Metal Artifact Reduction

Standard and Advanced Magnetic Resonance and Computed Tomography Techniques

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KEYWORDS

• Metal artifact reduction • Techniques • MR • CT • Hardware

KEY POINTS

- MR imaging and computed tomography (CT) artifacts from metallic implants are related to various factors, such as the type, size, and shape of the metal and the imaging parameters that are used.
- MR imaging artifacts can be reduced using standard techniques, such as scanning on lower-field-strength systems and using fast spin echo and short tau inversion recovery sequences with high bandwidth parameters, as well as using advanced techniques, such as view angle tilting, slice encoding for metal artifact correction, and multi-acquisition variable-resonance image combination.
- CT artifacts can be reduced using standard techniques, such as using high kilovolts peak and milliampere second, narrow collimation, and thinner slices, as well as advanced techniques, such as monoenergetic dual-energy CT and sinogram inpainting methods.

INTRODUCTION

An increasing number of joint replacements are being performed in the United States[1,2] owing to several factors, including increased life expectancy of the population, increased demand by younger patients seeking a better quality of life,[3,4] and increased access, with more surgeons performing these procedures. Between 1990 and 2002, the annual number of primary and revision total hip replacements (THR) per 100,000 persons increased by 46% and 60%, respectively; the annual number of primary and revision total knee replacements (TKR) per 100,000 persons increased by 295% and 166%, respectively.[2] Similarly, the number of shoulder arthroplasties increased by 236% per annum in 2008 compared with 1993.[1] It is projected that this trend will continue and that by 2030 the number of primary and revision THR will increase by 174% and 137%, respectively, in comparison with 2005; for TKR, these numbers will increase by 673% and 605%, respectively.[5]

Patients undergoing these procedures can have various complications, including loosening of the implant (both infectious and aseptic), fracture, dislocation, component failure and wear of the

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implant, synovitis, bursitis, and tendon tears. Imaging is usually one of the primary means of diagnosing these complications. Radiography has been and continues to be the first-line modality for the evaluation of patients with implants. However, radiographs may significantly underestimate the extent of any complication. Cross-sectional imaging techniques, such as computed tomography (CT) and MR imaging, are more sensitive than radiographs for the evaluation of complications (**Fig. 1**). In a study by Walde and colleagues,[6] the sensitivity of radiographs in detecting osteolysis was found to be only 52%; the sensitivities for CT and MR imaging were 75% and 95%, respectively. CT, MR imaging, and ultrasound are also superior to radiography for the evaluation of periprosthetic soft tissues.[7,8] However, the use of CT and MR imaging in patients with metallic implants is limited by the presence of artifacts, which can obscure pathologic findings and lower the reader's confidence. These artifacts can be reduced through the use of metal artifact reduction (MAR) techniques. This review discusses the causes of metal artifacts on MR imaging and CT, contributing factors, and both conventional and novel methods to reduce the effects of these artifacts on scans.

CAUSES OF METAL ARTIFACTS ON MR IMAGING

Metallic objects cause artifacts on MR imaging because of their magnetic susceptibility, which is the tendency of a substance to become magnetized when exposed to an external magnetic field. When an object becomes magnetized, it exerts its own magnetic field, thereby distorting the external magnetic field (B_0). This distortion results in a field inhomogeneity near the metal, which in turn alters the phase and frequency of the local spins. Alteration in phase results in loss of signal intensity by intravoxel dephasing (also known as the T2* effect). Alteration in frequency results in spatial misregistration, primarily in the frequency-encoding and the slice selection direction. This misregistration results in distortion of the image within the x-y plane of the image (in-plane distortion) and in the z-direction (through-plane distortion).

FACTORS THAT DETERMINE THE DEGREE OF METAL ARTIFACT ON MR IMAGING

Composition of the Implant

The degree of artifact caused by a metallic implant depends on its magnetic susceptibility, which in turn depends on the implant's composition. Metals with higher magnetic susceptibility demonstrate more artifacts than metals with lower magnetic susceptibility. Materials can be broadly divided into diamagnetic, paramagnetic, and ferromagnetic substances based on their magnetic susceptibility, with ferromagnetic substances having the highest susceptibility, followed by paramagnetic materials; diamagnetic materials have the lowest susceptibility.[9] Implants composed of ferromagnetic metals, such as iron, nickel, and cobalt, generate more artifacts than those composed of titanium, which is paramagnetic.[10,11] In clinical practice, orthopedic implants composed of stainless steel or cobalt-chromium (CoCr) alloys will result in greater artifact than implants composed of titanium (**Fig. 2**).

Size, Shape, and Orientation of the Implant

The size, shape, and orientation of the implant relative to the B_0 direction contribute to the degree of artifact. A larger implant will result in a greater

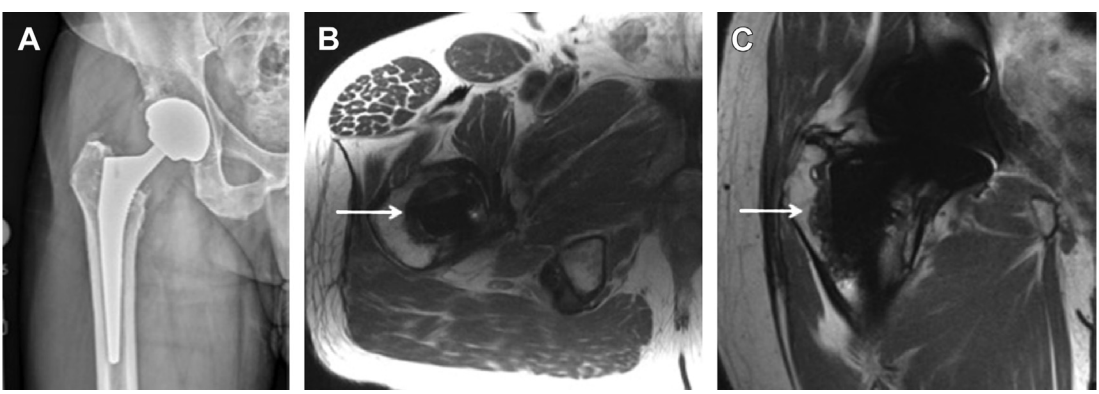

Fig. 1. Radiograph (*A*), axial (*B*), and coronal (*C*) non–fat-suppressed high-bandwidth proton density MR images in a patient with a metal-on-metal right hip arthroplasty. Several radiographs performed in the preceding 2 years had been interpreted as normal. However, because the patient reported chronic pain, MR imaging was performed; the images demonstrated osteolysis (*arrows*) adjacent to the femoral component.