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1994 Physiol. Meas. 15 201

(http://iopscience.iop.org/0967-3334/15/2/008)

Physiol. Meas. 15 (1994) 201–216. Printed in the UK

An evaluation of safe practices to restrict exposure to electric and magnetic fields from therapeutic and surgical diathermy equipment

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Received 22 November 1993

Abstract. Stray electric and magnetic fields have been measured near to therapeutic and surgical diathermy equipment for many different treatments. The highest field strengths are associated with continuous wave (CW) 27 MHz therapeutic diathermy equipment for which fields above national reference levels extend for 1 m from the electrodes and cables. The extent of the fields does not vary substantially with the type of treatment being performed. Recommendations that operators remain 1.0 m from CW therapeutic diathermy equipment, 0.5–0.8 m from pulsed treatments with capacitive electrodes and 0.2 m from pulsed inductive applicators can be applied to restrict exposure for any treatment with each type of unit. In a proposed European Community (EC) directive, action levels similar in magnitude to the reference levels are used to trigger requirements for assessments of hazard, measures to reduce exposure and personnel training. Assessments and appropriate recommendations of measures to reduce exposure can be linked to the type of equipment. Fields associated with electrosurgical units operating at frequencies of 0.3–0.5 MHz only approached reference levels within 20–30 cm of the cables, and because of the relatively short durations of the emissions, precautions were considered unnecessary with the units tested.

1. Introduction

Possible hazards from exposure to electromagnetic fields have been reviewed extensively in recent years (NCRP 1986, Michaelson 1991, Saunders *et al* 1992, Bernhardt 1992). Reference or investigation levels have been recommended to provide guidance on field strengths at which precautions should be taken to restrict worker exposure (IRPA/INIRC 1988, NRPB 1989, 1993). A proposal for a European Community (EC) directive (EC 1993), which would formalize requirements for specific control measures, has been made.

In hospitals and health clinics, significant stray electric and magnetic fields may be associated with therapeutic and surgical diathermy equipment. In physiotherapy departments short-wave (27 MHz) and microwave (434 and 2.45 GHz) diathermy are used to treat a variety of conditions. Short-wave diathermy uses either a pair of electrodes positioned near to the part of the body to be treated, the capacitive method, or a coil placed close to the body surface, the inductive method. The therapeutic effect of continuous wave (CW) diathermy is thermal, but in recent years pulsed diathermy, for which athermal effects are claimed, has become widely used (Kitchen and Partridge 1992). Studies have been published on stray fields from therapeutic shortwave and microwave diathermy equipment (Ruggera 1980,

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Moseley and Davison 1981, Stuchly *et al* 1982, Lau and Dunscombe 1984, Martin *et al* 1990, Moseley 1990, McDowell and Lunt 1991) and broad recommendations on working practices have been made (Delpizzo and Joyner 1987, Martin *et al* 1991, CSP 1991, Docker *et al* 1992). In this study electric and magnetic field distributions have been investigated for different types of equipment. Field strengths have been measured for a variety of diathermy treatments performed on different units in order to determine whether recommendations can be made which are appropriate for the whole range of treatments carried out.

Surgical diathermy units operating in the frequency range 0.3–1 MHz are employed in operating theatres and clinics for cutting and coagulating tissue. The electrosurgical knife forms the active electrode of a monopolar electrosurgical unit and a dispersive electrode of area 100–200 cm^2 is placed on a suitable area of skin close to the operation site, such as a thigh or buttock, to take the return current to the generator. A 4–8 kV waveform is applied and an arc is formed between the active electrode and the tissue. This localizes heat deposition, vaporizing cells and thereby cutting tissue. The units can also produce pulses with a repetition frequency of tens of kHz alternately heating the tissue and allowing it to cool, thereby producing coagulation. A number of different blend options are available, combining the properties of cutting and coagulation, and there is a bipolar coagulation mode in which current flows between two electrodes separated by 5–10 mm. Some measurements have been made of stray electric and magnetic fields near to electrosurgical units (Fox *et al* 1976, Ruggera 1977, Paz *et al* 1987). the units tested operated at frequencies between 0.5 and 2.4 MHz, but emitted a range of frequencies up to 100 MHz. Only limited data are available on fields associated with units currently in use. In this study electric and magnetic fields have been assessed during a variety of procedures with two electrosurgical units, using detectors sensitive over different frequency ranges. The results have been used to determine whether any precautions need to be considered with the recommended reference levels.

2. Recommended reference, investigation and action levels

Levels recommended to limit personnel exposure are designed to protect against thermal effects, radiofrequency burn and electric shocks. A maximum specific absorption rate (SAR) of energy of 0.4 W kg^{-1} is recommended for the average absorption in the body over a period of 6 min (IRPA/INIRC 1988). Additional localized SAR restrictions are applied of 10 W kg^{-1} for any 0.1 kg of internal organ or tissue in the head and trunk and 20 W kg^{-1} for any 0.1 kg in the limbs. Suggested occupational field strength exposure limits (IRPA/INIRC 1988), and reference levels recommended for the UK (NRPB 1989) are given in table 1. These have been derived using the SAR values and taking account of resonant absorption by the human body in the frequency range 10–500 MHz. Revised investigation levels (NRPB 1993) are also included in the table. These involve a slight reduction of levels in the region of body resonance and a small relaxation of restrictions in other frequency ranges. No additional restrictions for pregnant staff are recommended in current guidance, but an additional restriction that the localized SAR should not exceed 10 W kg^{-1} in any 10 g of foetal tissue is included in the NRPB (1993) recommendations.

The proposed EC (1993) directive includes various levels used to trigger actions. Ceiling levels of SARs in the human body are similar in magnitude to values recommended by the NRPB (1989), with a limit for contact current of 50 mA. There would be a general requirement to minimize risks and provide information for workers at thresholds equal to one fifth of the ceiling levels. Action levels for electric and magnetic field strength, equal to the reference levels of the NRPB (1989), would trigger requirements for hazard assessments

Table 1. Reference, investigation and action levels. Figures in brackets apply to areas where there is no access for children.

	IRPA/INIRC (1988)		NRPB (1989) EC (1993)			NRPB (1993)	
Frequency (MHz)	*E* field ($V m^{-1}$)	*H* field ($A m^{-1}$)	*E* field ($V m^{-1}$)	*H* field ($A m^{-1}$)	Power density ($W m^{-2}$)	*E* field ($V m^{-1}$)	*H* field ($A m^{-1}$)
0.300	614	5.3	614	16.3	—	1000	64
0.500	614	3.2	614	9.8	—	1000	64
27.12	61	0.16	61.4	0.18	—	50 (60)	0.13
434	62.5	0.167	64.0	0.17	10.8	100 (137)	0.26
2450	137	0.36	137	0.364	50	194	0.52

and field measurements, provision of information and training for workers, and supply of personal protective equipment where appropriate. A second action level of 1.6 times the first would require employers to establish a programme of control measures and restrict access to hazardous areas, while a third action level, three times the first, would require marking of equipment and notification of activities.

3. Methods

Both electric and magnetic fields should be measured at frequencies below 30 MHz in order to assess the possible hazard. Several isotropic probe detectors were used: a model 8716 meter (Microwave-Narda, USA) with magnetic field probes 8731 (10–300 MHz) and 8754 (300 kHz–10MHz), and electric field probe 8761 (300 kHz–1 GHz), and a Raham Model 4 meter (200 kHz–26 GHz) (General Microwave Corporation, USA). The Narda probes and meter were calibrated at the start of the study by the Narda Microwave Corporation. The meters are calibrated in terms of power density (S), which in a plane wave field is related to the squares of the electric or magnetic field strengths by the equation

$$S = H^2 Z = E^2/Z$$

where H and E are the root mean square values of the electric and magnetic field strengths and Z is the impedance of the medium. In a pulsed field, the probe response is a time average given by

$$S = pfH^2 Z = pfE^2/Z$$

where p is the pulse length and f the pulse repetition frequency. Some equipment also emits bursts of pulses (e.g. one in three or two in three). The probe response for a pulsing regime of a in b is given by

$$S = a/b(pfH^2 Z) = a/b(pfE^2/Z).$$

Results are quoted in terms of field strengths, and for pulsed units the field strengths derived from time averages of the squares $(H^2)_{av}$ and $(E^2)_{av}$ are used, as these are related to the heating effect. These are given by $(H^2)_{av} = pfH^2$ and $(E^2)_{av} = pfE^2$ for regular sequences of pulses, and $(H^2)_{av} = (a/b)pfH^2$ and $(E^2)_{av} = (a/b)pfE^2$ for bursts of pulses.

Electrotherapy treatments with a number of electrode configurations were monitored with both patients and phantoms in the Physiotherapy Department at Woolmanhill Clinics and in the Bio-Medical Physics and Bio-Engineering Department, Aberdeen Royal Hospitals (ARH). Limited ranges of measurements were carried out in other departments. The units investigated were three pulsed 27 MHz units (Curapuls 419, Enraf-Nonius; Megapulse, EMS; Erbotherm 11OP, EMS), three CW 27 MHz units (Ultratherm 608 and 708S, Siemens; Megatherm Jnr Mk 5, EMS), one CW 434 MHz unit (Sieretherm 609S, Siemens) and one CW 2.45 GHz unit (Microtron 200, EMS). Phantom simulations of the most common treatments were carried out using bodies made up from 5 and 1 l plastic modules filled with saline of conductivity 600 mS m^{-1}, which is similar to that of muscle tissue at 27 MHz (Guy *et al* 1974). Grids of 200 mm squares were marked on the floor around therapeutic diathermy units, and field strengths measured at intersections in a horizontal plane at the same height as the electrodes. These data were used to generate contour plots of field distributions around equipment. Diathermy treatments of many parts of the body are carried out using a variety of electrode configurations with different power and pulse settings. A survey of unit settings for 450 therapeutic diathermy treatments in 14 physiotherapy departments with 22 units was used to determine typical treatment settings. In order to determine how much variation there was between treatments, measurements were made of distances perpendicular to the direction of the electrode supporting arms and cables at which reference levels were exceeded for a selection of treatments with the settings most frequently used. Some measurements were made during patient treatments, and for others a whole-body phantom was used. Measurements were made with several Curapuls, Megapulse and Ultratherm units to investigate how much stray fields varied from one unit to another.

Electric and magnetic field strengths around surgical diathermy units were measured during a variety of surgical procedures in the Theatre G block of ARH. There are 50 electrosurgical units in use in eight hospitals in Grampian, most of which operate between 0.3 and 0.5 MHz. The units monitored were the Eschmann TD 300 (300 kHz), one of the most widely used units in the region, and the Valleylab Force 2 (500 kHz), which is used for some of the procedures requiring higher power settings. Surgical procedures were also simulated using legs of pork incorporated into a body made up of saline-filled modules.

4. Results and discussion

4.1. Physiotherapy 27 MHz diathermy equipment

Plots of field strength distributions during capacitive electrode treatments with CW and pulsed short-wave diathermy and during a treatment with a pulsed inductive pancake coil applicator unit are shown in figures 1, 2 and 3, respectively. These represent examples of the three main categories into which it is useful to divide short-wave diathermy treatments when considering the stray fields. The field strengths associated with CW treatments are significantly larger than those with the pulsed treatments. Higher magnetic fields were associated with the connecting cables, which are unshielded. Fields of similar magnitude extend from the generator to the electrodes. The electric fields were greater around the electrodes and decreased with distance from the electrodes in all directions, although there were high localized fields close to the cables. The positions of the cables produced hot spots, such as that near the left hand cable in figure 2(a) caused by a section of vertical cable. Regions beyond the patient were usually shielded by the patient's body, causing the field strength to fall rapidly. Magnetic field strengths associated with the cables of inductive applicators were greater than the electric ones (figure 3), but both field strengths were lower

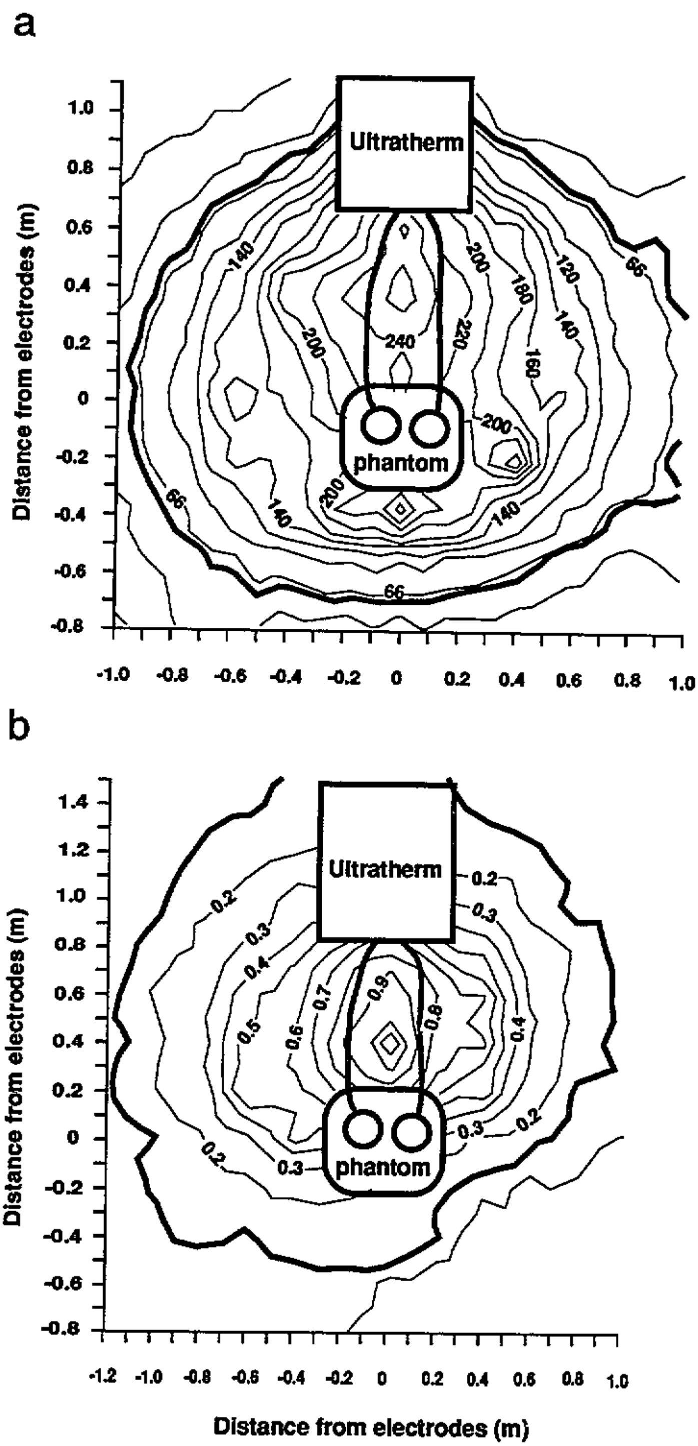


Figure 1. Maps of stray field strength distributions around an Ultratherm 608 cw 27.12 MHz unit during a co-planar treatment of a back, with power setting four: (a) electric field in V m^{-1} and (b) magnetic field in A m^{-1}. Contours at the NRPB (1989) reference levels are marked as thicker solid lines.

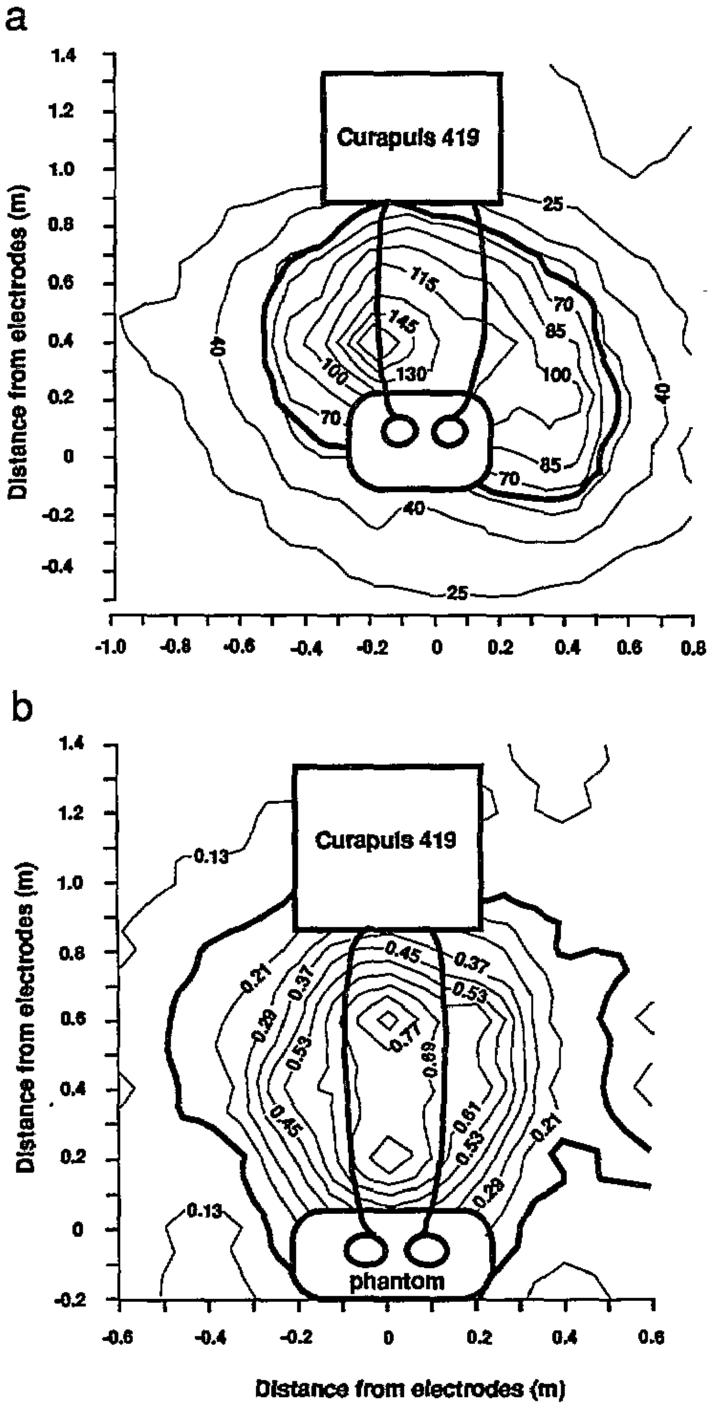
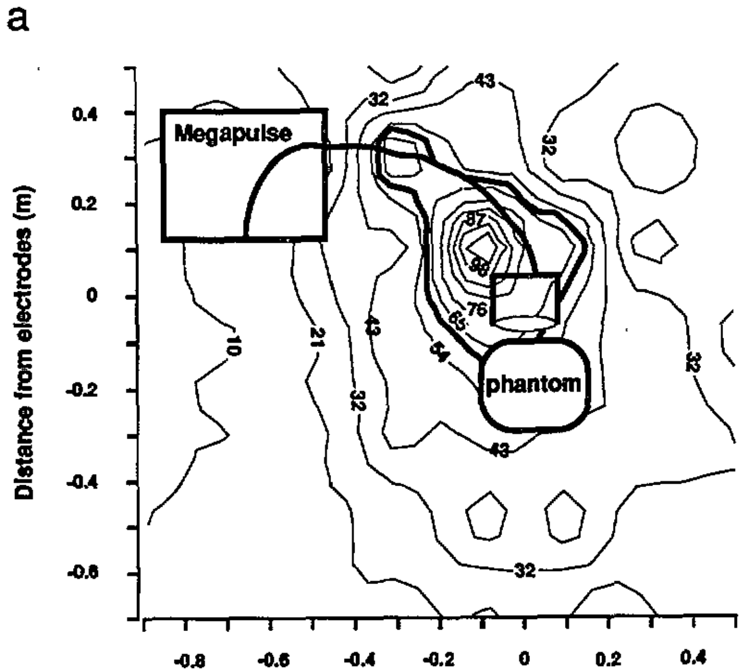


Figure 2. Maps of stray field strength distributions around a Curapuls 419 pulsed 27.12 MHz unit during a co-planar treatment of a back, with power setting five and pulse setting 110: (a) electric field in V m^{-1} and (b) magnetic field in A m^{-1}. Contours at the NRPB (1989) reference levels are marked as thicker solid lines.



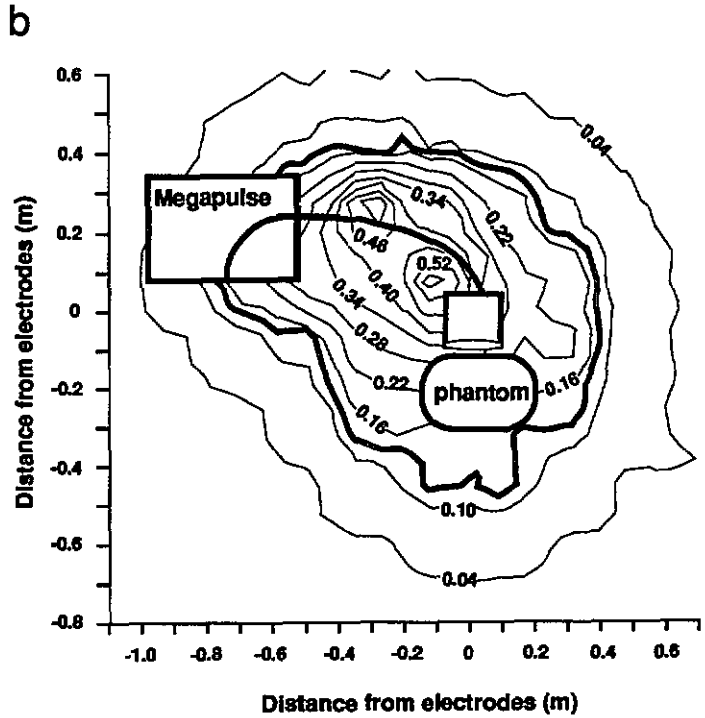


Figure 3. Maps of stray field strength distributions around a Megapulse pulsed 27.12 MHz inductive applicator treatment of a shoulder, with pulse frequency 600 Hz and pulse duration 200 μs: (a) electric field in V m^{-1} and (b) magnetic field in A m^{-1}. Contours at the NRPB (1989) reference levels are marked as thicker solid lines.

than with capacitive treatments. Faraday cages incorporated into applicators such as the *Curapuls Circuplode* greatly reduce stray radiated fields (Health Devices 1979). The field strengths measured were of similar magnitude to those found in other studies on individual units (Stuchly *et al* 1982, Moseley 1990, McDowell and Lunt 1991).

There are many factors affecting the extent of stray fields from diathermy units apart from the power and pulse settings. Magnitudes of stray fields associated with contraplanar treatments, where the electrodes are placed on opposite sides of the part of the body to be treated, tend to be greater than those with co-planar configurations. Field strengths varied by 20–30% with electrodes having diameters between 6 cm and 14 cm. In addition, as the electrode separation increased field strengths decreased in the region of the phantom. For the assessments of distances from units at which reference levels were exceeded, the electric field strengths were measured at the height of the electrodes in the region between the centre of the cables and the electrodes, and the magnetic field strengths were recorded near the mid-point of the cables, as suggested by examination of figures 1–3. Distances were measured in the direction perpendicular to the suspending arms and cables, and taken from the edge of the electrode or cable closest to the detector probe. The results are given in table 2 and are divided into four sections, corresponding to the categories CW 27 MHz, pulsed capacitive 27 MHz, pulses inductive 27 MHz and microwave. Figures 1–4 give examples of distributions for these categories. Data for a hinged inductive electrode called a flexiplode used with Curapuls units are included. An indication of the frequency with which each setting was used for a particular treatment was determined from the survey data (table 2). The Curapuls and Megapulse units had a range of power and pulse settings and the choice varied in different hospitals, so the percentage of treatments performed with any one combination was small, whereas with CW units, where the only option was the power level, most departments used settings at the lower end of the range.

Similar measurements were repeated with two Ultratherm 608, three Megapulse and eight Curapuls 419 units, which gave variations in field strength of 20%–30%. Fluctuations of 50%–75% in power output corresponding to 20%–30% in field strength have been reported with variations of 25% in the line voltage (Health Devices 1979). Variations of this magnitude cause differences of less than 0.1 m in the extent of the fields above the reference level, because of the rapid fall off in the field strength with distance. Differences in the extents of the fields from CW units were relatively small, but differences between pulsed units may be larger because of the variety in pulsing regimes, in addition to differences in electrode design and screening. Fields for the treatments performed with the Erbotherm Unit were greater than those with the Curapuls 419 Unit (table 2). Differences between units of different types have been reported in Health Devices (1979).

The results showed that for CW capacitive treatments, fields above the reference level extended for 0.8–1.1 m (table 2), whereas for the pulsed capacitive treatments fields generally extend for 0.4–0.8 m from the equipment. Fields with CW options available on pulsed units also extended for 1 m from the cables and electrodes. A recent survey by Moseley (1990) measured fields above the reference level up to 1.5 m from one unit. Pulsed treatments with inductive applicators only gave rise to fields above the reference levels at distances up to 0.1–0.4 m using typical treatment settings (table 2). The range of distances resulted primarily from differences in power levels used for various treatments. On the highest power settings, the extents of fields above the reference levels were about 0.1 m greater than the distances in table 2 for all units, but these settings were not used for any patient treatments during the survey period. The proportion of all short-wave treatments with fields extending further than the distances quoted was less than 1%. Thus it is reasonable to recommend single safe working distances, which can be applied to each category of

Table 2. Distances from cables and electrodes at which reference field strengths are exceeded for a selection of physiotherapy diathermy treatments. (The table is split into four groups of treatments: A, cw 27 MHz; B, pulsed capacitive 27 MHz; C, pulsed inductive 27 MHz and D, cw microwave.) cw, continuous wave; U6, Ultratherm 608; U7, Ultratherm 708S; MT, Megatherm Jnr Mk 5; SI, Sieretherm 609S; MI, Microtron 200; CU, Curapuls 419, ER, Erbotherm 110P; ME, Megapulse; CN, contraplanar; CO, coplanar; IM, inductive monode applicator; IF, inductive flexiplode; RA, 20 cm applicator; RB, 8 cm applicator; RC, 3.5 cm applicator.

Group	Unit and electrode configuration	Frequency (MHz)	Treatment	Power setting	Pulse setting	Distance E-field level exceeded (m)	Distance H-field level exceeded (m)	Percentage of treatments on unit (%)
A	U6 CO	27.12	back	4	cw	1.0	0.8	74
A	U6 CO	27.12	shoulder	2	cw	0.8	0.7	50
A	U6 CN	27.12	hip	3	cw	0.9	0.8	50
A	U7 CO	27.12	back	4	cw	1.1	0.9	70
A	MT CN	27.12	shoulder	4	cw	1.1	0.7	75
A	MT CN	27.12	knee	4	cw	1.1	0.7	80
A	CU CO	27.12	back	4	cw	1.0	1.1	10
B	CU CN	27.12	shoulder	3	26	0.2	0.2	6
B	CU CN	27.12	shoulder	5	110	0.5	0.4	8
B	CU CN	27.12	shoulder	6	150	0.6	0.5	8
B	CU CO	27.12	back	4	82	0.4	0.5	10
B	CU CO	27.12	back	5	110	0.5	0.6	10
B	CU CO	27.12	back	7	200	0.7	0.8	2
B	CU CO	27.12	hip	5	82	0.5	0.6	18
B	CU CO	27.12	hip	6	35	0.4	0.5	14
B	CU CN	27.12	knee	2	20	0.4	0.3	8
B	CU CN	27.12	knee	4	82	0.6	0.5	12
B	CU CN	27.12	knee	5	110	0.7	0.6	6
B	ER CO	27.12	back	3	30	0.7	—	10
B	ER CN	27.12	shoulder	5	50	0.8	—	55
C	CU IM	27.12	hip	5	110	0.0	0.1	4
C	CU IF	27.12	shoulder	5	82	0.1	0.2	6
C	CU IF	27.12	hip	6	62	0.1	0.2	9
C	ME IM	27.12	shoulder	400	100 2:3	0.2	0.3	25
C	ME IM	27.12	shoulder	800	400 2:3	0.3	0.4	10
C	ME IM	27.12	back	600	200 2:3	0.3	0.4	17
C	ME IM	27.12	knee	400	100 1:3	0.2	0.3	21
C	ME IM	27.12	wrist	600	65 1:3	0.2	0.3	40
C	ER IM	27.12	knee	5	50	0.4	0.4	80
D	ST CN	434	hip	5	cw	0.9	—	67
D	ST CN	434	knee	3	cw	0.8	—	75
D	ST IM	434	neck	4	cw	0.0	—	67
D	MI RA	2450	neck	50 W	cw	0.4	—	50
D	MI RA	2450	back	100 W	cw	0.5	—	50
D	MI RB	2450	back	50 W	cw	0.2	—	10
D	MI RC	2450	—	10 W	cw	0.2	—	—

treatment. The reference levels take account of possible resonant absorption effects in the human body. The extent of the fields associated with cw short-wave equipment is such as to make resonant absorption effects a possibility, but because of the more limited extent of fields around pulsed equipment resonant absorption effects are less likely to occur. Thus if operators stand 1 m from electrodes and cables of CW treatments, 0.5–0.8 m from pulsed capacitive treatments and 0.2 m from pulsed inductive ones, there should be little risk of exceeding recommended SAR levels. The recommendations for CW equipment concur with those proposed in recent guidance issued by the Chartered Society of Physiotherapy (Docker *et al* 1992). Suggested changes in reference or investigation levels proposed by the NRPB (1993) lower the 27 MHz level by 20%–30% (table 1). Field strengths above these revised levels would only extend for a further 0.05–0.1 m than the values quoted in table 2 and thus would make little difference to basic recommendations.

4.2. Microwave therapy equipment

Fields above the reference level for 434 MHz extended for 0.8–1.0 m from the electrodes and cables of the unit tested (table 2). 434 MHz lies within the range where resonant absorption could occur in the foetus, but mathematical simulations suggest that the SAR at field strengths equal to the reference level would be of the order of 0.1 W kg^{-1} (Fleming and Joyner 1992) compared to the limiting value of 0.4 W kg^{-1} for wholebody exposures (NRPB 1989). It is unlikely that the level of 10 W kg^{-1} for localized exposure of the foetus (NRPB 1993) would be exceeded with fields at this level.

The power density distribution derived from measurements of electric field strength around a 2.45 GHz unit are shown in figure 4. The reference level field strength at 2.45 GHz is double that for short-wave equipment (table 1), because this is outside the range of whole-body resonant absorption effects. These reference levels were not exceeded at more than 0.5 m from the 20 cm microwave applicator and at 0.2 m from the 8 cm applicator and the hand held 3.5 cm one (table 2). Significant emissions have been measured to the sides of larger microwave applicators, for which beam directionality can be poor (Brown and Johnson 1975). Reflections of microwaves at the skin surface and at the fat/muscle interface can be significant, so regions of enhanced power density can occur if an applicator is at an angle to the body surface or if reflections occur from nearby metal objects (Delpizzo and Joyner 1987), and these must be borne in mind when recommending safe working distances. In addition, refraction effects can produce local hot spots in the body in the frequency range 200 MHz–3 GHz (Bernhardt 1992). For the unit, applicators and treatments studied, if operators stood at 1 m from 434 MHz and 2.45 GHz applicators during treatments and avoided standing in the vicinity of large metal objects that could reflect the microwave radiation, they should not be exposed to fields above the reference level. Recent guidance issued by the Chartered Society of Physiotherapy recommends that operators should stand at least 1.5 m from the applicator (CSP 1991). This provides a safety margin to protect against reflection and higher fields associated with larger applicators and is appropriate as a general recommendation for all microwave equipment. The criteria do not need to be applied to the 2.45 GHz low-power hand-held applicator tested.

4.3. Surgical diathermy

Several surgical operations were monitored with Narda 8761 and 8754 probes. Transurethral resection of the prostate gland (TURP) procedures are performed regularly at ARH with the Valleylab Force 2 unit using 160 W for monopolar cut and 60 W for blend. These are the highest settings employed for any procedures in the theatre block, although the unit has a maximum output of 200 W. The fields were greatest adjacent to the electrodes and cables, and the fall off in field strength with distance from the cable is shown in figure 5. Fields near the cables from the active and dispersive electrodes were similar. Measurements were made

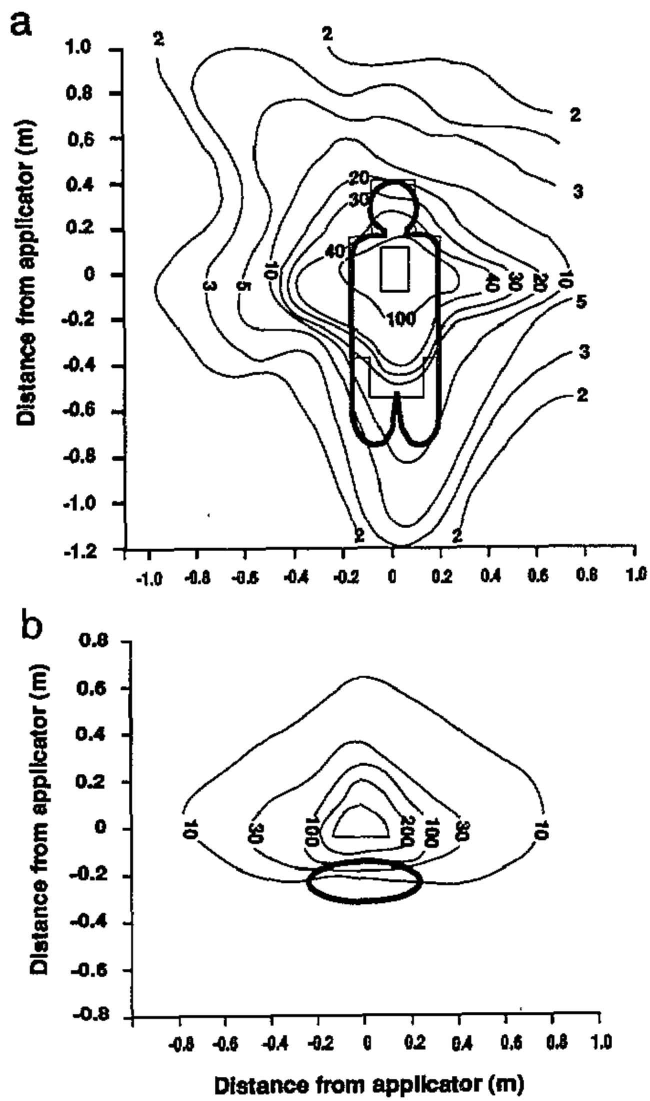


Figure 4. Maps of power density distributions (W m^{-2}) around an EMS Microtron 200 2.45 GHz unit with a 20 cm applicator treatment of a back on 50 W power setting in (a) the horizontal plane and (b) the vertical plane.

up to within a few centimetres of the cables, because parts of the surgeon's body could be in contact with a cable. However, the large field gradients result in different sensors being exposed to widely differing field strengths, which limits the accuracy that can be obtained. Other proximity effects such as coupling between the antenna and the field may also affect the measurement (Peterson 1991). The electric field probe would only measure fields up to 270 V m^{-1} and fields of this strength were found at 0.15 m from the cables. The highest magnetic field found was 2.3 A m^{-1} near a section of uncoiled cable. Plots of electric field strength distributions around the operating table when the unit was in cut mode are shown in figure 6. Only fields on the side of the body adjacent to the electrodes and cables are significant. Settings used with the Valleylab Unit for mastectomy and general surgical

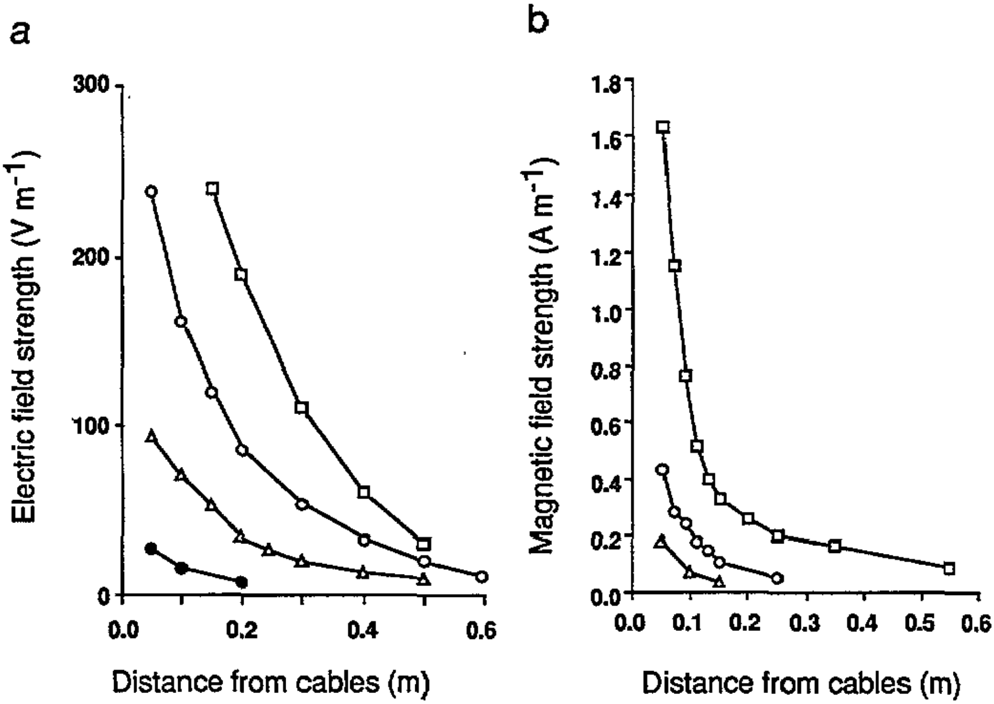


Figure 5. Fall off in (a) electric (V m^{-1}) and (b) magnetic (A m^{-1}) field strength with distance from the cables of electrosurgical units, for Valleylab Force 2 used in cut mode with a power setting of 160 W, □, and for an Eschmann TD300 used in cut, ○, coagulate, △ and bipolar, ● modes, with power settings of three to four.

procedures were 60 W for cut and 25–35 W for coagulate. Electric field strengths recorded for cut mode with these settings were 140 V m^{-1} at 10 cm from the cables, 110 V m^{-1} near the surgeon's eyes, and 90 V m^{-1} at 30 cm from the operation sites.

Measurements were made with an Eschmann TD 300 unit for pulmonary cardiac bypass and other general surgical procedures. Electric field strengths of 160 V m^{-1} and 43 V m^{-1} were recorded at 0.15 and 0.3 m, respectively, from the operation site with cut mode, and 20 V m^{-1} at 0.3 m from the active electrode in coagulation mode. More detailed studies were carried out with simulated surgical procedures using meat. Plots of the fall off in electric and magnetic field strength with distance from the cables are shown in figure 5. If the active and dispersive cables ran side by side the field strengths were significantly lower. The results for both units represent fields measured during pulses of 1–2 s. A unit would typically be used for 30–50 pulses during a 30 min procedure.

A Narda 8731 magnetic field probe, which is designed for monitoring frequencies down to 10 MHz, gave no response, showing that there were no significant higher-frequency components in the fields from the units tested. Studies by Fox *et al* (1976) and Ruggera (1977) had recorded some emissions at frequencies up to 100 MHz or greater from older electrosurgical units. Paz *et al* (1987) used probes covering frequency ranges from a few megahertz or less up to several hundred megahertz, so it is uncertain whether there were significant emissions above 10 MHz from the unit they tested. However, the stray fields around the units included in this study are associated with the 300 kHz–10 MHz range, where resonant absorption effects are less significant. The reference level for the electric and magnetic field strengths for 0.1–1 MHz are five to 10 times those for 27 MHz (table 1),

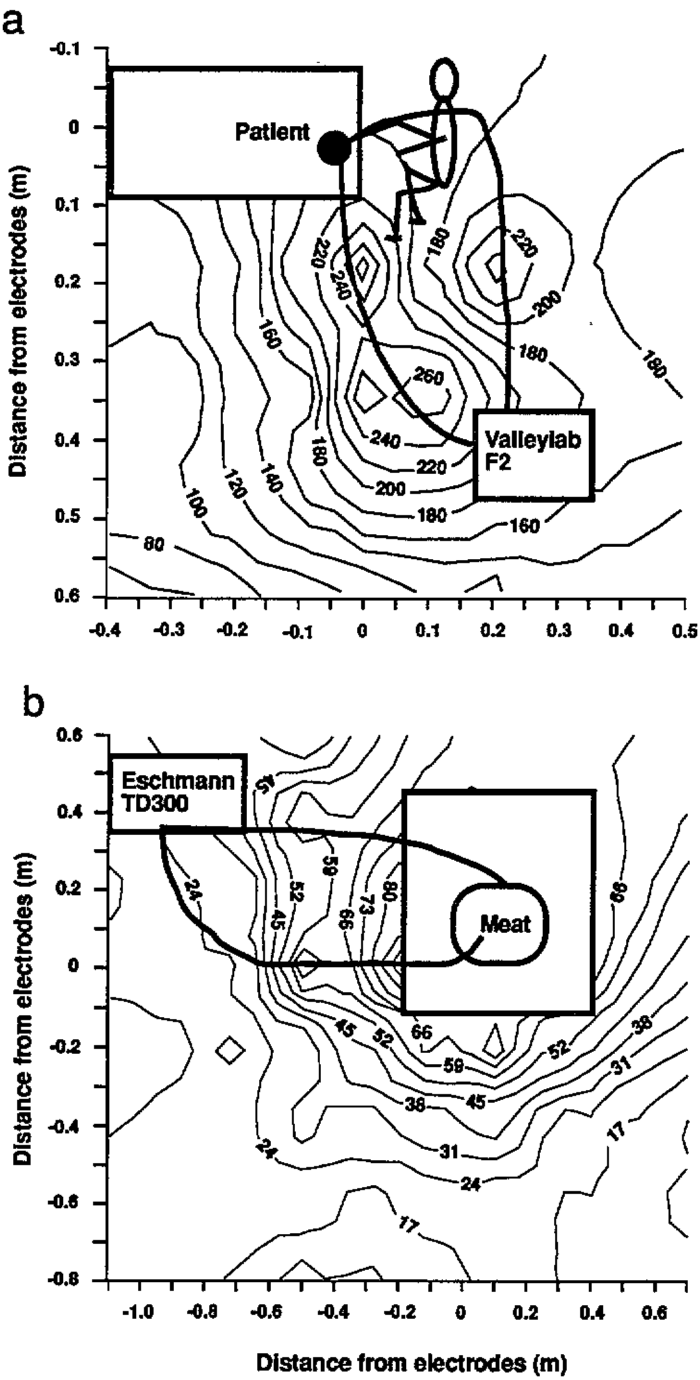


Figure 6. A map of stray electric field strength distributions in V m^{-1} around two electrosurgical units: (a) a Valleylab Force 2 used in monopolar cut mode with a power setting of 160 W during a TURP procedure and (b) an Eschmann TD300 with monopolar electrode used in cut mode on power setting three during a simulated treatment using meat.

and field strengths were not recorded above these levels. Parts of the surgeon's hands, arms and trunk can be close to the cables, but as a video system linked to the endoscope is used to view the treatment, his head does not come close to the active electrode. It is estimated that localized electric field strengths within 1–5 cm of the cables could be 500–2500 V m^{-1} and magnetic field strengths up to 2–10 A m^{-1}. These peak electric field strengths are comparable with measurements reported elsewhere (Ruggera 1977, Paz *et al* 1987) and the magnetic field values are slightly higher. The localized electric field strengths exceed the reference levels in table 1, but the limitation in this frequency range is the restriction on induced current density from fields of large extent. Limits for local peak SARs are unlikely to be exceeded at these levels. Moreover, the periods for which the field is on are short, so that the time averaged exposure is small even for parts of the body in contact with the cables and electrodes. Thus, no special precautions are required to ensure that reference levels are not exceeded with the units tested. The main hazard in surgical diathermy is one of burns to the patient either from poor contact between the dispersive plate and the body or a break in the dispersive electrode lead with an earthed unit, which can result in current flowing to earth via an alternative route.

5. Recommendations and implications of proposed EC directive

The action levels described by the EC (1993) are exceeded at 0.5–1.0 m from most therapeutic capacitive diathermy units, and fields may be several times this level closer to the equipment, so the EC directive would, if adopted, require certain actions to be taken. It should not be necessary to apply restrictions to pulsed units using only single inductive applicators such as the Megapulse. Magnitudes of fields around the surgical diathermy units tested would not require any action to be taken.

5.1. Assessment and measurement

The extents of fields above the reference level were similar for a range of treatments carried out on a particular type of therapeutic diathermy equipment. Thus, the hazard could be predicted for each type of unit and appropriate recommendations made. Because certain models have higher stray fields associated with them, the availability of stray field data would be useful. Some form of simple measurement during the acceptance test could provide this data. This could take the form of measurement of the field with a dummy load such as a 5 l plastic container filled with saline in a standard configuration. The extent of the field around a simple phantom of this type was 5%–15% greater than that for a patient treatment with a similar electrode separation. If data were available nationally, it would not be necessary for individual regions to make their own measurements.

5.2. Reduction of exposure and restriction of access

Avoidance of exposures above the reference levels can be achieved through organizational measures: operators should stand at least 1 m from the electrodes and cables of CW 27 MHz diathermy units, 0.5–0.8 m from pulsed capacitive treatments and 0.2 m from pulsed inductive treatments. Where sufficient space was available, application of a 1 m restriction to all 27 MHz capacitive treatments would provide a wide safety margin and avoid the need for field measurements on individual units. The 1 m restriction can also be applied to CW 434 MHz equipment and a 1.5 m restriction for 2.45 GHz units. The operator should not move closer than half the recommended distances even for short periods and the radiofrequency field should be turned off whenever the electrodes are set up or repositioned. The cables present the greatest risk of unintentional exposure to both the operator and the patient. Care should also be taken to ensure that the cables do not lie too close to parts of the patient's body where treatment is not intended, and to minimize any exposure of the patient's eyes, although this is not covered by the EC (1993). Non-conducting couches should be used to avoid concentration of fields, which could overheat or burn tissues, primarily of the patient but also of the operator. Treatment areas should be delimited to avoid exposure of other staff or patients. The use of cubicle boundaries and spaces between couches and beds can be used to achieve safe working distances. Cubicles for CW shortwave treatment should be at least 2.5 m wide if other staff and patients could be adjacent to the boundary on the far side of a curtain, and those for microwave units should be larger. Local rules should be provided outlining the precautions to be taken.

6. Conclusion

Measurements have confirmed that stray electric and magnetic fields above UK reference levels extend for 1 m from CW therapeutic diathermy equipment, for 0.5–0.8 m from pulsed capacitive treatments and for 0.2 m from pulsed inductive ones. General recommendations that the operator does not stand closer than those distances from the electrodes and cables are appropriate, because there are only small variations in the extent of fields for different treatments. If the EC (1993) directive is implemented, assessments of hazard can be based upon the type of unit. No precautions would be required with the surgical diathermy units tested.

Acknowledgments

The authors wish to thank physiotherapists at Woolmanhill Hospital, and surgeons and operating theatre staff at G Theatres ARH for their assistance. They wish to thank Rhode and Schwartz UK Ltd, Fleet, Hampshire for loan of magnetic field probes, and staff in the Electronics Section in the Bio-Medical Physics Department for assistance in obtaining therapeutic and surgical diathermy units for assessment.

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