MRI Safety with Orthopedic Implants

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KEYWORDS

• Magnetic resonance imaging • Radiofrequency-induced heating • Implant migration • Torque • Safety

KEY POINTS

- This study reviews the current literature on MRI safety with orthopedic implants.
- MRI is safe in patients with orthopedic implants regarding migration and torque.
- Radiofrequency-induced heating of implants during MRI showed small differences among studies, although not clinically significant.
- Pediatric patients may be at an increased risk for thermal injury if anesthetized and/or unable to report temperature change during MRI.
- A risk-to-benefit ratio should be applied when using MRIs with orthopedic implants in pediatric patients requiring sedation.

INTRODUCTION

MRI is a valuable diagnostic tool, with utility in pediatric and musculoskeletal imaging due to its lack of ionizing radiation and excellent soft tissue contrast. A continual increase in MRI usage has been demonstrated in the United States, with a 5% rise annually, peaking at 118 examinations per 1000 population (64 in an ambulatory setting and 54 in an inpatient hospital setting).[1] Additionally, the United States has the second-most MRI units per capita, with a 188% increase since 1995, reaching 39 per 1 million population in 2015.[2,3] What makes MRI unique is the method by which the images are obtained. MRI uses a magnet to alter proton rotation, producing signals as the protons return to their baseline rotation at differing rates in various tissues of the body. The magnetic fields used to manipulate the protons during the imaging sequence come in varying strengths for different uses; however, nearly all clinically used scanners in the United States are under 3.0 T,[4] and only one 7.0-T scanner has received approval from the United States Food and Drug Administration for clinical use.[5] Scanners with strengths over 3.0 T are routinely used in research; however, this article's focus in on recommendations on clinically relevant field strengths.

MRI is considered safer and is generally preferred in the pediatric population compared with CT scans for advanced imaging because it does not use ionizing radiation. MRI is not without risk, however, and the Food and Drug Administration[6] receives reports of approximately 300 adverse events associated with these examinations annually. Second-degree burns are the most commonly reported problems and are often due to the formation of internal currents (via skin-to-skin contact)[7,8] or from external metallic objects contacting the body (electrocardiogram leads,[9] pulse oximeters,[10] microfiber tech clothing,[11] medical patches,[12] and so forth). Projectile events (objects drawn into the magnetic field), crush injury of the digits by the patient table, patient falls, and hearing loss or tinnitus are the next most commonly reported problems with MRI, all unrelated to the presence of an orthopedic

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implant. Additionally, pediatric patients requiring anesthesia to inhibit movement during the long MRI acquisition time are at higher risk of adverse events during the MRI sequence.[13–15] Over the past several decades, the safety, compatibility, and imaging artifact caused by surgical implants have been tested in numerous in vivo and ex vivo studies. Because MRI units use strong magnets, metal implants pose a particular hazard with their potential for dislodgment, heating of the implant, and possible damage to surrounding tissues. Although newer orthopedic implants seem safe for MRI, concerns remain with the increasing field strength of MRI scanners. Additionally, confusion remains regarding MRI use immediately postoperatively in patients with surgical implants. This study reviews the current literature concerning the safety of MRI in patients with orthopedic implants. Information was sought about displacement, torque, and radiofrequency-induced (RF) heating of orthopedic implants, paying special attention to any articles pertaining to pediatric orthopedics.

LITERATURE SEARCH

This study did not require institutional review board approval. PubMed was searched using the terms, "MRI and Safety and Orthopedic Implant"; "MRI and Safety and Surgical Implants"; "MRI and Safety and Medical Implants"; "MRI and Orthopedic Hardware and Soft Tissue"; "Magnetic Resonance Imaging and Radiofrequency Heating and Metal Implants"; "MRI and Safety and Pediatric and Orthopedics"; and "MRI and Safety and Spinal Implants." Google Scholar was also searched using these terms to capture relevant articles not listed on PubMed. Only articles published within the past decade were reviewed and only those that discussed MRI safety pertaining to orthopedics were included. In addition, the Web site mrisafety.com was reviewed.

LITERATURE SEARCH RESULTS

The PubMed search produced 402 articles. After narrowing the results to the past 10 years, 219 articles remained. After excluding duplicate articles, articles not pertaining to orthopedic implants, and articles discussing topics other than safety, 15 remained for review.[16–30] Implant displacement was discussed in 11 articles,[16–22,26–28,30] RF heating in 13,[16–21,23–25,27,28,30] and torque in 4.[21,22,26,27] Table 1 summarizes the results of the 15 studies.

Implant Displacement

Implant displacement in 1.5-T, 3.0-T, and 7.0-T scanners has been the focus of numerous studies.[16–22,26–28,30] The experimental studies examined the change in the hanging angle of implants in scanners during an imaging sequence compared with prior to imaging (Fig. 1). A displacement angle of 45° indicated that the translational force of the magnet was equivalent to the force of gravity, and an angle over 45° indicated a potential for implant displacement with MRI.[21,29] Overall, significant displacement in orthopedic implants was infrequent. Two studies reported deflection angles over 45° using a 7.0-T MRI.[21,22] In Feng and colleagues'[21] study, 2 stainless-steel implants showed deflection of more than 45° at 7.0 T. Dula and colleagues[22] reported a deflection angle of 55° for the Synergy Hip System (Smith and Nephew, Memphis, TN) (metal not reported). The deflection angle for all other implants reported was well below 45°, with most below 10° (see Table 1). Except for a known ferromagnetic posterior spinal implant with a deflection angle of 65°,[26] all other implants had no significant displacement in 1.5-T and 3.0-T scanners. All studies but 2[19,28] were performed in ex vivo conditions, and the 2 in vivo studies failed to demonstrate any clinically or radiographically significant implant migration. Two studies also found no detrimental effects of MRI on magnetic-controlled growing rods.[27,28]

Torque

Torque describes the rotational displacement and speed at which the implant aligns with the magnetic field. Only 4 studies reported torque values.[21,22,26,27] Feng and colleagues[21] reported 1+ (minimal) torque in 2 titanium implants and 1 titanium alloy implant. Dula and colleagues[22] reported 2+ (moderate) torque in a pyrocarbon knee implant, a Synergy Hip System, and a titanium alloy hip stem with a cobalt-chrome head stem. They also reported 1+ (minimal) torque in a cobalt-chrome staple and an oxidized zirconium knee implant. McComb and colleagues[26] reported 2+ (moderate) torque in 1 highly ferromagnetic posterior spinal implant but deemed the risk to patient safety minimal, given the rigid fixation of the implant.

Radiofrequency-induced Heating

RF heating of implants during MRI sequencing was discussed in 13 of the 15 articles,[16–21,23–25,27–30] with 8 showing a change