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ORIGINAL PAPER

A health and safety model for occupational exposure to radiofrequency fields and static magnetic fields from 1.5 and 3 T MRI scanners

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Abstract
The exposure of MRI staff to SMFs and RF fields in the MRI units happen as a result of their induced movement in the MRI room during patients' examination. Exposure to SMFs among health care workers has been associated with vertigo, nausea, increased heart rate, hypothermia and metallic taste in the mouth. The only known adverse effects associated with RF fields' exposure include induced tissue heating, and the scientific arguments regarding non-thermal effects are inconclusive. The emission of MRI-related electromagnetic fields and exposure of workers to RF energy and SMFs can be reduced through implementation of reasonably practicable control measures. This study attempts to recommend the hierarchy of controls that can be implemented in the MRI units to reduce emissions and exposure of MRI staff to RF energy and SMFs. The controls are recommended based on exposure assessment conducted to quantify the exposure levels and self-reported priori-related and unrelated health consequences. In the MRI units, elimination is an impractical measure, hence, the implementation of engineering and administrative control measures as well as the utilisation of personal protective equipment (PPE) are recommended to mitigate exposure. Engineering controls include modification of MRI scanners to reduce emissions while administration controls include the design of work schedules and processes to be adaptive by MRI staff. PPE is recommended as a last resort and include protective equipment that are fit to reduce exposure arriving to workers. In South Africa, there is no legislation to assist in enforcing exposure limits and as a result, exposure levels are not monitored. The model of this kind could assist in reducing exposure levels in the MRI units and substantially reduce exposure-related effects amongst workers.

Keywords Health and safety · Occupational exposure · Model · SMFs · RF energy

1 Introduction

The discussion about safety issues and potential hazards associated with MRI procedures among workers has been very controversial in the past decades [1]. This has been based on assertions about the role of EMF as carcinogenic "group 2B" and effects on tissue growth abnormalities as well as development [2]. It was also based on the assumption that MRI procedures were inherently safe, which reduced the importance of publishing undesirable results [3]. Recently, MRI technologies have an increased use of strong SMFs and time-varying magnetic fields, and subsequently induced RF energy [4]. In the current health care system, 1.5 and 3.0 T SMFs are used for diagnostic purposes while 7 T is mainly used in research [4], with the newest MRI units reaching 11.7 T [5]. The advancement in clinical imaging science have led to health risks gaining increased attention, with some of the studies looking at the safety of ferromagnetic objects, tissue heating caused by RF energy above recommended SAR limits, simulation of peripheral nerve and temporary hearing damage due to acoustic noise [6, 7].

The use of magnetic resonance (MR) devices such as MRI scanner is associated with increased occupational exposure to static magnetic fields and produces high intermediate magnetic fields [8, 9]. Several studies assessing the health risks for

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exposed MRI staff have been published, and occurrence of transient symptoms such as tinnitus, nausea, vertigo, dizziness, severe headache and concentration problems have been highlighted in studies focusing on 1.5, 3.0 and 7 T scanners in MRI units [10, 11]. According to Hartwig et al. [4], the long-term health implications of the reported transient symptoms among MRI workers are not yet known. The safety of MRI scanners with regard to scans taken during pregnancy and the potential risks to obstetric patients have been extensively discussed in many studies [12, 13]. However, there is a significant need to define and develop methods for health risks and exposure assessments, and this should be done together with providing guidelines for safe working procedures and training for MRI workers [14].

2 Methodology

2.1 Development of health and safety model with guidelines to reduce RF energy and SMFs exposure in the MRI units

In order to reduce occupational exposure to RF energy and SMFs among MRI workers and provide protection against the discussed and known potential health effects, the International Commission for Non-ionising Radiation (ICNIRP) has developed safety guidelines to limit occupational exposure levels. These guidelines recommend exposure levels below which no adverse health effects should occur in healthy adult workers [4]. The purpose of developing this model was to guide the health care sectors on how to reduce occupational exposure to RF energy and SMFs emitted by 1.5 and 3.0 T MRI scanners, and thus preventing the occurrence of transient and potential long-term health implications. This model focuses on the principles of occupational hygiene, which are identification, recognition, evaluation, monitoring and control of exposure to RF energy and SMFs. The model was developed based on the exposure levels of RF fields and SMFs emitted by 1.5 and 3.0 T scanners as well as priori-related and unrelated health effects associated with exposure to these fields.

According to Raphela [15], the first step in developing a model of this kind is to recognise electromagnetic fields (EMFs) as hazard in the workplace, and this should be followed by the assessment of exposure levels and prevalence of exposure-related health effects amongst workers. The hierarchy of control measures should be implemented at all times as the exposure levels remain significantly high in the MRI units, since elimination is impossible. This is achieved by recommending the implementation of engineering controls, which takes into account the design of the work processes, followed by administrative control measures and utilisation of personal protective equipment as a last resort [16]. Figure 1 below illustrate the order in which the implementation of control measures should be followed to reduce exposure. Radiofrequency energy and SMFs are a major challenge in the MRI environment and exposure of MRI staff during interventional procedures is inevitable, hence the development of this model was significant. Figure 1. illustrate the hierarchy of controls that can be implemented to reduce exposure workers to RF energy and SMFs in the MRI units.

2.2 Identifying the hazards and risks

This is the first step in identifying and recognising RF energy and SMFs as hazards in the health care setting, particularly the MRI units. Occupational exposure to RF fields occurs when scans are performed [4] and it causes tissue heating [17]. Exposure to SMFs causes transient health symptoms such as visual perceptions, neurobehavioral patterns and ocular reflexes [18], headache and tiredness [19], insomnia [20], vertigo, nausea, metallic taste and illusions of movement [21], and could lead to long-term health implications if exposure is not reduced. In order to perform exposure assessment for occupational exposure to RF fields and SMFs, a preliminary inspection must be conducted and during this process, consultation should be made with either workers or health and safety representatives to obtain information that will inform a health and safety priority inventory. The inventory should consist of workplace hazards and risks, work processes, work rate, effectiveness of control measures in place, duration and frequency of exposure [16, 22].

2.3 Exposure assessment: Health risks and safety hazards associated with exposure to RF energy and SMFs

Assessment of hazards and risks in the workplace is done through exposure assessments [22]. It is also stated by the occupational health and safety act [23] that employers should ensure that exposure assessments are undertaken in the workplace, and this is the second step in the modelling of exposure. The exposure assessment is conducted to ensure that the duration and frequency of exposure among workers is assessed. During the exposure assessment, the work rate, work processes and exposure to by-products are measured, potential sources of exposure are identified, and effectiveness of existing control measures is evaluated [16, 22].

2.4 Quantification assessment of SMFs and RF energy from the MRI scanners

Worldwide, an estimate of 60 million MRI scans are performed every year in healthcare settings [24]. In a study conducted by Fatahi et al. [25], SMFs was measured during movement of researchers in an active shielded 3.0 T MRI room and the recorded exposure levels were variably high amongst workers with the maximum exposure value of 2057

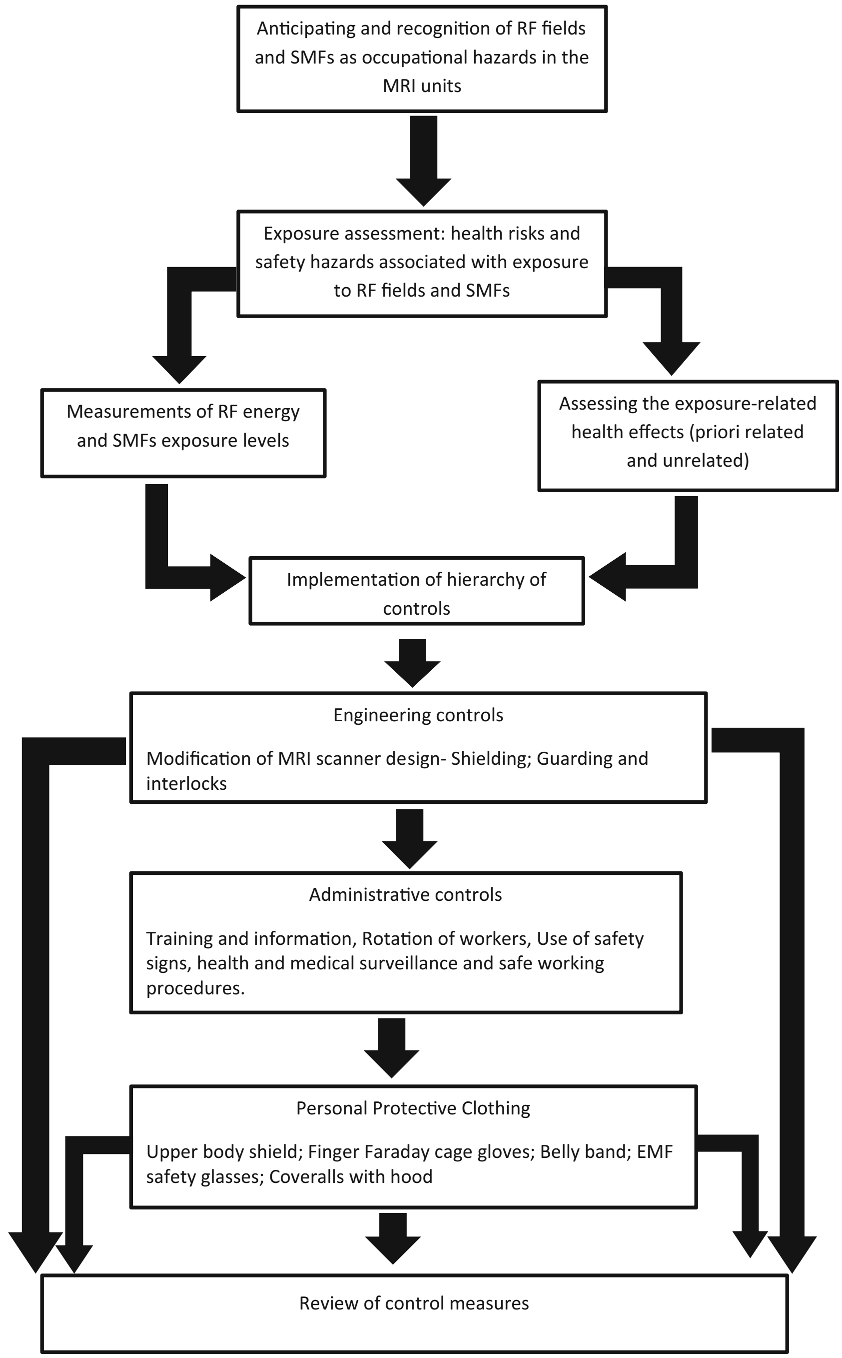


Fig. 1 Health and safety model for reducing occupational exposure to RF energy and SMFs from the MRI scanners

mT. A decline in terms of exposure levels was also observed when workers moved away from the scanner. In a personal exposure assessment study conducted by Batistatou et al. [26], highest geometric mean of 559 mT was recorded among radiographers working in static fields with an exposure range of 20 to 2891 mT in 1.5 and 3.0 T scanners. Exposure of MRI staff to MRI-related electromagnetic fields is likely to increase in the near future due to an increase in the number of scans, new systems with high strength fields and new real-time interventional procedures [27]. Schaap et al. [5] conducted a quantitative measurement to assess the exposure of personnel to SMFs in 3.0 and 7 T MRI scanners. In the said study, the exposure was high in academic hospitals as compared to animal research facilities where MRI is used. The highest recorded exposure level was 4928 mT, with an exposure mean value of 814 mT. However, when comparing exposure values from MRI scanners with different strengths, the type of scanner. i.e. open, closed or extremity scanner as well as the type of shielding used should be considered [5].

During an MRI examination, there are different scanning mode to choose from; normal operating mode with SAR that should not exceed 2.0 W/kg over an average six minutes period and the first-level controlled operating mode that allows SAR to reach >4.0 W/kg, however, this is mainly used in research [28]. RF fields are mainly pulsed and with low duty cycle, the exposure peak can be significantly high. According to Frankel et al. [29], sequence with an estimated of 1 W/kg over 6 min and a duty cycle of 1%, SAR would reach 100 W/kg in each pulse. Since every MRI requires RF fields [24], exposure at a sequence and duty cycle described by Frankel et al. could result in induced tissue temperature, and subsequent tissue burns [30]. The SARs from 1.5 to 3.0 T scanners can potentially increase by a factor of four, if other parameters are kept equal [31]. If the field strength increases from 1.5 to 3.0 T, there is a risk of induced thermal effects to patients as well as MRI workers who are present in the MRI room during patient examination.

3 Results

3.1 Recommendation of control measures

Exposure to RF energy and SMFs is a primary cause of exposure-related health effects among exposed MRI staff and it should be controlled. However, control of exposure should be done by implementing reasonably practicable control measures and implementation should be in an order of hierarchy [23].

3.2 Implementation of hierarchy of controls

The hierarchy of controls should be implemented to reduce occupational exposure to RF fields and SMFs from 1.5 and 3.0 T MRI units. The purpose of the implementation of control measures is to eliminate health risks and safety hazards associated with work in such environments [22]. The RF energy and SMFs are the major health risks in the MRI units, thus implementation of engineering and administrative control measures should reduce the exposure levels. However, personal protective clothing should be considered as a last resort if engineering and administrative controls have been identified to fail during exposure assessment.

3.3 Engineering controls

The consideration and implementation of elimination or substitution of MRI-related electromagnetic fields could be the most effective mechanism, however, it is not straightforward and possible solution. The MRI units rely on RF energy and SMFs during examination for image acquisition [32], therefore elimination of the fields will not be possible. Engineering controls are applied to reduce the rate of emissions by process modification or capture the emission once released and they are as follow:

3.3.1 Shielding / screening

The European Directive [33] regards shielding as the most effective measure of reducing electromagnetic fields (EMFs), and this can be incorporated into the design of MRI scanners in order to limit emissions. The shielding of MRI components is done to prevent interference with RF signals and excessive heating from RF transmit coil. However, shielding of components does not protect the MRI staff from high exposure levels. The shielding of MRI units is normally done by enclosing the MRI room with a Faraday shield. The Faraday shield is made of metal mesh and ceramics or plastics with metallic coating (European Directive [33]), this is mounted on the walls to prevent RF fields from escaping the MRI room. In trying to protect workers from exposure to RF fields, the RF transmit coils, cables and waveguides should be wrapped with metallic coated plastic with the same absorption properties found in Faraday shield. The minimum emissions of SMFs are primarily obtained through active and passive shielding, however, passive shielding is often impossible to attain. Active shielding is obtained using a solenoid coil to generate an opposing magnetic field, which result in rapid reduction of magnetic fields far away from the MRI scanner (European Directive [33]). The MRI scanner should be lined or wrapped with magnetic shielding film to reduce the stray fields near the scanners. The magnetic shielding film works on direct current (DC) magnetic fields with a frequency range of 0-1000 Hz [34].

According to Schaap et al. [5], MRI facilities are built in a manner that the stray static fields drops to 0.5 mT within the walls of the MRI room. However, in some cases, the design of the MRI room allows the 0.5 mT to extend beyond the walls, into the control room. If the stray fields extend beyond the MRI room, workers in the control room could be exposed to static fields over 0.5 mT, the below structural controls could minimise the exposure. In a study that tested the effectiveness of shielding EMFs radiation through textile shielding materials, Brzeziński et al. [35] proved that a shielding paint containing micro-powders of Al, Cu, Ni, non-cross linked acrylic (PAC) or urethane (PUR) polymer provide significant attenuation. Brzeziński et al. [35] further suggest that plastic foils metallised with Al and Cu/Al decreases the strength of EMFs in a frequency range of up to 18 GHz. Since the frequency of 1.5 T scanner is approximately 64 MHz and 127 MHz for 3.0 T, the recommended attenuation materials are likely to reduce the stray fields in and outside the MRI facilities (Figs. 2,3,4,5,6,7,8).

A high frequency shielding paint should also be applied in the MRI rooms, the paint ground kit should be installed according to manufacturer's requirements to provide significant attenuation.

3.3.2 Interlocks

Once the moveable guards are introduced in the MRI units to restrict access near the scanners when not in use, the guard

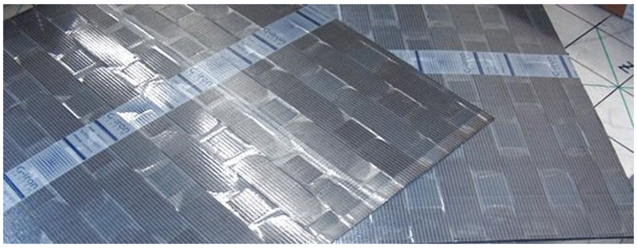


Fig. 2 Magnetic shielding film made of Al or Cu

should be interlocked to restrict access to MRI scanners. The device used for interlocking should be of non-ferromagnetic material and be wrapped or painted with shielding paint to reduce emissions. According to European Directive [33], interlocks are found in different types with significant advantages and disadvantages. In the MRI units, the types of interlocks that can be used to reduce emissions include type 1 interlocks which are mechanically actuated switch without coding. They either have rotary cam switch on hinged guard, linear cam switch activated by rail on sliding guard or switch mounted internally within hinge. Type 2 interlocks mechanically activated switch with coding. They include tongue activated position switch and trapped key system to reduce emissions. Type 3 interlocks are non-contact position switch without coding, with proximity switch based on inductive, magnetic, capacitive, ultrasonic or optical detection. Another set of recommended interlocks are type 4, they are also non-contact position switch with coding but has proximity switch with coded magnetic detection and switch with radiofrequency identification (RFID) detection. Mechanical actuated interlocks are mainly recommended to be used in 3.0 T MRI units as they are less susceptible to interference (European Directive [33]).

Fig. 3 Grounding kit for shielding paint

Fig. 4 MRI room applied with shielding paint (containing micro-powders of Al, Cu, Ni, non-cross linked acrylic (PAC) or urethane (PUR) polymer)

3.3.3 Guarding

The guarding devices should be made of non-ferromagnetic material, be wrapped with magnetic shielding film and placed in close proximity to MRI scanners when not in use. The guarding should indicate exposure levels of RF fields and SMFs per distance and should be placed to prohibit access in areas where high fields exist. Coupling the fields with guarding material should be significantly considered especially with strong SMFs emitted by 3.0 T MRI scanners. The guarding material should be made of non-ferromagnetic material i.e. plastic barriers, this will assist in avoiding spark discharges and ballistic effects (European Directive [33]).

3.4 Administrative controls

The administrative control measures include the introduction of precautionary measures to lower workers' exposure to MRI-related electromagnetic fields. Administrative controls

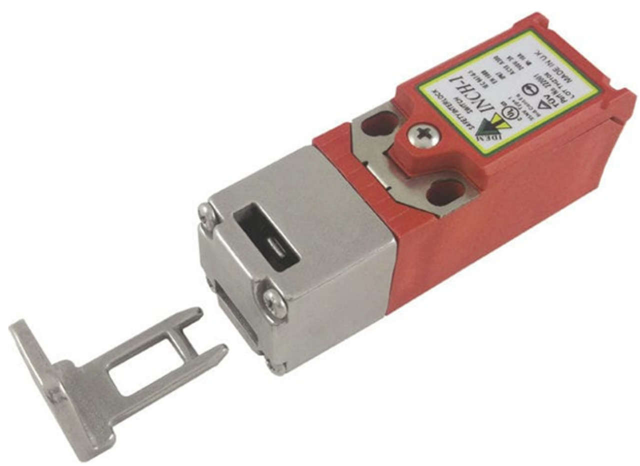


Fig. 5 Type 2 interlock device

Fig. 6 Magnetic field warning sign

reduce exposure to minimal if coupled with process modification and re-design. The below recommended administrative controls do not eliminate exposure. However, when administered during working shifts, they reduce exposure to minimal.

3.4.1 Training and information

The information and training must be given to all MRI staff who are subjected to risks identified during exposure assessment. In instances where an MRI staff report to experience some of the priori-related health effects and the occupational exposure limits recommended by the ICNIRP are exceeded, then health and medical surveillance should be conducted.

Fig. 7 EMF safety glasses

Fig. 8 Belly band made with rayon as well as Ni, Cu or Co coated fabric

The training and information sessions should include an explanation on the occupational exposure limit values, details of exposure-related health effects, safe working procedures that needs to be adopted to reduce exposure risks, details on the use of recommended PPE and how workers who are declared pregnant as well as those who frequently come in close proximity to MRI scanners can be subjected to a medical surveillance [36]. The new MRI staff including students' radiographers, medical physicists, engineers and nurses should receive general safety training which emphasises on MRI safety guidelines and requirements. Another special training on the health hazards of exposure to RF energy and SMFs should be conducted amongst new employees and students. The training should be conducted when job roles change, HCWs return from long absence, and every time when maintenance is conducted in the MRI units and new MRI scanners are installed.

3.4.2 Health and medical surveillance of MRI staff

Since there is no scientific evidence on the long-term health effects of exposure to RF and SM fields, a health surveillance programme should only aim on the transient exposure effects reported by workers. The records of medical examinations should be kept, and examination should be conducted on hours specified by the employer and agreed to by the worker [36]. The aim of health surveillance is to detect adverse health consequences resulting from exposure, at an early stage, so that effective control measures can be promptly implemented [37]. This study recommend that the purpose of medical surveillance should be communicated with workers and the records of such should be kept for a minimum period of 40 years [23]. Medical surveillance assist significantly in identifying adverse health outcomes that may be related to exposure and also techniques required for early detection of symptoms ascribed to exposure [38]. The MRI staff should undergo medical surveillance 14 days after commencement of their employment [23]. Since there is a dearth of literature suggesting frequency of medical surveillance for MRI staff during their employment, this study suggest workers to undergo medical surveillance according to intervals defined by the responsible person to administer health surveillance, which in this case, it is an occupational health practitioner [39]. The occupational health practitioner should set up the intervals or frequency of health surveillance after considering exposure records and scientific evidence available on the dose-response effects [39]. The steps that occupational health practitioner should undertake in setting up a health surveillance are defined by Baker and Matte [40]. According to Baker and Matte [40], the first step is to screen detectable health effects during preclinical phase, and at this stage, intervention is more beneficial. The second step is to respond to medical tests through developing an action criteria. This is followed by standardisation of medical tests, provision of information, confidentiality of results and quality control. Although long-term health effects are not yet known, the health surveillance programme will detect exposure-response before long-term effects can manifest [39]. When developing and administering health surveillance programme, MRI staff are best positioned to report any health concerns that emanate from exposure to MRI-related electromagnetic fields. In the process of reporting the health effects, anonymity should be ensured in order to reduce fear of reprisal [41].

3.4.3 Rotation of workers

The schedule that ensures rotation of workers should be designed with an aim of reducing exposure time amongst MRI staff. Rotation of workers reduces number of workers exposed to MRI-related electromagnetic fields to minimum. According to the [42] guidelines of the National Institute of Occupational Safety and Health (NIOSH), the number of workers exposed to occupational hazards should be kept to minimum and at the same, their daily exposure to RF energy and SMFs should not exceed the recommended occupational exposure limits by the ICNIRP of 1998 and 2009. Sorawit and Suebsak [43] propose reduction of exposure to occupational hazards by adopting heuristic job rotation procedures. The heuristic job rotation procedures could significantly reduce exposure to RF energy and SMFs amongst MRI staff, and the procedures are as follow; 1. a shift is divided into work periods of equal duration, 2. one worker should perform each job within one work period, 3. job rotations are only allowed at the end of work shifts, 4. number of workers should be substantially higher than jobs to be performed, and as a result, some workers can idle in some work shifts, and 5. all workers should know the list of jobs they are able to perform. Rotation of workers should be implemented simultaneously with introduction of short-term exposure limit (STEL) and rest breaks to reduce exposure to minimal. According to the Occupational Health and Safety Act, Act no 85 of [23], STEL is a 15-min time weighted average exposure that should not be exceeded at any time during a workday. The exposure of HCW to RF energy and SMFs should be for a duration of not above 15 min per day.

3.4.4 Maintenance and written safe work procedures

The exposure to MRI-related electromagnetic fields can also be reduced by clearly documented procedures, which should form part of the exposure assessment (European Directive [33]). The safe working procedures should describe areas within the MRI units with specific restrictions on access and exposure, especially cleaning staff. Furthermore, the procedures should specify the conditions such as duration of work in the MRI room, number of visits in the MRI room per day, fields present and exposure consequences as well as the type of PPE required for workers when they enter the MRI room. One of the important factors to include in the safe working procedures keep and maintain a list of personnel authorised to enter the MRI room as well as personnel responsible for enforcing access. There should be written instructions about actions to be taken in the case of emergency situation. The copies of written safe working procedures should be given to all MRI staff. Regularly and adequate maintenance of MRI scanner by maintenance engineers could reduce emission of MRI-related fields to minimal level and subsequently reducing the exposure amongst workers (European Directive [33]). The on-going inspections and emission testing of RF and SMFs from MRI scanners will assist in identifying deterioration within the components of MRI scanner.

3.4.5 Use of warning signs

The warning signs are an important safety demarcation in every institution. Safety signs should be clear and unambiguous, they should be placed at eye level to induce visibility (European Directive [33]), and emission levels of RF energy and SMFs as well as exposure-related effects likely to develop following exposure should be defined on the warning signs. The warning signs should also warn workers with implantable medical devices as well as pregnant female workers. The example of safety sign to be demarcated at the entrance of the MRI room is shown below.

3.5 Personal protective clothing

Personal protective equipment is regarded as the last resort of control measure implemented once engineering or administrative controls have failed. If it is impossible to reduce the rate of

RF and SMF emissions by process modification or capture the emission once released, PPE suitable to frequencies emitted by 1.5 and 3.0 T MRI scanners can be used. Personal protective equipment should be properly maintained and regularly inspected to ensure that it remains fit for purpose (European Directive [33]). The continuous use of PPE could be uncomfortable [16], training and supervision on the correct use should be provided on constant basis. The PPE that can be used to reduce exposure of MRI staff to RF energy and SMFs include; EMF safety glasses, belly band, coveralls, faraday gloves and upper body shield. However, the recommended PPE should be coated with EMF shielding additives incorporated into textiles. Brzezinski et al. (2012), Cheng et al. [44] and Perumalraj et al. [45] recommend Knitted fabric coated with Ag, Cu or Ni deposited on the textile surfaces, this provides shielding effectiveness with high contribution to absorption coefficient, reduced transmission and reflection coefficients.

Fig. 9 Coveralls with hood coated with Cu or Ni

Fig. 10 Finger faraday cage gloves

The EMF safety glasses provide 90% reduction of RF energy within frequency range of 50 to 900 MHz [46]. Such glasses should not contain any metal components. According to WHO [47], metal components in RF safety glasses may enhance local fields by acting as a receiving antenna.

The Belly Band is a radiofrequency tummy-front shield for pregnant female workers [46]. This band is idea for pregnant MRI staff who are allowed to enter MRI rooms during the first trimester of pregnancy. Bhattacharjee [48] suggests that fabric made with rayon as well as fabric coated with Ni, Cu or Co provide 90% RF attenuation.

The coverall with hood shown in Fig. 9 provides RF shielding to the entire body [46], ideal to provide protection to less blood supplied tissues. It can be worn by cleaning and maintenance staff when entering the MRI room.

The faraday gloves (Fig. 10) protect workers from developing electromagnetic hypersensitivity [46]. The faraday gloves should be coated with Cu or Ni to provide sufficient RF attenuation [48] (Fig. 11).

Fig. 11 Upper body shield coated with Ag, Al or Cu

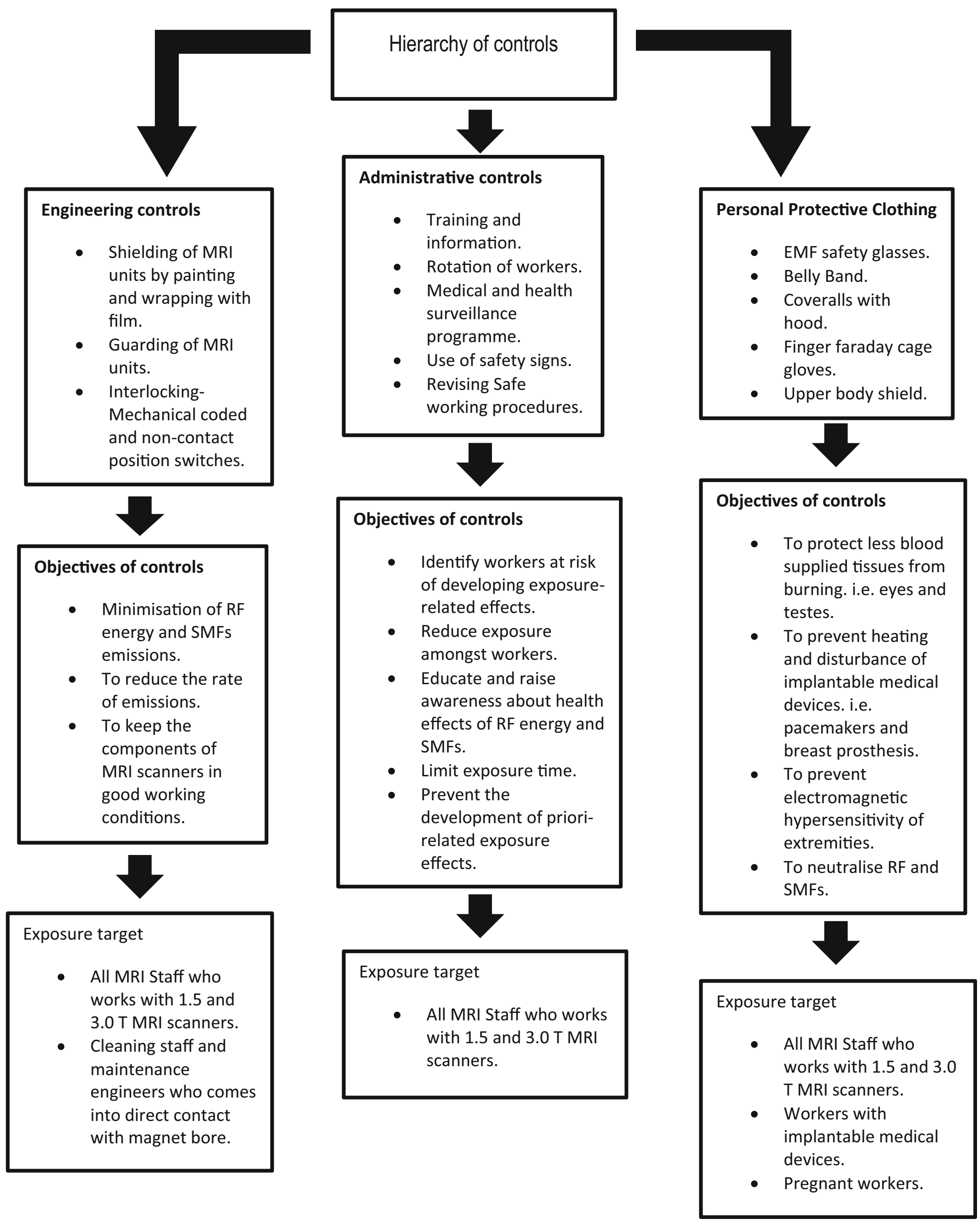
The upper body shield can be used by pacemaker wearers or workers with implantable medical device to shield their upper body from SMFs [46].

According to HSE [36], the benefits of using PPE is to reduce the risks of exposure from the remaining uncontained hazards, since engineering and administrative controls alone do not reduce the exposure completely. Provision of PPE should be free of charge and the occupational health practitioner should give instructions on the use, maintenance, monitoring, storage as well as review.

3.6 Review of control measures

Control measures should be reviewed regularly in order to determine their effectiveness [23]. The implemented control measures are mainly reviewed by conducting walkthrough survey [16]. In the process of walkthrough survey, workplace inspections are done, health and safety representatives are consulted, and medical surveillance records are reviewed [16]. During the review of implemented control measures, MRI-related electromagnetic field emissions from MRI scanners are tested and exposure-related health effects amongst workers are assessed. The primary objectives of reviewing implemented control measures is to assess the effectiveness of implemented controls, identify areas of concern, where measures could not be effective and to improve the efficiency of control measures [49]. Figure 12 illustrates the objectives for implementing the recommended control measures together with the target groups.

Fig. 12 Review of implemented controls



4 Discussion

The magnets of a flux density ranging from 0.2 to 3.0 T are used for MRI scanners [50], with 1.5 and 3.0 T used in South Africa [51]. Occupational exposure to SMFs has been associated with development of prior-related exposure effects [10, 52]. Healthcare workers are only exposed to RF fields when assisting patients with special needs. i.e. children or patients with severe medical conditions and they need to be monitored during the examination. They are present in the MRI room for approximately 2-15 min and usually at a distance of 0.3-1.5 m from the magnet housing [50]. In a study conducted by Wilén and de Vocht [53], 57% of symptoms such as drowsiness, headache, insomnia, nausea and vertigo were reported by nurses working with 1.5 and 3.0 T MRI scanners and this was as a result of exposure to SMFs. In the MRI room, the highest exposure of MRI staff occurs in the direct proximity of magnet's housing [54]. The main effect of exposure to RF fields in the MRI is tissue heating, the scientific evidence on the non-thermal effects is not conclusive [24]. The SMFs has also been associated with cognitive effects which were reported to be extremely mild [55] and absent in some cases [56, 57]. The exposure-related neurobehavioral effects such as visual and auditive working memory as well as eye–hand coordination speed problems have been reported amongst health workers exposed to SMFs at 1.5 and 3.0 T [58].

Experimental studies have suggested that exposure to SMFs lead to temporary effects on vestibular system [59]. The effects were reported to be stronger as a result of head movement in the heterogeneous stray fields, particularly on the edge of the magnet bore [60]. In a study performed by Schaap et al. [11], exposure levels near whole body closed-bore scanner increased from 30 to 76% for each additional tesla of scanner strength. The area around the scanner is usually subjected to strict access control [61], because the static fields change over distance in the MRI room, resulting in magnetic attraction of ferromagnetic objects nearby [24]. In South Africa, there are no strict access rules in the MRI units, this pose serious risks of ballistic effects and health consequences caused by induced movements of workers around the scanners. According to McRobbie [24] and Schaap et al. [52], health effects such as vertigo and magnetophosphenes experienced by workers in the MRI units, arise from their induced movements closer to the magnet housing. Although exposure-related effects have been well studied, McRobbie [24] suggests that a precautionary measure to be taken by health care workers is to move slowly within the field gradient in order to reduce motion-induced sensations.

The literature presents the acute exposure-related effects experienced by MRI staff working with MRI units ranging from 0.5 to 11 T scanners, however, there is still controversy with regard to non-thermal effects ascribed to RF energy exposure. The exposure levels recorded in the present study were within the recommended limits but significantly high in a 3.0 T scanner as compared to the 1.5 T scanner. Although there is no clear link between the reported priori-related exposure effects and the recorded exposure levels, it is important to mitigate exposure to SMFs and RF energy in the MRI units through the recommended control measures.

5 Conclusion

The exposure of workers to MRI-related electromagnetic fields could lead to the development of priori-related health effects and safety accidents in the MRI suites. However, the development of adverse health effects depends on duration, frequency, fields intensity and absorbed dose among workers. Complete reduction of MRI-related electromagnetic fields is a major challenge and elimination of emitted fields is impractical. Reduction of exposure levels can be achieved by implementing the recommended control measures, and this can subsequently lead to reduction of reported health effects. The use of recommended PPE could provide sufficient shielding to reduce high number of reported transient health effects ascribed to RF energy and SMFs exposures. The introduction of the model of this kind in the South African health care sectors could reduce occupational diseases which might be caused by prolonged exposure to MRI-related electromagnetic fields. In South Africa, there is no legislation that protect workers from exposure to electromagnetic fields, the implementation and frequent review of control measure could promote the health, safety and well-being of workers in the MRI units.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

Ethical approval Ethical clearance was obtained from the Health Sciences Research Ethics Committee of the University of the Free State (reference number: UFSHSD2018/0438).

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