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MRI issues for ballistic objects: information obtained at 1.5-, 3- and 7-Tesla

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Abstract

BACKGROUND CONTEXT: Few studies exist for magnetic resonance imaging (MRI) issues and ballistics, and there are no studies addressing movement, heating, and artifacts associated with ballistics at 3-tesla (T). Movement because of magnetic field interactions and radiofrequency (RF)-induced heating of retained bullets may injure nearby critical structures. Artifacts may also interfere with the diagnostic use of MRI.

PURPOSE: To investigate these potential hazards of MRI on a sample of bullets and shotgun pellets.

STUDY DESIGN: Laboratory investigation, ex vivo.

METHODS: Thirty-two different bullets and seven different shotgun pellets, commonly encountered in criminal trauma, were assessed relative to 1.5-, 3-, and 7-T magnetic resonance systems. Magnetic field interactions, including translational attraction and torque, were measured. A representative sample of five bullets were then tested for magnetic field interactions, RF-induced heating, and the generation of artifacts at 3-T.

RESULTS: At all static magnetic field strengths, non–steel-containing bullets and pellets exhibited no movement, whereas one steel core bullet and two steel pellets exhibited movement in excess of what might be considered safe for patients in MRI at 1.5-, 3- and 7-Tesla. At 3-T, the maximum temperature increase of five bullets tested was 1.7°C versus background heating of 1.5°C. Of five bullets tested for artifacts, those without a steel core exhibited small signal voids, whereas a single steel core bullet exhibited a very large signal void.

CONCLUSIONS: Ballistics made of lead with copper or alloy jackets appear to be safe with respect to MRI-related movement at 1.5-, 3-, and 7-T static magnetic fields, whereas ballistics containing steel may pose a danger if near critical body structures because of strong magnetic field interactions. Temperature increases of selected ballistics during 3-T MRI was not clinically significant, even for the ferromagnetic projectiles. Finally, ballistics containing steel generated larger

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artifacts when compared with ballistics made of lead with copper and alloy jackets and may impair the diagnostic use of MRI.

Keywords: Magnetic resonance imaging, safety; Heating, MRI; Artifacts, MRI; Bullets; Ballistics

Introduction

In consideration of the prevalence of both civilian and military gunshot injuries resulting in retained bullets, it is important to determine the risks involved with magnetic resonance imaging (MRI) [1]. This is especially relevant because MRI is often used as part of the initial injury workup or as part of the preoperative planning process. Although most small arms ballistics are fabricated using nonferromagnetic materials and, therefore, will not cause patient injuries because of movement or dislodgment in tissue, prior studies demonstrated that many have ferromagnetic impurities [2]. Furthermore, although most shotgun pellets were historically lead based, environmental pollution concerns have led to the introduction of steel-based pellets that may be ferromagnetic [3]. Any retained ballistic object displaying magnetic field interactions, whether because of occult impurities or actual fabrication material (such as steel or nickel), poses a potential risk to soft-tissue, vascular, and neural structures because of migration and torque in association with the powerful static magnetic field encountered during an MRI examination [2–7]. The effect of MRI-induced heating of conductive materials (both ferromagnetic and nonferromagnetic) may also pose a risk [8,9].

With few exceptions, the numerous theoretical risks have not been effectively substantiated in the current literature [2–6,8,9]. The conclusions of prior studies are that, ballistics known to contain iron or nonaustenitic steel should not be allowed in patients referred for MRI examinations, whereas the vast majority of commonly encountered American-made bullets have minimal or no ferromagnetism and are not considered to pose a risk to patients relative to the use of MRI [2–4]. However, these investigations were conducted in the setting of magnetic resonance (MR) systems using static magnetic fields up to 1.5-tesla (T) only. Presently, MRI scanners using magnets with static magnetic fields of 3-T are used clinically, and even 7-T scanners now exist in the research environment. Accordingly, it is critical to understand how retained bullets will behave in the setting of more powerful MRI systems because the outcome of unanticipated behavior of metallic objects near critical anatomic structures could be catastrophic [1,10].

For this investigation, we hypothesize that commonly encountered bullets and shotgun pellets are not subject to magnetic forces sufficient to pose harm to patients undergoing MRI in 1.5-, 3-, and 7-T scanners. The goals of this ex vivo study were to determine the magnetic field interactions (at 1.5-, 3- and 7-T), MRI-induced heating (at 3-T), and image artifacts (at 3-T) for a representative sample of ballistic objects that are commercially available and commonly encountered in criminal trauma.

Materials and methods

Bullets and pellets

Thirty-two different bullets and seven types of shotgun pellets (Table 1) obtained from the San Francisco Police Department underwent MRI evaluations in this study. The samples were representative of those commonly encountered in urban crime-related trauma and hunting accidents. Each bullet and pellet was tested for translational attraction in 1.5-T (Signa; General Electric Healthcare, Milwaukee, WI, USA), 3-T (GE 750; GE Healthcare, Milwaukee, WI, USA), and 7-T (GE 950; GE Healthcare, Milwaukee, WI, USA) MR systems.

Magnetic field interactions

Translational attraction

The deflection-angle method described by New et al. and used in previous similar studies [2,8–16] was used to assess translational attraction for the samples. This method involved suspending the object on a string (20-cm length; weight $<1\%$ of each sample) attached to a stable nonferromagnetic structure fixed with a plastic protractor with 1° graduated markings (Fig. 1). The apparatus was then placed eccentrically near the scanner portal at the experimentally determined point of highest spatial magnetic gradient for each MR system [17]. The deflection angle from the vertical position to the nearest 1° was measured three times, and the mean value was calculated. Following the methodology of previous studies, a deflection greater than 45° was considered to be potentially relevant [10,11].

A single bullet (no. 32) that was found to deflect 90° was retested in a 3-T MR system (Excite, HDx; General Electric Healthcare, Milwaukee, WI, USA) using a digital force gauge (model 475040; Extech Instruments, Waltham, MA, USA) to measure the translational attraction, as previously described [18,19]. The bullet was positioned within the 3-T MR system at the point of highest magnetic spatial gradient to measure a peak translational force.

Torque

Torque was assessed using a qualitative measurement technique used by previous studies, in which each test item was placed on a flat plastic material with a grid etched on the bottom (Fig. 2) [8,14–16]. Each test samples were