Imaging of Metallic Prostheses Using Novel Sequences: Early Experience

Leon D. Rybak, M.D.[1]; Mary Bruno, B.S.[1]; Mathias Nittka, Ph.D.[2]; Christian Geppert, Ph.D.[3]; Holly Delaney, M.D.[1]; Park Jong, M.D.[1]

[1]New York University Medical Center, Department of Radiology, New York, NY, USA
[2]Siemens Healthcare, Erlangen, Germany
[3]Siemens US R&D Collaborations, New York, NY, USA

Introduction

For many years, diagnostic imaging in patients with metallic implants had been limited to plain X-rays and nuclear medicine studies. Although there have been advancements with regards to imaging of hardware using computed tomography, many of the changes involve increasing the radiation dose at a time when the public has become increasingly sensitive to reported long term risk of carcinogenesis posed by this exposure. With recent technical developments, magnetic resonance imaging (MRI) in the presence of metal is quickly becoming a reality with the added benefits of excellent soft tissue resolution and contrast. This could not come at a better time considering that new methods of hip and knee arthroplasty have led to unique complications which require timely diagnosis and treatment to prevent implant failure, damage to the surrounding soft tissues and, possibly, carcinogenesis [1, 2]. This article outlines some of these advances and describes the author's early experiences in regards to the clinical use of these techniques.

The clinical incentive

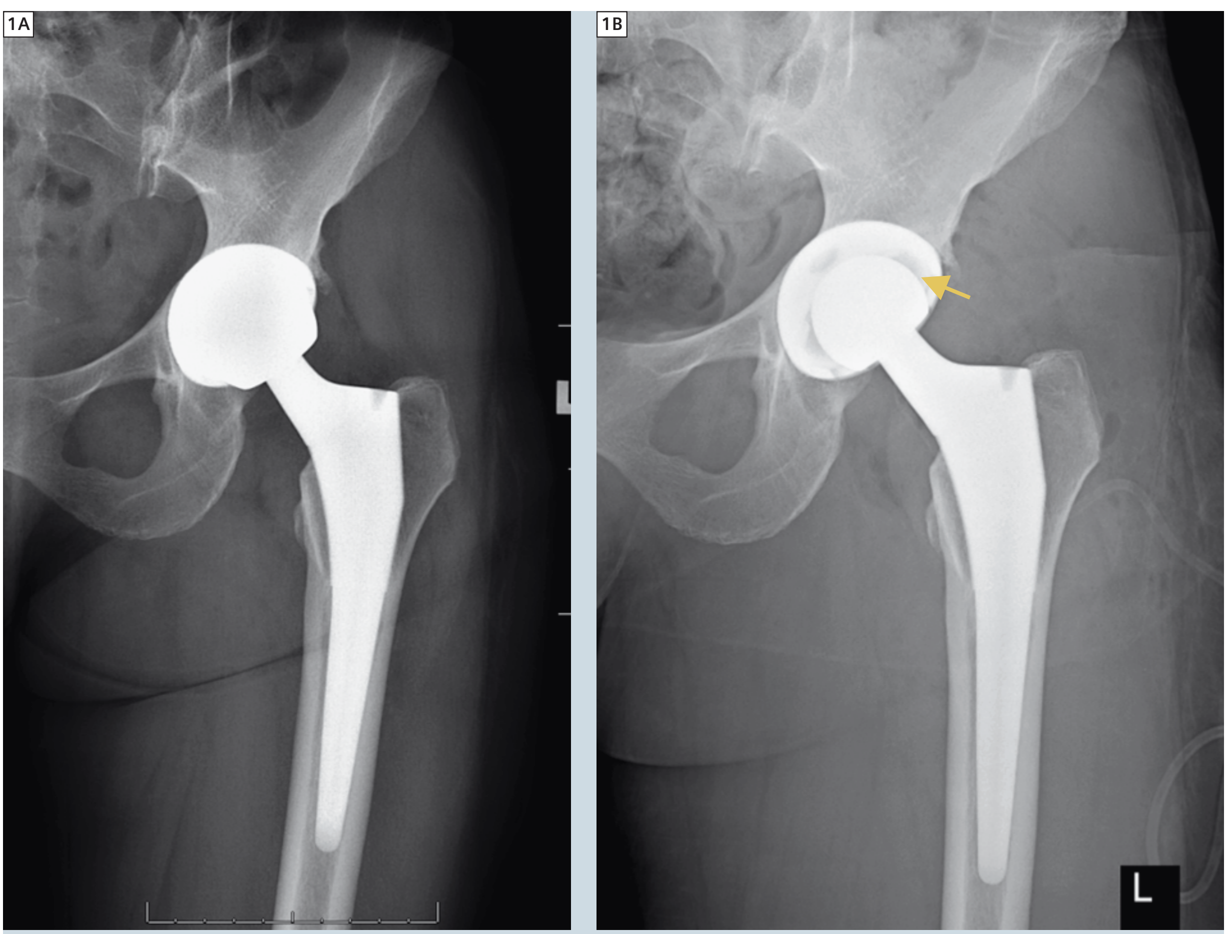
Initial attempts at arthroplasty involved the interposition of various substances including fascia lata, porcine bladder, gold foil, glass, rubber and Vitallium [3–5]. Early versions of hip arthroplasties were marred by flawed design and poor materials resulting in early failure. It was not until the 1960s that Sir John Charnley of the Manchester Royal Infirmary developed the initial prototype of what would become a long line of modern hip arthroplasties. It soon became apparent, however, that the longevity of these devices was limited, in large part to wear of the various components. It was also discovered that the particles which resulted from this wear could incite an inflammatory response that led to areas of bone destruction. This process was given several names over the years, some of which included 'cement disease', 'particle disease', 'foreign body granuloma formation' or, simply, 'osteolysis' [6, 7]. Although most cases were limited, more florid cases resulting in widespread and extensive bone loss were noted. This 'aseptic' form of loosening which, though not without consequence, would have to be differentiated from septic or infectious loosening. Infected arthroplasties, require removal and, in many cases, a two staged procedure with a period of antibiotic therapy prior to re-implantation. Though the gold standard in these cases has remained joint aspiration and culture, imaging has played a role with certain plain film findings and nuclear imaging studies helping to confirm the diagnosis.

Initial reports of osteolysis around arthoplasties implicated methacrylate (cement) as the inciting factor. However, with the advent of non-cemented components, the majority of cases have been attributed to wear of the polyethylene components [6]. Regardless of the presence of bone destruction, the inevitable loss of the polythene weight-bearing surfaces has led to a limited lifespan of the prosthesis and the need for revision surgery. In an effort to increase the longevity of the components, much research has centered on the creation of new, more durable plastics included cross-linked ultrahigh-molecular-weight polyethylene as well as the use of other substances such as ceramic [4, 5]. Though initially explored in the 1960s, metal-on-metal systems had not met with success and were abandoned. In an effort to prevent the complications resulting from component wear, the feasibility of such a system was revisited in the past decade. Theoretically, metal-on-metal systems would eliminate the need for plastic altogether, reduce the rate of wear and allow for the use of larger femoral heads providing for greater stability and range of motion [5] (Fig. 1). Though these new systems showed early promise, they have created a new set of problems and complications. Metal wear resulting in 'metallosis' with elevated blood levels of ions has been noted, creating a fear of possible carcinogenesis [1, 2]. More recently, a new form of perivascular lymphocytic infiltration involving the soft tissues of the hip girdle referred to as aseptic lymphocyte-dominated vasculitis-associated lesions (ALVAL), has been described [8–13]. In addition to areas of osteolysis, this pathologic entity has been noted to manifest as synovitis, peri-prosthetic soft tissue masses and bursal fluid collections. Like osteolysis, ALVAL needs to be discriminated and has even been implicated as a risk factor for infection [14, 15].

These developments have created an additional incentive to find a safe and effective mechanism of non-invasively evaluating both the prosthetic components themselves, but also the joint space and surrounding soft tissues. Recent advances in magnetic resonance imaging have made this possible.

The physics

In order to be able to fix a problem, one must first be familiar with the issues. When a patient with an arthroplasty is placed in the magnetic field, the relatively easily magnetized metallic components of the arthroplasty are in direct apposition to poorly magnetized soft tissues creating large localized fluctuations of the static magnetic field. The result is either spatial mismapping or even complete signal loss. One should be aware that the mismapping takes place in two dimensions: one is the in-plane signal misregistration in the frequency direction which occurs during readout, closely related to the well known chemical shift effect. The second effect is a through-plane distortion due to warping that occurs at the time of slice selection. Metal artifacts are strongly dependent on the type and shape of the metal used and the orientation of the metal within the magnetic field. Titanium implants, being less magnetic, tend to pose the least problem for the imager, with stainless steel causing more perturbation of the field and cobalt chrome presenting the greatest challenge. As the susceptibility artifact occurs in the frequency direction, orienting the metallic components with the longest axis in the frequency direction will allow optimal resolution of changes along the greatest proportion of the metal soft tissue interface. Alternatively, two acquisitions with a swap of phase and frequency will optimize resolution around all portions of the prosthetic components. Finally, curved or rounded portions of the metal components like the femoral head tend to



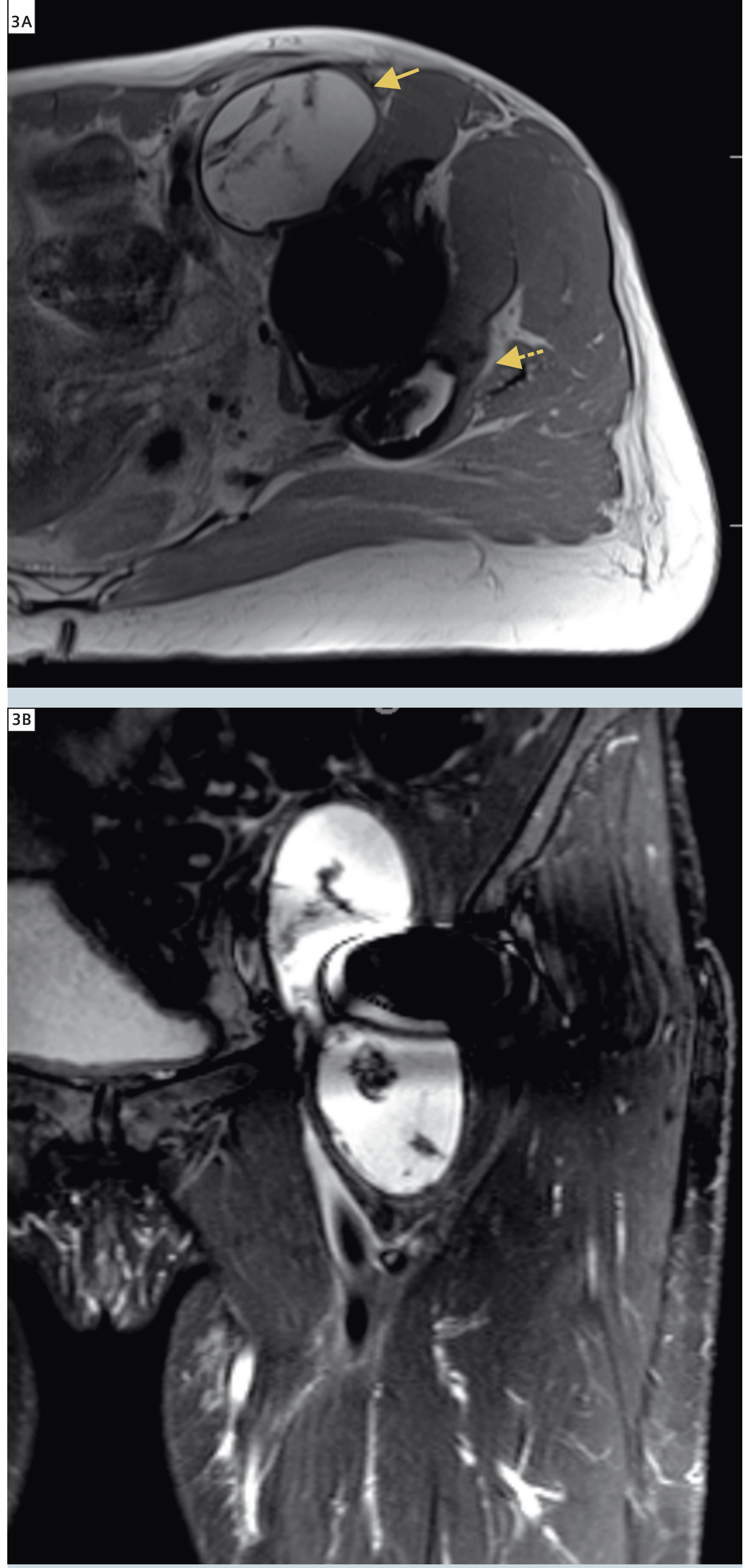
1 AP radiographs of the hip in the same patient before **(1A)** and after **(1B)** revision arthroplasty. The original prosthesis in **(1A)** consists of a metal on metal device with no interposed plastic component. Note the large size of the metallic femoral head which articulates directly with the acetabular cup. In the more traditional revised prosthesis in **(1B)**, note the lucent zone (arrow) between the femoral head and acetabulum which reflects the interposed polyethylene liner.

2 STIR contrast images of a total knee prosthesis in the sagittal plane **(2A, 2B)** and a total hip prosthesis in the coronal plane **(2C, 2D)** obtained on a 1.5T magnet (MAGNETOM Avanto, Siemens Healthcare). In each case, the left sided image was obtained with routine technique and the right image, with the SEMAC* sequence. The imaging times were between 3–4.5 minutes for the conventional and 9–12 minutes for the SEMAC sequences. Arrow pointing to the lateral soft tissue.

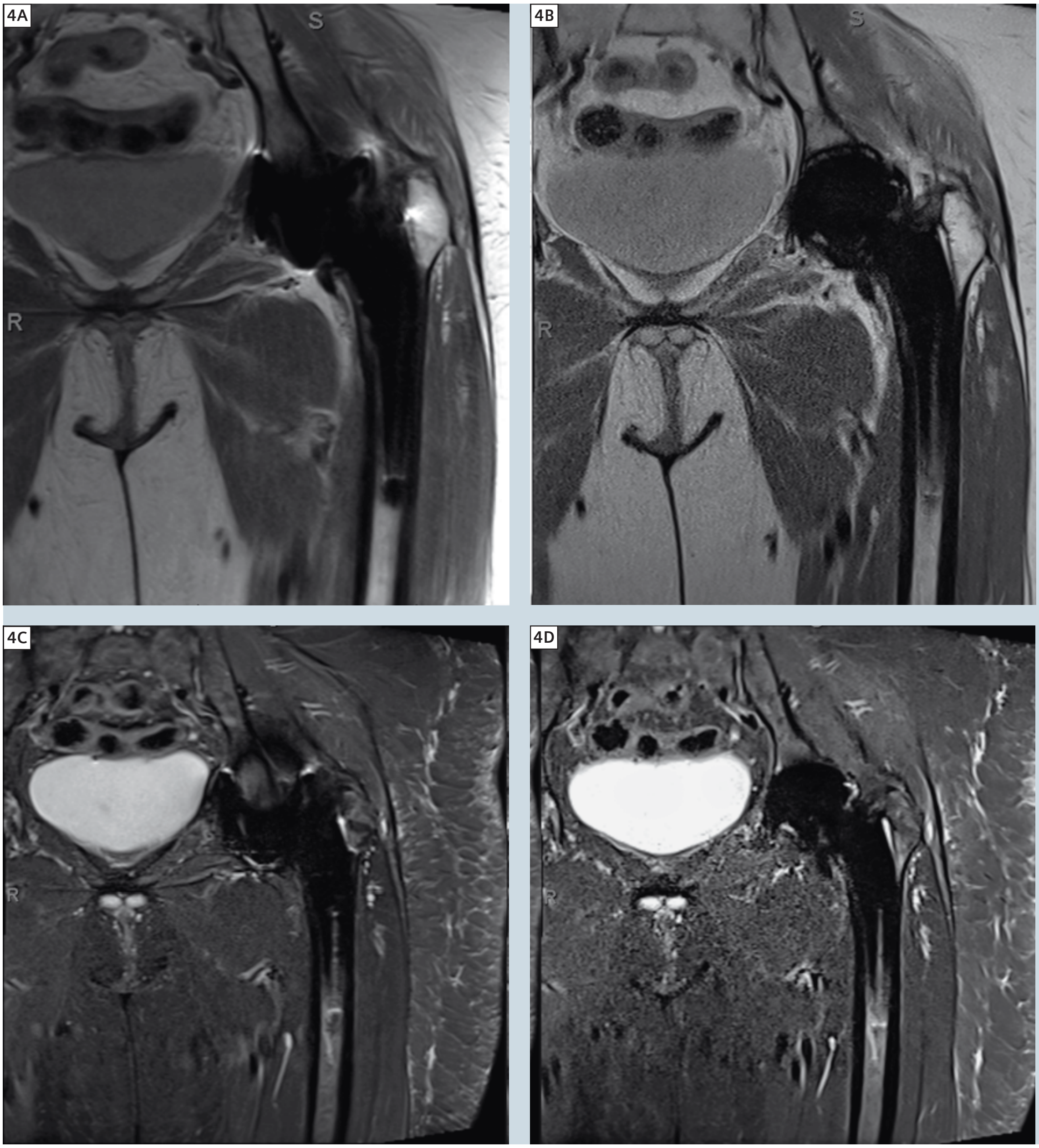
cause more disturbance of the magnetic field than the linear portions [16–20]. It is, thus, possible to eliminate a certain amount of artifact making changes in several of the basic sequence parameters. First, turbo spin echo (TSE) techniques are used to take advantage of the multiple 180 degree refocusing pulses which result in rephasing of the signal. Second, receiver bandwidth is increased to reduce the shift in the frequency encoding direction in the area of the metal. Third, spatial resolution is increased by using a finer matrix to decrease the conspicuity of the artifact. Last, if fat suppression is required, inversion recovery is favored over frequency selective techniques which may suffer as a result of field inhomogeneity.
In addition, there are more sophisticated approaches to metal reduction which change the actual acquisition scheme of the conventional TSE sequence. One of these which is referred to as view angle tilting* (VAT) involves applying an additional readout gradient with the same amplitude as that employed during slice select, thereby re-phasing the spins in the x-axis and correcting for in-plane distortion [21]. Slice Encoding for Metal Artifact Reduction[1] (SEMAC) is a novel technique which is presently being tested for clinical applications. With SEMAC, additional phase encoding steps are applied in the z-direction, correcting through plane distortions. This method is used in conjunction with VAT [22, 23]. Though artifact reduction has been demonstrated, there is a significant time cost with SEMAC and much of the research at this time is focused on increasing the speed of image acquisition with this technique.

Early clinical results

Several groups using various methods of metal reduction have reported good to excellent results in visualization of both the prosthetic bone interface as well as the surrounding soft tissue envelope in patients [20, 24, 25]. Using their standard protocol with simple parameter modifications designed for optimization of metal artifact reduction, White et al.



3 1.5T MR images (MAGNETOM Avanto, Siemens Healthcare) from a surgically proven case of metallosis with ALVAL status post metal on metal hip replacement in a 48-year-old female. Both the optimized proton density-weighted image in the axial plane **(3A)** and the STIR image in the coronal plane using SEMAC[1] **(3B)** demonstrate a large bilobed fluid-like collection extending both along the posterior joint margin (dashed blue arrow) as well as into the iliopsoas bursa anteriorly (solid blue arrow) with areas of low signal internal debris. This is the same patient whose plain films are depicted in figure 1.



4 1.5T images (MAGNETOM Aera, Siemens Healthcare) of the same hip prosthesis obtained in the coronal plane using proton density **(4A, B)** and STIR **(4C, D)** contrast. In both cases, the image on the left is obtained with traditional non-optimized technique and that on the right with the WARP* sequences with VAT employed. Note the significant reduction of artifact using the WARP technique, particularly along the acetabular component. The increased bandwidth of the WARP sequence leads to the increased noise level.

reported on MRI of 14 total hip arthroplasties and found depiction of the periprosthetic structures to be of diagnostic quality for all of the femoral components and 36% of the acetabular components [20]. They found abnormalities in 11 cases and correctly diagnosed pathology in all 7 cases in which surgical correlation was available. Potter et al., using a similar technique, found good delineation of the bone-implant interface and surrounding soft tissues in 100% of 28 hip prostheses and correctly diagnosed areas of osteolysis in 15 patients with surgical correlation.

The NYU experience

At NYU, between August of 2011 and August of 2012, we imaged 39 consecutive patients with painful hip (28 hips in 29 patients) and knee (11 knees in 10 patients) prostheses. Early in our experience, we used a combination of routine, routine optimized for metal reduction, VAT only and SEMAC[1] sequences, the latter two being a prototype provided by Siemens (WARP WIP#648, works in progress package*). All patients were imaged on the same 1.5 Tesla magnet (MAGNETOM Avanto, Siemens Healthcare, Erlangen, Germany). There was significant reduction of metal artifact both with the use of the optimized and VAT only sequences in scan times comparable to those used in routine imaging studies. The best result using STIR contrast was with SEMAC at a time cost. An example of the conventional and SEMAC sequences using STIR contrast in a hip and knee in two different patients is provided in figure 2. Our clinical results were similarly encouraging with significant findings diagnosed in 26 of the 39 cases and confirmation of the findings in all 11 cases with surgical correlation. These surgically confirmed findings included 5 cases of metallosis/ALVAL, 2 cases of patellar tendon rupture, 1 case of an infected bursal collection, 1 case of patellar component loosening, 1 case of acetabular osteolysis from polyethylene wear and 1 case of marked capsular thickening resulting in contracture in a knee. A case of metallosis/ALVAL is provided in figure 3.

More recently, we compared conventional imaging to *syngo* WARP*, an 'out of the box' optimized metal reduction sequence which can be used with or without the addition of VAT. Imaging was performed at 1.5T (MAGNETOM Aera, Siemens Healthcare, Erlangen, Germany). A side by side comparison of conventional and *syngo* WARP sequences of the same hip prosthesis in the coronal plane using proton density (Fig. 4A) and STIR (Fig. 4B) contrasts demonstrates significant improvement in image quality with similar imaging times. The increased noise in the images is caused by the increased readout bandwidth.

Conclusion

Excellent reduction of metal artifact can be achieved through the use of optimized traditional sequences as well as novel techniques such as VAT and SEMAC[1]. At NYU, we have decided to adapt a protocol which consists of *syngo* WARP imaging with VAT obtained in all three planes using a combination of contrasts suited to answering the particular clinical questions being posed in each case (Table 1). The SEMAC sequence was used with STIR contrast in the coronal plane in the hip and the sagittal plane in knees in patients who appear to be able to tolerate the longer imaging time. Further enhancements to the SEMAC sequence with reductions in imaging time are being explored.

*510(k) pending. Not for sale in the US and in other countries.

[1]Works in Progress in the USA. The information about this product is preliminary. The product is under development and is not commercially available in the USA and its future availability cannot be ensured.

Table 1: 1.5T MAGNETOM Aera protocols.

		TA [min]	Matrix	resolution [mm]	FOV [mm]	phase encoding direction	slices	TR [ms]	TE [ms]	TI [ms]	BW [Hz/Pixel]	PAT accel. factor	VAT	turbo factor
Hip	COR STIR	3:46	320	0.9x0.9x3.0	280	RL	36	4680	39	145	504	off	on	17
	AX PD	5:29	320	0.7x0.7x3.0	220	AP	78	5450	31		521	off	off	9
	COR PD	5:07	512	0.5x0.5x4.0	280	RL	28	5000	31		514	off	on	33
	SAG PD	4:35	512	0.5x0.5x4.0	280	AP	40	4590	27		514	2	on	21
Knee	SAG STIR	3:42	384	0.5×0.5×3.0	200	HF	36	4800	45	150	383	off	on	19
	AX PD	2:10	320	0.5×0.5×3.0	160	AP	58	5580	21		504	off	on	12
	COR T1	1:34	320	0.6×0.6×4.0	200	RL	30	600	12		401	1	on	3
	SAG PD	2:18	448	0.4×0.4×4.0	200	HF	30	4000	25		558	off	on	32

The protocols we developed for hip and knee implants based on the new *syngo* WARP* sequence on 1.5T MAGNETOM Aera. Note that all protocols apply VAT*, except for the axial hip, where the difference with or without VAT was not considered significant.

Disclaimer:
MR imaging of patients with metallic implants brings specific risks. However, certain implants are approved by the governing regulatory bodies to be MR conditionally safe. For such implants, the previously mentioned warning may not be applicable. Please contact the implant manufacturer for the specific conditional information. The conditions for MR safety are the responsibility of the implant manufacturer, not of Siemens.

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Contact
Leon D. Rybak
Assistant Professor,
Vice Chair of
Operations in Radiology
New York University
Langone Medical Center
301 East 17th Street
New York, NY 10003
USA
Phone: +1 212-598-6655
Leon.Rybak@nyumc.org