Section 7

The Use of Electromagnetic Fields in Medicine and Its Effect on Patients and Health Care Workers

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Summary

- This section of the toolkit presents studies on the exposure and health of patients and health care workers exposed to RF from medical devices.
- Electromagnetic fields (EMF) of lower frequencies up to 200 MHz are commonly used in medicine for diagnosis and therapy; included are exposures to radiofrequency (RF) fields above 100 kHz (0.1 MHz).
- Three main EMF applications in medicine are magnetic resonance imaging (MRI), radiofrequency ablation (RFA) used in cardiology and tumour therapy, and localized dielectric heating (short wave diathermy) used in physiotherapy.
- MRI produces three different fields to generate images: (1) a static magnetic field of zero frequency; (2) low power time-varying magnetic field gradients (100 Hz to 1 kHz); and (3) RF fields (10 to 400 MHz). No long-term effects of EMF exposures to MRI patients on reproductive, cardiovascular and cognitive function outcomes have been reported. While MRI operators may be exposed to RF when working less than 0.5 meters from the bore, there is no indication of chronic effects from their occupational exposure to the EMF fields.
- RF ablation is a minimally invasive medical procedure that destroys tumours and unhealthy tissue in heart muscle by thermal means from RF. Complications to patients, which may arise due to non-target thermal damage, are usually reversible. We found no studies of occupational health risks for workers administering RF ablation.
- Diathermy is used in physiotherapy to heat surface or deep tissue to relieve joint and muscular problems. There was no literature concerning adverse effects on patients. Although female physiotherapists have been found to be at a slight increased risk for spontaneous abortions and heart disease, these may be relevant only to the older practice of microwave diathermy rather than the more current common use of shortwave diathermy.

7.1 Introduction

EMF of lower frequencies up to 200 MHz is commonly used in medicine for diagnosis and therapy. EMF is classified according to frequency and type of field. Static magnetic fields do not vary in time, while time-varying EMF up to 100 kHz is classified as low frequency (LF) fields. Above 100 kHz and up to 300 GHz, it is referred to as RF fields.

Patients are exposed to EMF from specific medical devices when undergoing diagnosis and/or therapy. Attending personnel (medical, paramedical) also may be exposed to RF in the course of their work.

The purpose of Section 7 of the toolkit is to review available information related to exposure to RF from medical devices and possible health effects on patients and health care workers.

7.2 Methods

A literature search for peer-reviewed publications and reports relating to exposure and adverse health effects of EMF in medicine was carried out using EBSCO and OVID databases. The key words used in this search were “magnetic resonance” or “magnetic resonance imaging” or MRI or “radiation ablation” or “radiofrequency ablation” or “radio frequency ablation” or “diathermy” combined with “health effect” or “health outcome” or cancer and occupation* or complication or “physical therapist” or physiotherapist or staff or worker or personnel or technician or patient. Additional searches were done manually from the reference lists and by using Google.

Because few review articles and primary reports had been published on long-term health effects of exposure to EMF on patients or health care workers, none of the English publications were initially excluded.

7.3 EMF Applications in Medicine

A combination of magnetic and RF fields are employed in diagnostic imaging. Applications involving heat-generating RF waves are used for therapeutic purposes.

The three main EMF applications and areas of medicine using EMF sources are:

- MRI – diagnostic imaging
- RF ablation – cardiology and cancer (tumour) therapy
- Localized dielectric heating (shortwave diathermy) – physiotherapy.

Table 1 below summarizes power and frequency ranges applicable to various medical devices: MRI; cardiology; physiotherapy; and tumour therapy.

Table 1. Frequency and power of EMF machines used in medicine

Application		Power or Magnetic Field Strength	Frequency
MRI	Main magnetic field	1.5, 3 Tesla (T)	64, 128 MHz
	Gradient magnetic field	few milliTesla (mT)	Multi-frequency in the MHz range
	Radiofrequency field	Up to few kilowatts but not radiative (no radio waves emitted)	100 to 200 MHz
Cardiology		RF generator: 50 Watts	460–480 KHz
Tumour Therapy		RF generator: 200 Watts	461 KHz
Physiotherapy		RF generator: 500 Watts	27.12 MHz

7.3.1 Magnetic resonance imaging

MRI is a medical imaging technique used in radiology to visualize internal structures. An MRI unit produces three different EMF fields to generate images:

- A static magnetic field of zero frequency (average magnetic flux density of 1.5–3 Tesla) produced by a large magnet for the alignment of hydrogen nuclei (protons) inside the body
- Low power time-varying magnetic field gradients (100 Hz–1 kHz) generated by small magnets in three orthogonal planes (X, Y and Z directions) to provide the spatial position of the protons. Further, these MF gradients allow image slices to be created by focusing on the patient body part under examination
- RF fields (100–200 MHz) produced in the non-radiative near field of the emitter to excite the protons (in the body) and cause the protons to emit radio waves (radiative RF) for the acquisition of anatomical images.

The layout of a typical MRI unit is given in Figure 1 below[1] showing "controlled" areas and "inner controlled" areas. The maximum level of the static magnetic fields in the controlled area is kept under 0.5 milliTesla (mT). For the inner controlled area in the immediate vicinity of the imaging equipment, the limit of the static magnetic field is set at 3 mT (30 Gauss). RF shielding surrounding the MRI is placed to prevent exterior RF interferences from affecting the operation of the imaging unit.

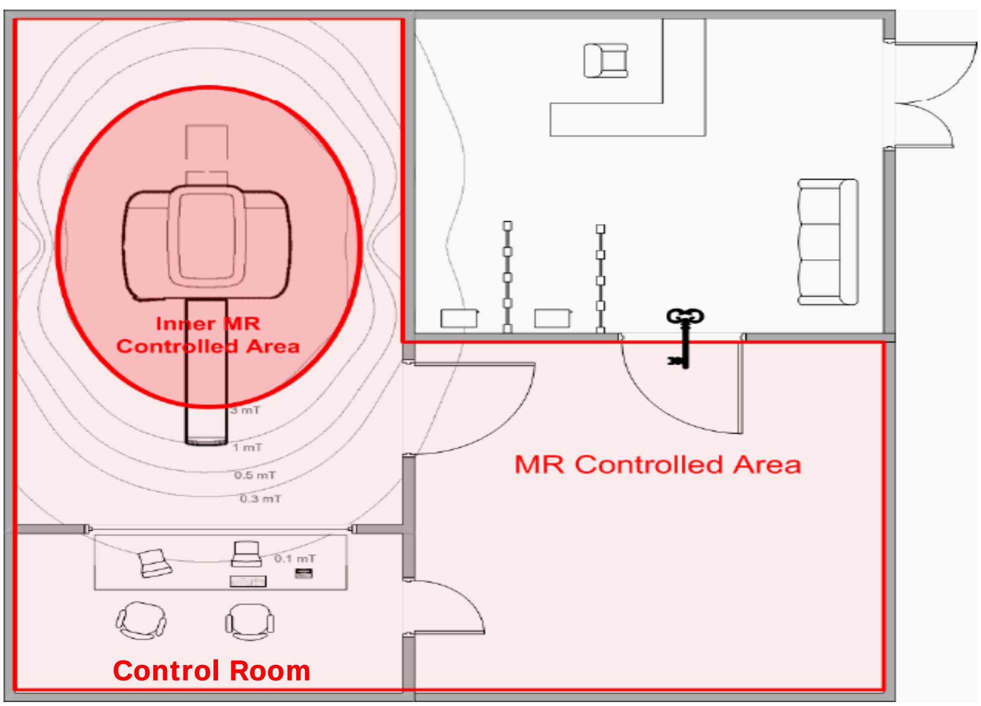

Figure 1. Example of MRI Layout[1]

As a source of non-ionizing radiation, MRI is considered safer than x-ray imaging and, as such, represents an alternative to some x-ray diagnostic procedures, particularly for imaging children and pregnant patients. MRI is best suited for imaging soft tissue, making it particularly useful to image some principal anatomical structures (e.g., brain, muscles, heart) and to detect cancers.[2,3] Each year, approximately 60 million MRI scans are performed worldwide.[4]

7.3.1.1 Adverse health effects for patients exposed to MRI fields

The RF frequencies used in an MRI scanner can result in high absorption of RF over the whole body, with the eyes and testes being especially vulnerable to heating effects. Metal-based pigments such as tattoos increase the probability of burns, as do metallic implants. However, there have been no epidemiological studies on long-term health effects specifically attributed to RF fields associated with MRI procedures.[5] Rather, adverse outcomes for patients who have undergone MRI treatments have been associated with their exposure to static magnetic fields.

Cancer: Although there is no epidemiological literature on cancer attributed to patients being examined by MRI, there is suggestive evidence of possible DNA damage as micronuclei induction (associated with carcinogenesis) has been shown to temporarily increase during MRI diagnostic scans.[5]

Reproductive and development outcomes: The available data on fetal exposure to EMF during MRI examinations do not point to adverse effects on the developing fetus.[6] The main concern would be the temperature increase that could be generated by the RF fields of MRI. However, temperature increases in the fetus during MRI examinations are under strict guidelines and unlikely to reach 0.5°C. A 2008 UK-HPA review[7] of studies related to reproductive and development outcomes concluded that there was no evidence of adverse effects on eye and ear functions or reproductive outcomes on children previously exposed to MRI in utero.

Cardiovascular effects: During MRI examinations, the time-varying magnetic field gradients at frequencies ranging from 10 to 100 Hz could cause cardiac problems to patients if the induced current density is higher than the cardiac stimulation threshold of 1.2 Ampere/m^2.[1] However, modern MRI machines are designed to deliver lower time-varying fields, far below the cardiac stimulation threshold current density.[8,9] Furthermore, no significant cardiovascular changes in patients undergoing MRI procedures have been reported.[10] A consideration is that above 100 Hz, muscle tissue (including cardiac muscle) is less responsive to electrical stimulation.

Peripheral nerve stimulation: Time-varying magnetic fields up to 5 kHz can induce currents in the MRI patient. Peripheral nerve stimulation is possible but only when the magnitude of the induced current densities is sufficiently high. The threshold current density for nerve stimulation is comparable to the level for cardiac stimulation, but MRI machines are designed to operate far below this threshold by keeping the current densities below 0.4 Ampere/m^2.[8] At frequencies higher than 5 kHz, nerve cells are less responsive to electrical stimulation.

Effects on cognitive function: A recent study by Schlamann et al. involved the participation of 25 volunteers without history of neurological diseases in a series of neuropsychological tests before and after undergoing MRI examinations at 1.5 Tesla and **7** Tesla.[11] The testing, which focused on the volunteers' attention capabilities, consisted of paper-based and computer-based neurobehaviorial tests. The study did not reveal any adverse effects on cognitive test performance after exposure to MRI fields.

Non- specific symptoms: Acute symptoms such as vertigo and nausea may be due to low frequency sensory effects which can occur with rapid patient movement inside the MRI machine. However, these symptoms are less frequent when patients are carefully moved at a slow pace into the magnet bore and are not associated with any long-term consequences. Such non-specific symptoms may also result from anxiety due to the claustrophobic nature of the procedure.

Some precautionary measures to protect patients from any potential harmful thermal effects are recommended when undertaking MRI procedures.[12] For vulnerable patients, including cardiac patients, those wearing metallic implants, pregnant patients and children, there are general guidelines to limit increase in the core temperature of the patients undergoing MRI procedures.[12,13] In general, whole body temperature increase to the patient should be less than 0.5˚C; temperature for the head region should be less than 38ºC; temperatures for the trunk less than 39˚C; and for extremities, temperatures should be less than 40˚C. The fetus is particularly vulnerable to RF exposures; exposures within allowable limits to the pregnant mother's abdomen may result in excess RF absorbed by the fetus.[14]

7.3.1.2 Occupational health risks related to MRI

In general, health care workers in MRI are only exposed to the static magnetic field because the time-varying magnetic field gradients and the RF fields are essentially only present inside the scanner. However, incident field limits of RF can be exceeded within short distances (0.2–0.5 m depending on the model) of the bore entrance during the scan acquisition (estimated to occur during 3% of scans or 40,000 examinations a year in the UK).[4] This is an issue particularly with open scanners and possibly the new generation of wide bore scanners.

Patients are exposed to static magnetic fields (zero Hz frequency) up to 3 Tesla during the MRI examinations while health care workers are regularly exposed to much lower fields ranging from .5 mT to 3 mT (mT being one thousandth of a Tesla). Occupational exposures from medical RF devices differ from patient exposures in that they occur for longer periods during the day and over the duration of employment; however, the intensity of exposure may be minimal.

Workers exposed to EMF in the manufacture of MRI scanners had more vertigo, metallic taste, headache and concentration problems than workers in a reference department but these symptoms were transient, disappearing after exposure ended.[15] Field surveys also revealed that MRI engineers and nurses had the following symptoms: nausea, concentration problems, memory loss, tiredness or drowsiness, illusions of movement and ringing sensation in the head during their work, and sleep disorders. The frequencies of these symptoms were mainly associated with the strength of the MRI systems, the time spent close to the bore, and the workers' speed of movement. Whether there are long-term health consequences from these acute neurobehavioral symptoms is unknown.[16]

In general, there is very little scientific literature on the long-term adverse health consequences for health care workers in the MRI field. There is a lack of consistent evidence of cancer risks in industrial groups exposed to static magnetic fields (among other hazards) or of reproductive effects based on the few limited studies of female MRI workers.[17]

7.3.2 Radiofrequency thermal ablation

Radiofrequency ablation (RFA) procedures in medicine are mainly used in cardiology for the treatment of cardiac disorders and in oncology for tumour treatment.[18]

For interventional cardiology, RFA is a minimally-invasive medical procedure used to correct irregular heart rhythms (primarily atrial fibrillation). The RF device consists of an ablator (catheter), RF generator, and a control console.[19] The energy-emitting probe (electrode) is at the tip of a catheter which is inserted through very large veins into the heart. Ablation involves destroying small diseased parts of heart muscle by means of the resistive heat due to the electric current generated by high frequency RF waves in the catheter.

RF is also used to treat tumours in lung, liver, kidney, and bone but with the generator at a higher power than used for cardiology purposes. A needle-like RFA probe is placed inside the tumour.[20] RF waves passing through the probe increase the temperature within tumour tissue resulting in its destruction. RFA may be combined with locally delivered chemotherapy treatment, and it is of particular value in reducing the size of inoperable tumours.[21] RFA is minimally invasive and repeated procedures can be done with few complications when performed under radiological guidance.

7.3.2.1 Adverse health effects of patients undergoing RFA procedures

Generally with RFA, unhealthy tissue is treated by thermal means at RF frequencies up to 200 MHz. However, the heat is generated in a small area. Temperatures in the treated areas could reach 100°C or slightly higher. Some complications are associated with RFA, but they are usually reversible.

The main adverse effects of RFA treatment are reported in the literature to be thermal consequences resulting from direct or indirect RF heating of tissue.

The following thermal effects on patients have been reported after use of tumour therapy:

- Thermal injury to the ureter following ablation of renal cell carcinoma[2]
- Case reports of skin thermal necrosis after treatment of osteoid osteoma[12]
- Non-target thermal damage to adjacent structures after treatment of liver, pulmonary, and renal tumours[19-23]
- Cardiac complications that can arise from thermal injury due to RFA such as esophageal temperature increase during pulmonary vein isolation.[24]

In general, the reported thermal effects have responded to treatment and did not lead to further complications. At relatively low levels of exposure to RF waves (levels lower than those that would produce significant heating), there is no evidence for long-term health effects on patients.

Precautions necessary for RFA are to ensure vulnerable patients are not adversely affected by the procedure and to adopt appropriate techniques of treatment to prevent excessive heating of non-target organs (such as those adjacent to tumours.)

7.3.2.2 Occupational health risks associated with RFA

We have not found literature concerning adverse health effects for acute or chronic exposures of RF associated with ablation procedures to hospital staff, particularly for physicians who are the most exposed to RF.

7.3.3 Localized dielectric heating (shortwave diathermy)

Shortwave diathermy is the therapeutic application of high frequency alternating current used in physiotherapy treatments. RF fields are used to speed up the healing of tissues by providing deep heat to a large area of the body positioned under conductance plates.[23] Continuous shortwave diathermy is the technique of choice when heating of deep tissue is required. Diathermy also allows superficial structures to be heated selectively by means of various surface heating techniques. Sub-acute or chronic conditions respond best to continuous shortwave diathermy which, when used properly, can be as effective as high power ultrasound. Diathermy is used to relieve pain and muscle spasm, resolve inflammation, reduce swelling, increase joint range and decrease joint stiffness.[24]

Measurements made of RF fields close to diathermy equipment show that for continuous wave shortwave equipment, recommended ICNIRP whole body levels were exceeded 0.5–1.0 m from the electrodes and cables. This distance was reduced to 0.5 meters for microwave units and pulsed shortwave diathermy models.[25]

7.3.3.1 Adverse health effects of patients undergoing diathermy

No published reports could be found concerning chronic effects related to patients' treatments with diathermy. An important precaution when administering shortwave diathermy is to ensure the heating is targeted accurately by using correctly positioned applicators.

7.3.3.2 Occupational health risks associated with diathermy

Physiotherapists can be exposed to elevated levels of RF during diathermy treatments if they work closely (less than one meter) to the electrodes and cables of the units.[25] Studies on long-term occupational health effects for physiotherapists have mainly focused on adverse reproductive outcomes.

Cancer: No literature was available on cancer risks for physiotherapists or other health care workers associated with occupational exposure to diathermy.

Reproductive outcomes: Studies on reproductive outcomes and occupational exposure have been conducted on physiotherapists using shortwave and/or microwave diathermy. Measurements of shortwave and microwave diathermy equipment exposures vary considerably depending on the equipment and location of the operator. Exposures above current recommendations have been documented, particularly within 0.5 meters of the device.[26] Four case-control studies have been conducted. Ouellet-Hellstrom et al. compared 1753 miscarriages and 1753 control pregnancies recruited via mailed questionnaire to female registrants of the American Physical Therapy Association.[27] Self-reported number of treatments administered, using both shortwave and microwave radiation per month, were used to categorize women into exposure categories. An overall increased risk of spontaneous abortion was found for use of microwave diathermy: odds ratio 1.28 (95% confidence interval 1.02–1.59). An increased risk was not found with reported use of shortwave diathermy equipment.

Ouellet-Hellstrom et al. collected their data in 1989; since then, use of microwave diathermy has declined substantially in favor of shortwave diathermy: a 2007 survey of British hospitals confirmed that there were no microwave diathermy units in use.[31] Safety guidelines for physiotherapists consistently suggest operators stand away from the patient during treatment, but the recommended distances vary from 0.5 to 1.5 meters and are based on avoiding exposures above ICNIRP limits.

Takinen et al. (1990)[28] conducted a nested case-control study of physiotherapists in Finland who had become pregnant in the 1973–1983 study period. Cases were derived from the medical registrar, and exposure information was based on recall of equipment and procedures used. The odds ratio of spontaneous abortions occurring after 10 weeks of pregnancy was significantly elevated (OR 2.5; 204 cases) for use of shortwave diathermy but did not remain significant after adjustment for occupational variablers and lifestyle confounders. However, for congenital malformations, shortwave diatherapy administered for at least 1–4 hours per week remained statistically significant (OR 2.3, 95% CI 1.1–5.2; 46 cases) after adjustment for confounding, but the highest exposure category showed no effect. Inconsistencies in dose-response and potential misclassification of exposure suggest further study is needed. The remaining two studies[29-30] had much smaller samples, did not distinguish between microwave and shortwave equipment, and failed to find statistically significant findings.

Cardiovascular disease: A 1983 cross-sectional study of American male physiotherapists found an increased prevalence of self-reported cardiovascular disease depending on use of microwave and shortwave diathermy.[32] However, these findings were not replicated in subsequent studies.

Cataracts: The lens of the eye is known to be sensitive to heat compared to other organs; however, we found no epidemiological data linking RF occupational exposure for physiotherapists to an increased risk of cataracts.

7.3.4 Other medical and paramedical RF uses

RF surgery is commonly used in dermatology for resolving skin disorders. The combination of using diode laser and bipolar RF energy is an effective modality for the treatment of superficial and deep acne scars.[33] RF treatments are a preferred method for dermatologists because of the minimal skin damage induced by this technique.[7,22] Some of the advantages of the RF technique are:

- the use of low RF intensity to control temperature rise during the procedure in order to prevent overheating of the treated area
- the use of high-frequency RF waves to limit the penetration of RF waves inside the skin
- the limited impact of RF energy on the surrounding healthy tissue as only the tip of the electrode comes in contact with the tissue for a short time.

RF devices are also used in paramedical aesthetics for the treatment of irregularly pigmented skin, acne, rosacea, psoriasis and other skin disorders using RF devices.

7.3.5 Comparison of medical sources of EMF to consumer devices

Exposure to RF from consumer devices differs in many ways from exposures from medical applications reviewed here. Some of the characteristics that differ include:

- ***Frequency:*** Consumer products such as mobile phones, blue tooth, laptops, baby monitors, and smart meters emit and receive RF waves at high frequencies ranging from 900 MHz to 2.45 GHz, while the medical devices use lower frequencies up to 200 MHz (which penetrate more deeply into tissue).

- ***Output power:*** Consumer products use very low power, generally below 1 Watt on average, while medical applications require powerful sources of EMF, as shown in Table 1.
- ***Duration of exposure***: Although the exposure of patients to medical EMF is substantially higher than established limits, it lasts only for the brief course of the examination or treatment. Health care workers may experience transient higher levels of EMF in the course of their work, and also may be exposed at low levels during the course of their work day. The general public is regularly exposed to very low levels of ambient EMF over 24 hours.
- ***Distance from the EMF source***: For most medical uses of EMF, patients are exposed to the near field, which has the highest EMF output power. For the public, higher levels of near-field RF exposure can only occur from personal use of wireless phones next to the head, but at much lower levels than experienced by patients exposed to medical devices.

As such, any demonstrated health effects related to RF/EMF exposure to patients and medical staff cannot be directly related to the type of exposures to RF received by the general public.

7.4 Research Gaps

There is a lack of follow-up studies on the long-term health consequences for patients exposed to relatively high levels of RF from diagnostic and therapeutic use of medical devices.

Exposure assessment and epidemiological studies of health care workers exposed to RF, particularly those involved in MRI, ablation and diathermy procedures, are needed to determine the likelihood of health consequences related to acute and long-term RF exposures in their work environment.

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