy did not produce significant heating.

An increase in tissue temperature can produce a number of physiological changes, related here to the literature evaluating the effects of SWD.

Blood Flow

Blood flow has often been examined in conjunction with temperature alterations; Lehmann (1971) showed through the use of animal studies that temperature and blood flow are related. He stated that a temperature of 41 °C is necessary to produce any significant change in blood flow and 45 °C is necessary to produce a maximal reaction. Abramson *et al* (1960) demonstrated an increase, sometimes approaching double, in blood flow in their subjects following the application of heating for a period of 30 minutes, in contrast to Hansen and Kristensen (1973), who applied the SWD for a period of five minutes only and showed smaller increases in flow.

Both Wyper and McNiven (1976) and Millard (1961) demonstrated some increase in blood flow following the application of both continuous and pulsed SWD but noted that it had to be much less than could be produced by gentle or moderate exercise. The results produced by Wyper and McNiven (1976) showed that SWD did not result in significant increases in blood flow while a ten-fold increase occurred with moderate exercise. Millard (1961) compared the use of SWD (condenser field method, dosage set at maximum skin temperature tolerance for a 20-minute period) with gentle exercise. Temperatures and blood flow were measured in the skin, quadriceps muscle, tibialis anterior muscle and knee joint of normal human subjects. Results varied widely; the quadriceps muscle, the most vascular of the structures, showed greatest variability. Again Millard (1961) notes that any changes are small compared with the effects of 'a few minutes' gentle exercise'.

Harris (1963) examined the effect of continuous SWD on the blood flow of people with rheumatoid arthritis and noted that the increase was greatest in those having the least disease activity. The dose was adjusted to produce 'maximum skin tolerance to heat'. Such results indicate the need to evaluate treatment modalities in relation to the target population.

Pulsed SWD has also been shown to produce increases in blood flow; Silverman and Pendleton (1968) demonstrated that both pulsed and continuous SWD produced equal changes in temperature and blood flow when the average power delivered was the same. Morrissey (1966) showed that at low average powers (40 watts) heating could not be demonstrated whereas at high average energy levels (80 watts) both tissue temperature and blood flow increased. This emphasises the need for full and accurate descriptions of parameters in trials; this is of particular importance when attempting to determine whether pulsed SWD is likely to have athermal effects.

The numbers in these trials are varied; Wyper and McNiven (1976) used only one person to evaluate the use of continuous SWD and up to eight for the remaining methods, whereas Millard (1961) used 150 subjects throughout the course of his study of both infra-red and SWD. It is, however, unclear how many subjects were involved at each stage of the work. Erdman (1960) employed 20 subjects and Morrissey (1966) recruited 28. No indication of numbers is given by Silverman and Pendleton (1968). These numbers are small, and taken individually make generalisation difficult; however, clear explanations of protocol and dosage parameters would facilitate comparison of different work and the replication of studies, thus allowing some conclusions to be drawn. The great variety of methodologies adds to the problem as it must be remembered that each configuration of subject and treatment may result in different heating patterns.

Neurological Mechanisms

SWD is claimed to be effective in the reduction of pain (Low and Reed, 1990; Lehmann and de Lateur, 1982), though these writers note the empirical basis for such a suggestion. Benson and Copp (1974) assessed the pain threshold of normal subjects, using an algesimeter to induce local pressure, measured in kg/cm^2; continuous SWD was given to the shoulder region. The condenser field method was used for 20 minutes at 'thermal intensity'; details of electrode size and spacing only are given. The pain threshold rose with the use of SWD, was maximum immediately following cessation of treatment, but returned to normal at between 15 and 30 minutes after the treatment.

Nerve conduction has been shown to respond to an alteration in temperature; Abramson *et al* (1966) demonstrated a significant increase in motor nerve conduction in the median and ulnar nerves of normal human subjects following the application of continuous SWD. In contrast, the results obtained by Currier and Nelson (1969) were not statistically significant. They tested the peroneal nerve, applying heat proximally to the sacral region. The heating patterns developed by each of these experiments are likely to have been different due to different physical arrangements of electrodes and body tissues; this could account for the different results.

Athermal Mechanisms

Any athermal effects are the subject of considerable controversy; Low and Reed (1990) intimate that 'all explanations advanced to explain the mechanisms of pulsed shortwave are entirely speculative'. However, they go on to list the gross physiological effects as an increase in the number and activity of cells in the injured region, resorption of haematoma, reduced inflammation and swelling, an increased rate of fibrin and collagen deposition and organisation, and increased nerve growth and repair. These claims are based on a very limited number of clinical studies (Wagstaff *et al*, 1986; Barclay *et al*, 1983; Goldin *et al*, 1981; Wilson, 1972, 1974; Kaplan and Weinstock, 1968) and a few experimental studies (Cameron, 1961; Nadasdi, 1960; Raji, 1984); the effects have not been reproduced in all trials (Livesley *et al*, 1991; Grant *et al*, 1989; Brown and Baker, 1987; Krag *et al*, 1979; Pasila *et al*, 1978; Constable *et al*, 1971.

Much work has been done in the last ten years on the effects of electromagnetic energy on biological systems. This has included extensive work on the effects of very low frequency currents and microwave (Adey, 1988). Research work has led to the development of the concept of 'frequency windows'. Tsong (1989) discusses work which suggests that cells are capable of absorbing energy from oscillating electrical fields of defined frequencies and amplitudes and using this energy to perform chemical work. If this proves to be so it becomes very clear that the details of dosage may be very important in determining whether a treatment procedure appears to have an effect. It is also likely that damaged cells may respond differently to stimulation, possibly responding at lower energy levels. Such a concept would indicate clearly the need to evaluate specifically the effects of pulsed shortwave diathermy on human tissues, both normal and damaged, and not simply extrapolate from other work in the area.

Efficacy of SWD

The efficacy of both continuous and pulsed SWD in the treatment of lesions of different types can be evaluated through the use of both experimental models and clinical trials, the first suggesting appropriate lines of investigation in human studies.

Experimental Models

A limited number of animal studies have been conducted, looking at the efficacy of both continuous and pulsed SWD on tissue lesions of different types. The results have varied greatly and provide no definite answers about the efficacy of these modalities in clinical practice. Most studies have been conducted on loose-skinned animals such as dogs, rabbits and rats, in whom healing of skin lesions differs from that in humans by being mainly through skin contraction over the wound (Basford, 1989). Studies which rely on the measurement of wound size over time in such models may not therefore apply directly to human subjects. A number of experimental studies have also used normal human subjects; again caution may be necessary when extrapolating to the clinical situation where tissue damage will exist. Work examining the efficacy of ultrasound and laser have suggested that damaged tissue may respond to treatments of lower intensity than would affect normal tissue (Dyson and Luke, 1986; Karu, 1988).

Soft Tissues

Mixed results have occurred in trials evaluating tissue healing using continuous and pulsed SWD. Bansal *et al* (1990) conducted a controlled trial to examine histological changes following application of continuous SWD to surgically induced lesions in a dog model. SWD was administered for five minutes, daily, from day two to eight at an 'intensity of bearable heat'. Tissue was excised for examination at day 15 and it was found that the collagen present at the site was of a more mature type, fewer fibroblasts were present and normal muscle fibres were generally identified adjacent to the lesion; atrophied and necrosed muscle fibres were seen in the control animals.

Pulsed SWD is thought to facilitate tissue healing. Cameron (1961) conducted a controlled trial to evaluate the effect of pulsed SWD on healing wounds in dogs and noted that healing, at a cellular level, was more advanced in those receiving treatment. Fenn (1969) examined the effect of Diapulse on chemically induced haematomas in the ears of rabbits and found that resolution was accelerated in those animals receiving active treatment. Details of dosage are, however, poorly defined in this paper, a penetration setting of '4' on the Diapulse being indicated. Raji (1984) conducted a double-blind trial, evaluating the efficacy of a pulsed electromagnetic field (PEMF) in accelerating the recovery of sectioned common peroneal nerves in rates; full details of surgical procedure, care and the assessment of regeneration are given. Animals treated with PEMF showed faster recovery than the control, placebo treated group, both in terms of function and histological analysis, values being statistically significant. In this report, PEMF is mainly described in terms of the unit used — pulse frequency 400; Diapulse 4, peak power — thus information regarding the dosage used is inadequate, making it very difficult to compare this result with others or to use the information to inform the debate concerning the efficacy of this form of treatment.

Other workers have been unable to provide evidence of the efficacy of pulsed SWD in animal experiments; Brown and Baker (1987) created muscle injuries in 32 rabbits by means of injection with Xylocaine®. Half the animals were treated with pulsed SWD, and treatment parameters were varied during the course of the treatment in line with the suggestions of the manufacturers of the machine (250 W Megnatherm machine). No statistically significant difference was seen in the histological condition of the lesions at eight or 16 days. The latter result was despite the fact that subjective assessment suggested that those animals treated demonstrated slightly better healing levels. This result confirmed the work of Constable *et al* (1971) who were unable to demonstrate any difference in the tensile strength of healing wounds in guinea pigs treated with pulsed SWD when compared with controls. Krag *et al* (1979) confirmed this view through the evaluation of the effect of pulsed SWD on the healing on experimental skin flaps in rats in a double-blind controlled trial. Full details of procedure and dosage are given. Seven days after surgery the animals were sacrificed; no statistical difference was found between the two groups in terms of microcirculation, which would be expected to influence the survival of the flaps.

Again, these experiments examining the healing that occurs in soft tissue lesions when treated with SWD vary in the dimensions they measure, the treatment protocols used and the lesions created. Details of dosage and procedures are not always complete. Negative results could result from inappropriate protocols but at present there is no evidence for this.

Joints

Pulsed SWD may be used to treat joint conditions; Vanharanta (1982) studied joint range and osteoarthritic changes in the rabbit resulting from periodic immobilisation of the knee joints; half received continuous SWD by the condenser field technique at 50 W power. They were treated five times a week between periods of immobilisation. Those animals receiving SWD demonstrated greater limitation of movement during free periods and showed equal osteo-arthritic changes when compared with the untreated animals. The author postulates that this could be due to the heat encouraging the proliferation of collagenous tissue and the development of adhesions and notes that this may suggest that care should be exercised when using SWD with people who have osteo-arthritis as it might exacerbate their condition. This result contradicts the report of Nadasdi (1960) which suggested that arthritis in rats was less when they had been exposed to pulsed SWD during the period of experimental joint damage, which was chemically induced. Such contrary results may point to the need for great care with the choice of parameters, the first study making use of continuous SWD and the second, pulsed. Clearly further work is needed in this area.

Clinical Trials

While animal studies can provide information about the actions of different forms of treatment on tissues it is necessary to evaluate the effects of these modalities in the human subject. Normal subjects may be studied but ultimately it is essential to perform studies on patient populations in order to establish the efficacy of treatment on specific pathologies at different stages of the disease process.

Soft Tissues

Soft tissue injuries have for many years been treated with continuous SWD but are now frequently treated with pulsed energy. The majority of recent studies evaluate the pulsed modality. Ginsberg (1961) used pulsed SWD (pulse duration 65 microseconds, rests 1,665 microseconds and average power 40 watts) in the resolution of 94 cases of calcification in bursitis; 80% of patients experienced symptomatic relief and 42 of the 46 cases subjected to X-rays before and after treatment showed signs of resorption. Wilson (1972, 1974) studied acute inversion injuries of the ankle; in 1974 matched pairs were allocated at random to two groups. The first group received continuous SWD and a base treatment of exercise and walking instruction; the second received pulsed energy and the same base treatment. No control or placebo groups were used as the author indicated that a prior comparison between an active and placebo pulsed treatments in a similar population had shown that pulsed SWD was effective in reducing pain and disability (Wilson, 1972). Continuous SWD was delivered for two 15-minute periods within the hour, once daily. Pulsed energy was given for one hour daily. Details of treatment are given. A noticeable difference between the two treatment regimens lies in the total power delivered; continuous SWD resulted in 22½ watt-hours energy being received while those on the pulsed programme received 15 watt-hours. Those receiving pulsed energy displayed greater improvement (82.8%) in terms of swelling, pain and disability than those in the continuous SWD group (44.2%). Wilson (1974) notes that greater improvement occurred using the lower energy transmission and suggests that this may indicate that pulsed energy acts in ways other than through heating.

Kaplan and Weinstock (1968) conducted a double-blind controlled trial to evaluate the effect of pulsed SWD on post surgical oedema following foot surgery; those receiving treatment demonstrated less pain and oedema than the control group. Resolution of bruising and swelling occurred more rapidly in those receiving treatment in a randomised, controlled trial of boys undergoing orchidopexy (Bentall and Eckstein, 1975); these two parameters were found to resolve more rapidly in those treated with pulsed energy. Significantly improved healing of surgical wounds following a variety of types of oral surgery were claimed by Aronofsky (1971); inflammation, pain and healing were evaluated by the clinician. The methods of assessment used relied on clinical experience and thus were subjective. Details of dosage (pulse length 65 microseconds, pulse frequency 600, peak power 975 watts, average power 38 watts), length and frequency of treatment are given and a control group incorporated into the design. Nicolle and Bentall (1982) produced similar results following bi-lateral blepharoplasty; 21 consecutive patients were treated unilaterally with continuous pulsed SWD (27.12 MHz; 1,000 pulses per second, 100 microseconds pulse duration). Nineteen subjects showed significant benefit in terms of swelling and inflammation on the treated side when compared with the untreated control side.

Goldin *et al* (1981) examined the healing of grafts in a controlled trial. The parameters were given as peak output 975 watts, 400 pulses per second, pulse duration 65 microseconds, mean energy output 25.3 watts. Healing was evaluated at seven days and pain monitored during the period of treatment. Healing in those receiving active treatment was more advanced. There is no discussion about the pain measurements.

Finally, Barclay *et al* (1983) evaluated the pulsed energy on 230 patients with a variety of hand injuries, randomly allocated to either treatment or non-treatment groups. Swelling, disability and pain were assessed. Dosage parameters are given in full (27.12 MHz; 65-microsecond pulses, 1,600-microsecond rest phases, 975 watts peak power, estimated to receive about 4 watts total energy). Those treated responded by showing greater healing, especially with respect to the parameter of swelling; this had marked effects on the pain experienced and the function demonstrated.

Not all researchers have been able to demonstrate such positive results; Pasila *et al* (1978), Barker *et al* (1985), Grant *et al* (1989) and McGill (1988) were unable to support the view that pulsed energy was effective in assisting health. Both Pasila *et al* (1978) and McGill (1988) examined subjects with ankle sprains and found no significant difference between those receiving active pulsed SWD or a placebo treatment. Barker *et al* (1985) also examined 73 patients with damage to the lateral ligament of the ankle in a randomised, controlled trial. Some treatment parameters and a full description of the clinical protocol and assessment are given. No other active physiotherapy treatment was given. However, those who were thought to need such management were withdrawn from the study after three days because the authors were concerned about ethical issues; this will undoubtedly have affected the results. No difference was found between those receiving either the active or placebo treatment but these results must be viewed with caution in the light of the limited information concerning dosage parameters and the withdrawal of certain subjects from the trial.

Grant *et al* (1989) evaluated peroneal trauma following childbirth, comparing ultrasound and pulsed electromagnetic energy. Patients were randomly allocated to either of these treatments or to matched placebo groups. The parameters given included frequency and duration (27 MHz; 100 pulses per second, 65-microsecond pulse width, duration ten minutes) but not intensity or power. Pain and healing were assessed immediately after treatment, at ten days and after three months; 90% of all the women, including those in the placebo group, felt that the treatment had helped, but there were no objective differences between the groups.

Livesley *et al* (1991) examined the use of pulsed SWD in the treatment of minimally displaced fractures of the neck of the humerus in a randomised controlled trial. Active treatment parameters given include pulse frequency of 35, but not duration, and a peak power of 300 watts. Intensity is given in terms of the Curapulse machine, 'intensity level 3' being indicated. Both groups additionally received standardised physiotherapy treatment. No significant difference was found between the placebo and active treatment groups.

Differences in treatment parameters and protocols, though not excessive, may account for the diversity of results obtained by these workers. A comparison of the different parameters used by researchers examining the efficacy of pulsed SWD is given in table 2. It can be seen that in many instances the information given is deficient; there are, however, no clear differences between the effective and ineffective groups which could be said to indicate reasons for success or failure to achieve significant clinical results.

Joint Studies

Osteo-arthrosis (OA) is frequently treated by the use of either continuous or pulsed SWD. A number of studies have evaluated the efficacy of such treatments. Quirk *et al* (1985) studied 38 patients with OA of the knee, randomly allocating them to three treatment groups; interferential stimulation plus exercise, continuous SWD plus exercise, and exercise only. Numbers of interventions varied, being less for the last group; SWD was given by the condenser field method for 20 minutes. No further details of treatment are given. The results indicated that all three groups showed a significant and similar decrease in pain levels and an improvement in the mean measure of their clinical condition. This is in keeping with work of Clarke *et al* (1974) who compared ice, continuous shortwave diathermy and placebo shortwave diathermy treatments for OA knees; they noted equal improvement in all three groups at three months after treatment. Chamberlain *et al* (1982) compared continuous SWD plus exercise with exercise alone and found both equally effective in relieving symptoms four weeks after treatment, however, the effect was only maintained at 12 weeks in those who continued the exercises, suggesting that the exercise may have been the effective intervention. Trials are needed which separate the exercise element from the heat element, though some feel that ethical problems may ensue (Quirk *et al*, 1985)

It is difficult to make any judgements concerning the clinical efficacy of these modalities based on these studies. Poor definition of parameters and the complexity of some of these trials, involving numbers of treatment modalities, preclude comparisons and replication. Experimental studies are needed which attempt to establish the types of dosage parameters which are likely to be most effective; these should be followed by clinical trials in which the control and recording of these details is stringent.

Pain Relief

Pain relief due to the use of SWD has been assessed in a number of different conditions. Nwuga (1982), Gibson *et al* (1985) and Wagstaff *et al* (1986) have studied the efficacy of both continuous and pulsed SWD on low back pain. Nwuga (1982) demonstrated that the use of continuous SWD and continuous SWD plus exercise were equally effective in relieving low back pain and suggested that this indicates that continuous SWD is effective in the treatment of low back pain. Gibson *et al* (1985) evaluated the efficacy of continuous SWD, osteopathic treatment and placebo continuous SWD; patients were randomly allocated to three groups, and stratified for age and duration of symptoms; no details are given for any of the types of treatment. All three groups demonstrated similar levels of improvement, about half of the patients showing significant degrees of relief after both two weeks and 12 weeks. The writers suggest that a placebo effect may have been responsible for improvement in all cases.

Wagstaff *et al* (1986) randomly allocated people with low back pain to three groups, receiving either continuous SWD or pulsed magnetic energy of different frequencies. Most details of treatment are given, though the power delivered to patients receiving continuous SWD is lacking. All patients received similar instructions about exercise and were given back care advice. All patients demonstrated significant pain relief, measured with a visual analogue scale, though those receiving pulsed energy experienced greater relief. No placebo or control group was used, making it difficult to draw firm conclusions. The difference between the continous and pulsed groups could be attributed to the use of pulsed energy but it is not possible to judge whether continuous energy had any effect due to the confounding effects of the exercise and advice. The authors, however, appeal to the work of Nwuga (1982) to suggest that continuous SWD is effective in treating low back pain.

Table 2: Pulsed shortwave diathermy: Details of dosage parameters used in clinical trials

Authors	Condition treated	Length of treatment (minutes)	Frequency	Peak power (W)	Average power (W)	Pulse length (micro-seconds)	Pulse frequency per second	Rest time (micro-seconds)	Other details
Pulsed SWD effective									
Ginsberg (1961)	Bursitis	10	—	1,025	40	65	600	1,665	Additional lower dose to liver and adrenals. Max no of visits apparently 34
Aronofsky (1971)	Surgical wound	15	24 hours pre-op, then at 24, 48 and 72 hours	975	38	65	600	N/A	
Wilson (1974)	Inversion injury of ankle	60	Daily for 3 days	975	—	65	N/A	1,600	
Bentall and Eckstein (1975)	Orchidopexy	20	3 x daily for 4 days	—	—	—	500		Dose: level 5 Diapulse. Additional 10 min lower dose to epigastrium
Goldin *et al* (1981)	Skin grafts	30	Pre-op then 6-hourly for 7 days	975	25.3	65	400	N/A	
Nicolle and Bentall (1982)	Blepharoplasty	Continuous	24 hours	—	—	100	1,000	N/A	
Barclay *et al* (1983)	Hand injuries	2 x 30	Daily to discharge	975	>4	65	N/A	1,600	
Pulsed SWD ineffective									
Pasila *et al* (1978)	Ankle and foot sprains	20	Daily for 3 days	—	38* 40†	—	—	—	*Diapulse †Curapulse
Barker et al (1985)	Lateral ligament injuries	45	Daily for 3 days	—	—	—	640	—	Therafield beta: setting 'high'
Grant *et al* (1989)	Peroneal trauma	10	Max of 3 in 36 hrs	—	—	65	100	—	
McGill (1988)	Ankle sprains	3 x 15	3 consec days	—	19.6	—	82 (Hz)	—	
Livesley *et al* (1992)	Fracture head of humerus	30	Daily for 10 days	300	—	—	35	—	Intensity 3 Curapulse

Foley-Nolan *et al* (1990) conducted a double-blind, controlled study to examine the effect of pulsed SWD on persistent neck pain. Subjects had persistent pain of eight weeks or more duration; pulsed SWD was applied via a cervical collar for a minimum of eight hours per day. The mean power supplied was 1.5 mW/cm^2, the pulse width 60 microseconds and the frequency 450 cycles per second. Pain and range of movement were assessed after three and six weeks' treatment. Those receiving active treatment demonstrated an increase in range and a decrease in pain which continued over the full period.

Post-surgical pain has been studied by Reed *et al* (1987), who conducted a randomised double-blind controlled trial to evaluate the effect of using PEME to relieve pain following inguinal herniorrhaphy. They state that no heating effect would result from the active treatment, which recorded a maximum output power of one watt. Full details of method are given. No significant analgesic effect could be detected. Svarcova *et al* (1988) examined the use of pulsed SWD, ultrasound and galvanic current in the relief of pain in 180 subjects suffering from OA of the hip joint. Half of each group also received active drug treatment and the other half placebo drug treatment. The authors concluded that pain relief was considerable for all groups and no significant differences could be found between the groups. Sylvester (1990) claims also significant pain relief in patients suffering from osteo-arthritis of the hip when treated with either continuous SWD and exercise or hydrotherapy; no detail of the SWD treatment is given and, as exercise is given in both treatments, it is impossible to know whether the SWD contributed to the result in any way.

Results again are mixed and the quality of information provided in the studies is very varied. Some descriptions of protocol and dosage are incomplete and numbers vary from 14 and 23 (Sylvester, 1990; Wagstaff *et al*, 1986) to 109 (Gibson *et al*, 1985). Random allocation and control groups are sometimes used and help in controlling variables. The choice of dosage parameters employed varies and appears to do so according to the preferences of the workers rather than being based on previous work and results.

Hazards

Shortwave diathermy results in thermal and, possibly, athermal effects on the tissues. Used carelessly, damage can be caused to the operator or subject. Delpizzo and Joyner (1987) note that the thermal effects of SWD can lead to a number of hazards, the nature of which depends on the specificity of the organ (specialised tissues such as the testes and ovaries may be at risk from SWD – Michaelson, 1990; Delpizzo and Joyner, 1987), the intensity and duration of the exposure and the size and health condition of the individual.

Burns and scalds can arise as the result of overdoses or can arise using normal levels of radiation. Guy *et al* (1974) and Christensen and Durney (1981) have shown that the subcutaneous fat layer is more easily heated than muscle tissue when using capacitor type applicators. Delpizzo and Joyner (1987) recommend that such applicators should not be used for obese patients. The use of applicators making use of the magnetic fields are to be recommended for such subjects. Scalds can easily arise and care should be taken always to use dry towelling materials; all synthetic materials should be avoided, clothing and dressings removed and the part exposed to view. If moisture appears, the writers recommend stopping the treatment, drying the area and then continuing.

Adverse effects from the use of electromagnetic therapy have been noted; a Canadian survey (DHW, 1980) demonstrated that about 4% of patients suffered from increased pain, burns and pacemaker interference.

Cancer cells respond to heating by proliferation, when the temperature achieved is in the region of 40–41 °C, or by death when the temperature rises above this level (Burr, 1974). The temperature developed in a tumour tends to be higher than in the surrounding tissues (Babbs and Dewitt, 1981) and thus, even when very mild thermal heating is being delivered, there is a risk of accelerating cancerous growth with therapeutic diathermy.

SWD has been shown to cause abortion and abnormal fetal development in animal models (Edwards, 1967, 1978). Brown-Woodman *et al* (1989) demonstrated reduced fertility levels in rats following repeated exposure to radiofrequency fields close to a SWD device. Kallen *et al* (1982) demonstrated an above average rate of abortion and abnormal fetal development in physiotherapists in Sweden, following the use of SWD equipment. More recently, Taskinen *et al* (1990) suggested that analysis of data concerning therapists exposed to SWD showed an insignificant relationship between exposure and spontaneous abortion but a significant association with congenital malformations, though only in the low exposure category. However, they conclude that 'the finding of an association between the exposure to shortwaves and congenital malformations does not justify conclusions of a causal relationship'. This evidence, in association with a limited number of other very small studies, would suggest that it is wise, though any danger is not proven, to avoid SWD exposure during pregnancy.

Metals intensify electromagnetic fields and therefore should not be allowed to enter the field; cardiac pacemakers may suffer interference; and loss of pain and thermal sensation contra-indicate SWD (Delpizzo and Joyner, 1987). Copper-bearing intra-uterine devices may, however, be used by both patients and operators as contraceptive devices; Nielson *et al* (1979) calculated the likely rise in temperature in these devices when placed in therapeutic field. They calculated that the rise in temperature would be appreciably less than 1.6 °C and suggest that there is no reason for such devices to be removed prior to treatment.

Care should be taken when positioning machines within the clinical setting as it is possible to produce excessive energy fields due to reflections from metallic filing cabinets, wall mountings and other equipment (Delpizzo and Joyner, 1987). Those operating SWD machinery should be within recommended limits if they remain approximately 1 m from the applicators and 0.5 m from the cables (Delpizzo and Joyner, 1987; DHW, 1983). McDowell and Lunt (1991) examined Megapulse machinery in terms of the fields surrounding machines and possible interference with other equipment such as telephones. He noted that the National Radiation Protection Board limits were exceeded only at distances of less than 50 cm from machines, and thus presented no hazard to staff. Interference with sensitive equipment is possible but the levels are such that damage is unlikely; a 1 m distance is recommended as a precaution.

This view is backed by studies in both the USA (Ruggera, 1980) and Canada (Stuchly *et al*, 1982). Exceptions have however been noted, some machines displaying unwanted power densities (Ruggera, 1980). Regular testing of equipment is recommended to avoid such 'rogue' machines being allowed to operate unchecked.

A code of practice for the safe use of SWD is provided by Delpizzo and Joyner (1987) for the use of therapists in Australia; this reflects the guide lines produced by the Canadian Department of Health and Welfare (DHW) [Canada], 1983). The Electrotherapy Safety Committee of the Chartered Society of Physiotherapy is currently producing a similar document for use by therapists.

Conclusion

Both continuous and pulsed SWD have been used for some time in the management of people with a variety of conditions. Although it is generally accepted that an increase in temperature, such as may be produced by continuous SWD, will result in a number of well-documented physiological effects, few clinical trials have been conducted which examine the efficacy of such treatment in isolation from other therapeutic measures. There is scant evidence for the efficacy of pulsed SWD; it is still not clear whether such treatments are effective in aiding healing and relieving symptoms in both the experimental situation and in clinical conditions. Trials are required which systematically examine different dosage parameters and treatment protocols in both situations. Specific clinical conditions must be examined and both acute and chronic complaints should be evaluated. Ways need to be found of minimising the confounding effects of adjunct therapy if it proves unacceptable to remove them altogether.

Further well defined and controlled trials are needed to discover the effects and benefits that these forms of treatment may offer in certain defined situations.

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References

Abramson, D L, Bell, Y, Rejal, H, Tuck, S, Burnett, C and Fleischer, C J (1960). 'Changes in blood flow, oxygen uptake and tissue temperatures produced by therapeutic physical agents', *American Journal of Physical Medicine*, **39**, 87–95.

Abramson, D L, Chu, L S W, Tuck, S, Lee, S W, Richardson, G and Levin, M (1966). 'Effect of tissue temperature and blood flow on motor nerve conduction velocity', *Journal of the American Medical Association*, **198**, 1082–88.

Adey, W R (1981). 'Electromagnetic field effects on tissue', *Physiological Review*, **61**, 3, 436–514.

Adey, W R (1988). 'Physiological signalling across cell membranes and co-operative influences of extremely low frequency electromagnetic fields' in: Frohlich, H (ed) *Biological Coherence and Response to External Stimuli*, Springer Verlag, Heidelberg.

Aronofsky, D H (1971). 'Reduction of dental post-surgical symptoms using non-thermal pulsed high-peak-power electromagnetic energy', *Oral Surgery*, 32, 5, 688–696.

Babbs, C F and Dewitt, D P (1981). 'Physical principles of local heat therapy for cancer', *Medical Instrumentation* (USA), 15, 367–373.

Bansal, P S, Sobti, V K and Roy, K S (190). 'Histomorphochemical effects of shortwave diathermy on healing of experimental muscle injury in dogs', *Indian Journal of Experimental Biology*, **28**, 766–770.

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

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

Basford, J R (1989). 'Low energy laser therapy: Controversies and new research findings', *Lasers in Surgery and Medicine*, **9**, 1–5.

Benson, T B and Copp, E P (1974). 'The effect of therapeutic forms of heat and ice on the pain threshold of the normal shoulder', *Rheumatology and Rehabilitation*, 13, 101–104.

Bentall, R H C and Eckstein, H B (1975). 'A trial involving the use of pulsed electromagnetic therapy on children undergoing orchidopexy', *Kinderchirugie*, **17**, 4, 380–389.

Brown, M and Baker, R D (1987). 'Effect of pulsed shortwave diathermy on skeletal muscle injury in rabbits', *Physical Therapy*, **67**, 2, 208–214.

Brown-Woodman, P D C, Hadley, J A, Richardson, L, Bright, D and Porter, D (1989). 'Evaluation of reproductive function of female rats exposed to radio frequency fields (27.12 MHz) near a shortwave diathermy device', *Health Physics*, **56**, 4, 521–525.

Burr, B (1974). 'Heat as a therapeutic modality against cancer', Report 16, US National Cancer Institute, Bethesda, Maryland.

Cameron, B M (1961). 'Experimental acceleration of wound healing', *American Journal of Orthopaedics*, 3, 336–343.

Chamberlain, M A, Care, G and Gharfield, B (1982). 'Physiotherapy in osteo-arthrosis of the knee', *Annals of Rheumatic Diseases*, **23**, 389–391.

Christensen, D A and Durney, C H (1981). 'Hyperthermia production for cancer therapy — A review of fundamentals and methods', *Journal of Microwave Power*, **16**, 89–105.

Clarke, G R, Willis, L A, Stenners, L and Nichols, P J R (1974). 'Evaluation of physiotherapy in the treatment of osteo-arthrosis of the knee', *Rheumatology and Rehabilitation*, **13**, 190–197.

Constable, J D, Scapicchio, A P and Opitz, B (1971). 'Studies of the effects of Diapulse treatment on various aspects of wound healing in experimental animals', *Journal of Surgical Research*, **11**, 254–257.

Currier, D P and Nelson, R M (1969). 'Changes in motor conduction velocity induced by exercise and diathermy', *Physical Therapy*, **49**, 2, 146–152.

Delpizzo, V and Joyner, K H (1987). 'On the safe use of microwave and shortwave diathermy units', *Australian Journal of Physiotherapy*, **33**, 3, 152–162.

Department of Health (1987). 'Evaluation Report: Shortwave therapy units', *Journal of Medical Engineering and Technology*, **11**, 6, 285–298.

Department of Health and Welfare (Canada) (1980). 'Canada wide survey of non-ionising radiation-emitting medical devices', 80-EHD-52.

Department of Health and Welfare (Canada) (1983). 'Safety code 25; Shortwave diathermy guidelines for limited radio frequency exposure', 80-EHD-98.

Dyson, M and Luke, D A (1986). 'Induction of mast cell degranulation in skin by ultrasound', Institute of Electrical and Electronic Engineers Transactions in Ultrasonics, *Ferroelectrics and Frequency Control*, UFFC-33, 194–201.

Edwards, M J (1967). 'Congenital defects in guinea pigs following induced hyperthermia during gestation', *Archives of Pathology and Laboratory Medicine*, **84**, 42–48.

Edwards, M J (1978). 'Congenital defects due to hyperthermia', *Advances in Veterinary Sciences and Comparative Medicine*, **22**, 29–52.

Erdman, W J (1960). 'Peripheral blood flow measurements during application of pulsed high frequency currents', *American Journal of Orthopaedics*, **2**, 196–197.

Fenn, J E (1969). 'Effect of pulsed electromagnetic energy (Diapulse) on experimental haematomas', *Canadian Medical Association Journal*, **100**, 251–253.

Foley-Nolan, D, Barry, C, Coughlan, R J, O'Connor, P and Roden, D (1990). 'Pulsed high frequency (27 MHz) electromagnetic therapy for persistent neck pain', *Orthopaedics*, **13**, 4, 445–451.

Frohlich, H (ed) (1988). *Biological Coherence and Response to External Stimuli*, Springer Verlag, Heidelberg.

Gibson, T, Grahame, R, Harkness, J, Woo, P, Blagrave, P and Hills, R (1985). 'Controlled comparison of shortwave diathermy treatment with osteopathic treatment in non-specific low back pain', *The Lancet*, June 1, 1258–61.

Ginsberg, A J (1961). 'Pulsed shortwave in the treatment of bursitis with calcification', *International Record of Medicine*, **174**, 2, 71–75.

Goldin, J H, Broadbent, N R G, Nancarrow, J D and Marshall, T (1981). 'The effects of Diapulse on the healing of sounds: 'A double blind randomised controlled trial in man', *British Journal of Plastic Surgery*, **34**, 267–270.

Grant, A, Sleep, J, McIntosh, J and Ashurst, H (1989). 'Ultrasound and pulsed electromagnetic energy treatment for peroneal trauma. A randomised placebo-controlled trial', *British Journal of Obstetrics and Gynaecology*, **96**, 434–439.

Guy, A W (1982). 'Biophysics of high frequency currents and electromagnetic radiation' In: Lehmann, J F (ed) *Therapeutic Heat and Cold* (3rd edn) Williams and Wilkins, Baltimore.

Guy, A W, Lehmann, J F and Stonebridge, J B (1974). 'Therapeutic applications of electromagnetic power', *Proceedings of the International Electrical and Electronic Engineers*, **62**, 55–75.

Hansen, T I and Kristensen, J H (1973). 'Effect of massage, shortwave diathermy and ultrasound upon ^{133}Xe disappearance rate from muscle and subcutaneous tissue in the human calf', *Scandinavian Journal of Rehabilitation Medicine*, 5, 179–182.

Harris, R (1963). 'The effect of various forms of physical therapy on radio sodium clearance from the normal and arthritic knee joint', *Annals of Physical Medicine*, **7**, 1–10.

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

Kallen, B, Malmquist, G and Moritz, U (1982). 'Delivery outcome among physiotherapists in Sweden: Is non-ionising radiation a fetal hazard?' *Archives of Environmental Health*, **37**, 81–84. Reprinted in *Physiotherapy* (1992) **78**, 1, 15–18.

Kaplan, E G and Weinstock, R E (1968). 'Clinical evaluation of Diapulse as adjunctive therapy following foot surgery', *Journal of the American Podiatric Association*, **58**, 218–221.

Karu, T I (1988). 'Molecular mechanism of the therapeutic effects of low intensity laser irradiation', *Lasers in Life Science*, **2**, 53–74.

Krag, C, Taudorf, U, Slim, E and Bolund, S (1979). 'The effect of pulsed electromagnetic energy (Diapulse) on the survival of experimental skin flaps', *Scandinavian Journal of Plastic and Reconstructive Surgery*, **13**, 377–380.

Lehmann, J F (1971). 'Diathermy' in: Krusen, F H, Kottke, F J and Elwood, J (eds) *Handbook of Physical Medicine and Rehabilitation*, W B Saunders, Philadelphia.

Lehmann, J F and de Lateur, B J (1982). 'Therapeutic heat' in: Lehmann, J F (ed) *Therapeutic Heat and Cold* (3rd edn) Williams and Wilkins, Baltimore.

Lehmann, J F, de Lateur, B J and Stonebridge, J B (1969). 'Selective muscle heating by shortwave diathermy with a helical coil', *Archives of Physical Medicine*, **50**, 117–123.

Lehmann, J F, McDougall, J A, Guy, A W, Warren, C G and Esselman, P C (1983). 'Heating patterns produced by shortwave diathermy applicators in tissue substitute models', *Archives of Physical Medicine and Rehabilitation*, **64**, 575–577.

Livesley, P J, Mugglestone, A and Whitton, J (1992). 'Electrotherapy and the management of minimally displaced fracture of the neck of the humerus', *Injury*, in press.

Low, J and Reed, A (1990). *Electrotherapy Explained: Principles and practice*, Butterworth-Heinemann, London.

McDowell, A D and Lunt, M J (1991). 'Electromagnetic field strength measurements on Megapulse units', *Physiotherapy*, **77**, 12, 805–809.

McGill, S N (1988). 'The effect of pulsed shortwave therapy on lateral ligament sprain of the ankle', *New Zealand Journal of Physiotherapy*, **10**, 21–24.

Michaelson, S M (1990). 'Effects of high frequency currents and electromagnetic radiation' in: Lehmann, H F (ed) *Therapeutic Heat and Cold* (4th edn) Williams and Wilkins, Baltimore.

Millard, J B (1961). 'Effect of high frequency currents and infra-red rays on the circulation of the lower limb in man', *Annals of Physical Medicine*, **6**, 2, 45–65.

Morrissey, L J (1966). 'Effects of pulsed shortwave diathermy upon volume blood flow through the calf of the leg. Plethysmography studies', *Journal of the American Physical Therapy Association*, **46**, 946–952.

Nadasdi, M (1960). 'Inhibition of experimental arthritis by athermic pulsing shortwave in rats', *American Journal of Orthopaedics*, **2**, 105–107.

Nicolle, F V and Bentall, R M (1982). 'The use of radiofrequency pulsed energy in the control of post-operative reaction to blepharoplasty', *Anaesthetic Plastic Surgery*, **6**, 169–171.

Nielson, N C, Hansen, R and Larsen, T (1979). 'Heat induction in copper bearing IUDs during shortwave diathermy', *Acta Obstetrica et Gynaecologica Scandinavica* (Stockholm), **58**, 495.

Nwuga, G B (1982). 'A study of the value of shortwave diathermy and isometric exercise in back pain management', *Proceedings of the IXth International Congress of the WCPT*, Legitimerader Sjukgymnaster Riksförbund, Stockholm, Sweden, 355–357.

Pasila, M, Visuri, T and Sundholm, A (1978). 'Pulsating shortwave diathermy: Value in treatment of recent ankle and foot sprains', *Archives of Physical Medicine and Rehabilitation*, **59**, 383–386.

Quirk, A S, Newman, R J and Newman, K J (1985). 'An evaluation of interferential therapy, shortwave diathermy and exercise in the treatment of osteo-arthrosis of the knee', *Physiotherapy*, **71**, 2, 55–57.

Raji, A M (1984). 'An experimental study of the effects of pulsed electromagnetic field (Diapulse) on nerve repair', *The Journal of Hand Surgery*, **9-B**, 2, 105–112.

Reed, M W R, Bickerstaff, D R, Hayne, C R, Wyman, A and Davies, J (1987). 'Pain relief after inguinal herniorrhaphy. Ineffectiveness of pulsed electromagnetic energy', *British Journal of Clinical Practice*, **41**, 6, 782–784.

Ruggera, P S (1980). 'Measurement of emission levels during microwave and shortwave diathermy treatments', Bureau of Radiological Health Report, HHS Publication (FDA), 80–8119.

Schwan, H P (1970). 'Interaction of microwave and radio frequency radiation with biological systems' in: Cleary, S F (ed) *Biological Effects and Health Implications of Microwave Radiation*, US Department of Health, Education and Welfare, Washington.

Silverman, D R and Pendleton, L A (1968). 'A comparison of the effects of continuous and pulsed shortwave diathermy on peripheral circulation', *Archives of Physical Medicine and Rehabilitation*, **49**, 429–436.

Stuchly, M A, Repacholi, M H, Lecuyer, D W and Mann, R D (1982). 'Exposure to the operator and patient during shortwave diathermy treatments', *Health Physics*, **42**, 3, 341–366.

Svarcova, J, Trnavsky, K and Zvarova, J (1988). 'The influence of ultrasound, galvanic currents and shortwave diathermy on pain intensity in patients with osteo-arthritis', *Scandinavian Journal of Rheumatology*, supplement **67**, 83–85.

Sylvester, K L (1990). 'Investigation of the effect of hydrotherapy in the treatment of osteo-arthritic hips', *Clinical Rehabilitation*, **4**, 223–228.

Taskinen, H, Kyyronen, P and Hemminki, K (1990). 'The effects of ultrasound, shortwaves and physical exertion on pregnancy outcome in physiotherapists', *Journal of Epidemiology and Community Health*, **44**, 196–201.

Tsong, T Y (1989). 'Deciphering the language of cells', *Trends in the Biological Sciences*, **14**, 89–92.

Vanharanta, H (1982). 'Effect of shortwave diathermy on mobility and radiological stage of the knee in the development of experimental osteo-arthritis', *American Journal of Physical Medicine*, **61**, 2, 59–65.

Verrier, M, Falconer, K and Crawford, J S (1977). 'A comparison of tissue temperature following two shortwave diathermy techniques', *Physiotherapy Canada*, **29**, 1, 21–25.

Wagstaff, P, Wagstaff, S and Downie, M (1986). 'A pilot study to compare the efficacy of continuous and pulsed magnetic energy (shortwave diathermy) on the relief of low back pain', *Physiotherapy*, **72**, 11, 563–566.

Wilson, D H (1972). 'Treatment of soft tissue injuries by pulsed electrical energy', *British Medical Journal*, **2**, 269–270.

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

Wyper, D J and McNiven, D R (1976). 'Effects of some physiotherapeutic agents on skeletal muscle blood flow', *Physiotherapy*, **63**, 3, 83–85.