Is magnetic resonance imaging safe for patients with retained metal fragments from combat and terrorist attacks?

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Background: Increasing numbers of military confrontations and terrorist attacks have led to increasing reports of retained metal fragments among patients referred for magnetic resonance imaging (MRI). The potential hazard of retained metal fragments for patients undergoing MRI has been studied among patients with retained metal fragments from domestic violence but not from combat and terrorist attacks.
Purpose: To retrospectively evaluate the safety of MRI in patients with subcutaneous warfare-metal fragments.
Material and Methods: 10,322 consecutive metal screening forms of patients scheduled for 1.5 Tesla (T) MR examination were retrospectively reviewed. All patients reported to have retained metal fragments were contacted by telephone and asked to describe the event in which they were exposed to the fragments and for any adverse sequelae or sensations during and after MRI. Their radiographs were evaluated for the number and size of the fragments. The data were analyzed for correlations between these factors.
Results: Seven of the 24 patients who reported retained metal fragments were excluded, since there was no validating evidence of their presence. Fragments in the remaining 17 patients (18 MRI examinations) were inflicted by military or terrorist attacks that occurred 2–39 years prior to the MRI. The fragment size ranged between 1 and 10 mm. One patient reported a superficial migration of a 10-mm fragment after MRI. No other adverse reactions were reported.
Conclusion: Conducting 1.5T MRI examinations is safe in patients with retained metal fragments from combat and terrorist attacks not in the vicinity of vital organs. However, caution is advised.

Key words: Adults; complications; foreign bodies; MR imaging; safety; soft tissues/skin

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Blast and fragment injuries of the musculoskeletal system are the most frequently encountered wounds in modern warfare (1). Most injuries to the musculoskeletal system involve so-called secondary blast injuries in which casing fragments and other debris become flying projectiles. Although blast and fragment injuries have traditionally been the purview of military surgeons, they are being seen more frequently among noncombatants because of increasing domestic terrorism.

With relatively high numbers of armed military confrontations and terrorist attacks, retained metals and bullet fragments and shrapnel (fragments from bombs and artillery shells) are not infrequently reported by Israelis who are about to undergo magnetic resonance imaging (MRI). There are innumerable types of bullets, pellets, and shrapnel fragments from various sources. Some are powerfully ferromagnetic, with potential hazard to neighboring vital organs (2, 3) and some are not (4). It was recommended by the American College of Radiology White Paper on MR Safety that the risk versus benefit of performing an MR procedure in a patient with retained metal fragments should be carefully considered (5). This recommendation was mainly based on experience with retained metal fragments, bullets, and shrapnel that resulted from domestic violence (3–9).

The purpose of our retrospective study was to evaluate a sequential series of patients with retained metal fragments resulting from combat and domestic terrorist

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events, in order to determine the safety and potential hazards of such subcutaneous metal fragments among patients undergoing MRI.

Material and Methods

All patients are required by our institutional policy to fill in and sign a safety screening questionnaire before entering the MRI suite. If a retained metal fragment(s) is reported, the patient is asked to supply an radiograph or any other imaging modality that can verify the location of the fragment. In a scenario of known fragments but with uncertain fragment position, further imaging is requested before MRI can be performed. Patients with metal fragments within or near vital viscera and other important structures, such as blood vessels, are precluded from undergoing MRI in our institution and their forms are not saved in the database. When possible, the imaging data are copied into the institution's picture archiving and communication system (PACS).

The MR screening forms of all patients who underwent MRI during 2006 were retrospectively screened, and the data on those who reported retained metal fragments post-combat or post-terrorist attack in their form were recorded. A structured telephone interview with these patients was then conducted. The interview consisted of five questions and was performed by one investigator. The patients were asked about the date (question 1) and the event (question 2) that produced the metal fragments, and the sensation and any possible adverse reactions they may have felt at three time points: during the MRI examination (question 3), immediately after the MRI examination (question 4), and in the period of time between the examination and the telephone interview (question 5).

The MRI studies of these patients, as well as available radiographs of the part of the body with retained metal fragments were further evaluated for the amount, size, and location of the metal fragments. The data were analyzed for correlation between sensation during and after the MRI examination and metal size, the interval between the injury and undergoing an MRI, as well as MR sequences and duration and type of MRI examination.

Permission to contact the selected patients by telephone and retrospectively review their radiological files was obtained from our institutional ethics committee.

Results

A total of 10,322 consecutive MRI screening forms were reviewed. Twenty-four patients who underwent 26 MRI studies reported retained metal fragments. There were 21 males and three females, with a mean age of 51 years (range 21–68 years). All 24 subjects were interviewed by phone 4–14 months (average 8 months) after the MRI examination. Seven patients who reported that they had misunderstood the questions on the screening questionnaire and denied having any retained metal fragments were excluded from the study. The 18 MRI examinations of the remaining 17 patients included nine examinations of the extremities and pelvis, three abdominal, five cardiac, and one spinal. Radiographs demonstrating the location of metal fragments in 12 patients were available in the PACS. Documentation in the form of hard-copy radiographs was supplied by the other five study participants.

All patients were examined by a 1.5 Tesla (T) MRI system (Signa, GE Excite2, Version 11; GE Healthcare, Milwaukee, Wisc., USA). Scanning included spin-echo (SE), fast SE (FSE), and gradient echo (GRE) sequences for the musculoskeletal examinations, FSE and GRE for abdominal examinations, and GRE sequences for cardiac examinations.

Fragments in all patients were inflicted by combat wounds or domestic terrorist attacks that had occurred between 2 and 39 years prior to the index MRI (average 24 years). All patients reported having superficial fragments, and none reported being aware of any fragment in proximity to vessels or vital organs that would contraindicate an MRI.

Twelve patients had retained fragments in the subcutaneous soft tissue of the pelvis and lower extremities, and the remaining five patients reported fragments in the upper extremities (Fig. 1) and torso (Table 1). Most patients had numerous minute fragments, and only two reported a solitary fragment. In one patient (patient 8) with retained fragments in one extremity, the body part was also examined by MRI. As seen on radiographs, the largest fragment measured 10 mm and the smallest was smaller than 1 mm (Fig. 2).

The duration of the MRI examinations was between 25 and 90 min (average 50 min). None of the patients reported any particular physical sensation, such as heating, burning, or itching, during the MRI examination. One patient reported a superficial migration of a fragment approximately 1 cm in size and located in the gluteus muscle after undergoing an MRI of the knee. He reported having noticed the migration only after leaving the MRI suite, but did not seek medical attention since he was aware from personal experience that such superficial fragments had a tendency to migrate. None of the other patients reported any adverse reactions following their MRI examination.

Discussion

Retained metallic foreign bodies, such as shrapnel and bullet fragments, are potentially harmful during MRI (10, 11). Safety recommendations for MRI in patients

Fig. 1. An upper-extremity radiograph shows multiple small subcutaneous metal fragments in a 21-year-old victim of a terrorist attack 5 years prior to the MRI. No adverse sensation was reported during or after the MRI examination of the ankle.

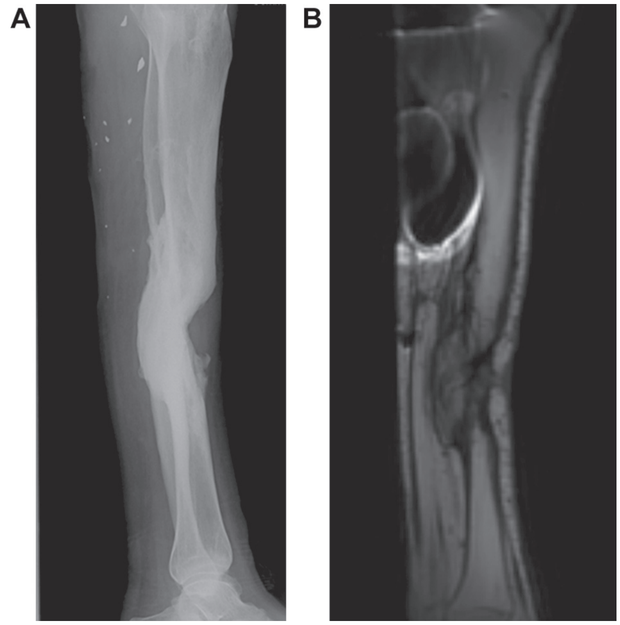

Fig. 2. A. Multiple metal fragments in the calf as well as bone deformation are evident on the lateral radiographs of a 56-year-old male with a combat injury sustained 30 years earlier. B. T1-weighted sagittal MRI of the same area with an artifact resulting from the fragments. No adverse sensation was reported during or after the exam.

with retained metal fragments are mainly based on studies on patients with fragments resulting from mostly domestic and criminal violence (3–9). In our series, only one out of 17 (5.9%) patients with known metal fragments afflicted during combat or terrorist attacks who underwent MRI reported an adverse reaction. This fragment that was reported to have moved was inflicted in combat more than 10 years prior to the MR examination.

Teitelbaum et al. (4) evaluated the magnetic deflection in 21 metallic specimens, and concluded that migration of bullets and bullet fragments caused by interaction of a metal fragment with the static magnetic field of an MR system (10, 11) poses only a small risk, which depended on the fragment shape and orientation. However, fragments from exploding munitions are smaller and irregularly shaped compared to bullets from small arms (12), and the ferromagnetism of bullets and shrapnel varies significantly. Therefore, Teitelbaum et al.'s conclusion would not necessarily be relevant to patients whose bodies retain shrapnel due to combat or terrorist attacks. Noteworthy, despite the fact that more than 10 years had passed since its impregnation, the surrounding granulation tissue of the fragment in one of our patients was not firm enough to prevent the fragment's motion.

Interaction of metallic fragments with radiofrequency (RF) electromagnetic fields and gradient magnetic fields can result in heating of the retained fragment and its surrounding tissue. No heating sensation was reported by our subjects, in agreement with the findings of Finitsis et al. who studied 19 patients with retained metallic bullets in various positions in potentially harmful sites in

Table 1. Locations of fragments

Patient no.	Organ examined	Organ with subcutaneous metal fragment	No. of fragments	Fragment size, mm
1	Knee	Pelvis	>10	2–5
2	Knee	Pelvis	>10	1–10
3	Knee	Thigh	2–10	<1
4	Pelvis	Arm	1	2–5
5	Ankle	Arm	>10	1–10
6	Ankle	Thigh	1	<1
7	Ankle	Arm	2–10	1–10
7	Ankle	Arm	2–10	1–10
8	Thigh	Thigh	2–10	1–10
9	Spine	Thigh	>10	5–10
10	Abdomen	Femur	>10	2–5
11	Abdomen	Torso	2–10	2–5
12	Abdomen	Pelvis	>10	>10
13	Heart	Pelvis	>10	2–5
14	Heart	Thigh	2–10	2–5
15	Heart	Pelvis	2–10	<1
16	Heart	Arm	2–10	1–10
17	Heart	Pelvis	>10	2–5

the spine (7). Reports of MRI-related burns are mostly concerned with implants, wires, and coils attached to the body (2, 6, 13). Our lack of evidence of heating during MR examinations does not rule out the possibility that it might occur. The largest retained fragment in our group measured 1 cm; larger fragments might cause heating. As the field strength of the MR systems increases, the RF power increases along with the specific absorption rate (SAR) of energy deposition in the body, but the actual SAR is not significantly different in practice due to safety regulations (10). There are no reports on the interaction of a stronger magnet (e.g., 3T) with retained ferromagnetic fragments.

Imaging sequences that utilize multiple 180° RF pulses (e.g., turbo spin echo, fast spin echo, etc.) are of greater concern than those with one 180° RF pulse (conventional spin echo), or none (gradient echo). The 180° RF pulses may produce high levels of RF energy deposition in the body, resulting in an increased absorption rate (10) and an increased potential for heating. However, even cardiac MR sequences that include such heavily multiple RF pulses did not cause heating of the fragments among our study patients.

The safety concern for gradient magnetic fields is related to the size and frequency of the time-varying fields, which become stronger moving away from the isocenter in all directions toward the periphery of the bore (10). Thus, heating a metal fragment and the surrounding soft tissues with gradient magnetic fields is potentially possible even when this part is not directly imaged.

Our study was not designed to detect patients with unknown and unreported metal fragments incidentally discovered on MRI. Few studies have reported the incidental findings of tiny metal fragments during MRI examinations (14), and there are no publications on the prevalence of such incidental MRI findings. We have no specific information on the metal composition of the soft-tissue fragments in our cohort. Many unique metal mixtures are found on today's battlefield, both in newly developed munitions as well as in improvised explosive devices such as the ones used in most terrorist attacks. These can include different types of metal mixtures, such as tungsten, nickel, and cobalt, with different amounts of stainless steel and iron and, in some cases, depleted uranium (12, 15, 16). In terrorist attacks, metal fragments could be caused not by the explosive device itself but also by the metals of the exploding vehicle in the case of a car bomb.

The retrospective design of our study is a major limitation, and it is possible that we missed some patients who had metal fragments but did not report them in the screening form. Also, because no follow-up MRI was performed after the initial MRI, subclinical damage to the surrounding tissue of the fragments cannot be excluded. In addition, the only adverse reaction reported in our series is based on self-observation of one of the patients, with no confirmation by a medical staff member.

Our institution does not keep track of patients for whom MRI was contraindicated due to potentially harmful metal fragments, and their responses to the questionnaires are not archived. A study on the frequency of referral of patients with a variety of safety-related contraindications to MRI was recently published, but it did not mention the prevalence of the ones whose retaining of metal fragments precluded their undergoing MRI studies (17).

In conclusion, our preliminary experience shows that conducting MRI examinations in patients with retained metal fragments resulting from combat and terrorist attacks is feasible after taking special caution, as well as taking into account a number of factors, such as the proximity of metal fragments to vital organs, fragment size, MRI strength, and other technical safeguards.

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