New MR Imaging Methods for Metallic Implants in the Knee: Artifact Correction and Clinical Impact

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INTRODUCTION

Total knee replacements (TKRs) are increasingly common in our aging population, with the number of TKRs having grown over 195% between 1990 and 2002, and over 555,000 TKRs placed in 2004 [1-2]. Recently developed MRI techniques correct for metal-induced distortion and signal loss, theoretically improving soft tissue and bony anatomy visualization for postoperative complications. In a phantom custom-fitted to a TKR, Slice Encoding for Metal Artifact Correction (SEMAC) [3] and Multi-Acquisition Variable-Resonance Image Combination (MAVRIC) [4-5] have been shown to significantly reduce artifact compared to the standard two-dimensional fast spin echo (FSE) [6], allowing for accurate measurement of metallic implant geometry [7]. This study investigates the potential of these methods in affecting clinically significant endpoints. First, SEMAC and MAVRIC were assessed for their ability to measure implant rotation, as implant misalignment is an important cause of revision surgery, pain, and implant loosening [8]. Secondly, artifact correction with SEMAC was evaluated for changing symptomatic patient management.

TKR Component	Rotation Angle Difference Percent Deviation			
	Known	FSE	SEMAC	MAVRIC
Femoral Component	-1.0°	+3.2°	-0.6°	-0.3°
		+4.2°	+0.4°	+0.7°
		-420.4%	-39.8%	-68.9%
Tibial Component	-17.0°	-21.1°	-17.6°	-17.8°
		-4.1°	-0.6°	-0.8°
		+242.5%	+3.5%	+4.4%

Table 1: Compared to the known rotational angles of the TKR phantom, SEMAC and MAVRIC accurately measure TKR component rotation, while FSE deviates to a larger extent.

METHODS

A total of 25 knees were imaged in this study. Fourteen TKRs in 12 volunteers (5 men, 7 women; age range 54-75 years) were imaged at 1.5T with SEMAC, MAVRIC, and FSE. Imaging was performed with 320x256 matrix, 16cm FOV, ±125kHz BW, 8-channel knee coil, and proton-density and inversion-recovery contrast. Scan times (min:sec) and TR/TE (ms), respectively, were 5:00 and 3000/6.4 for FSE, 8:23 and 3446/11 for SEMAC, and 11:23 and 3650/39 for MAVRIC. SEMAC was obtained with parallel imaging (R=2) and half-Fourier acquisition [9]. SEMAC and MAVRIC were reconstructed using a sum-of-squares combination [2]. The TKR phantom was scanned with a comparable protocol.

For evaluation of all 3 sequences in measuring TKR component rotation, the angles measured on MR images were compared to those measured on the reference standard, the TKR phantom, by percent deviation. The MR images of the human TKR volunteers were analyzed for combined femoral and tibial component rotation using the method described by Berger et al [8] and 2-factor repeated measures ANOVA.

Eleven symptomatic patients (6 men, 5 women; age range 25-83years; 8TKRs, 2 large complex knee reconstructions, 1 tibial plate) were scanned with SEMAC and FSE at comparable resolution. Using OsiriX, artifact extent was compared between SEMAC and FSE by measuring on a central slice through the implant a region of interest that encompassed the implant and metallic artifact, with a Bland-Altman plot and paired t-test performed. Changes in patient management after imaging were recorded.

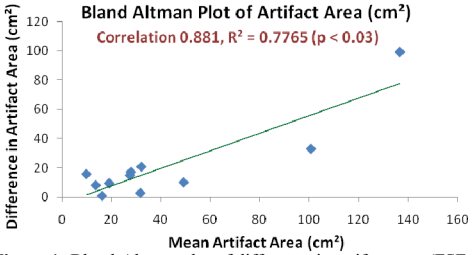

Figure 1: Bland-Altman plot of difference in artifact area (FSE-SEMAC) vs. mean artifact area, with strong correlation (R^2=0.7765) and statistically reduced artifact with SEMAC than FSE ($p<0.03$) for a variety of metallic hardware and clinical indications in the symptomatic knee.

Subject Population (number)	Imaging findings and changes in management (number)
Cancer follow-up (4):	Recurrent tumor on MRI; confirmed at biopsy (1)
	Recurrent tumor on MRI; plan for surgery (1)
	Stable to follow-up (2)
Painful total knee replacements (7):	Peroneal nerve injury on MRI confirmed at EMG and nerve conduction studies (1)
	Patellar tendon tear on MRI confirmed at surgery (1)
	Quadriceps tendon tear on MRI confirmed at ultrasound (1)
	Ganglion cyst on MRI confirmed at surgery (1)
	Ruled out hemangioma as source of pain; joint instability indicated revision surgery (1)
	Anatomically stable on MRI; referred to pain clinic (1)
	Large joint effusion; joint aspiration to rule out infection (1)

Table 2: Changes in patient management due to scanning with SEMAC.

RESULTS

SEMAC and MAVRIC were able to more accurately measure implant rotation, compared with FSE (Table 1). The TKRs of the volunteers were properly aligned, with all sequences measuring on average less than +6° (+ denotes external rotation). Patellofemoral complications are associated with rotation greater than +10° [8].

Our results in symptomatic patients with SEMAC in the knee are similar to previous preliminary work done with a variety of metallic implants [10]. In patients with knee hardware, SEMAC significantly reduced artifact compared to FSE ($p<0.03$) (Figure 1). Table 2 shows that imaging with SEMAC led to changes in patient management including biopsy, surgery, aspiration, and other studies in 9 of 11 patients. One subject suffered a near-complete tear of the patellar tendon visible on SEMAC that was obscured by artifact on FSE images (Figure 2) and confirmed at surgery for tendon repair. Another subject had recurrence of osteosarcoma in the prepatellar space visible on SEMAC, confirmed at biopsy (Figure 3).

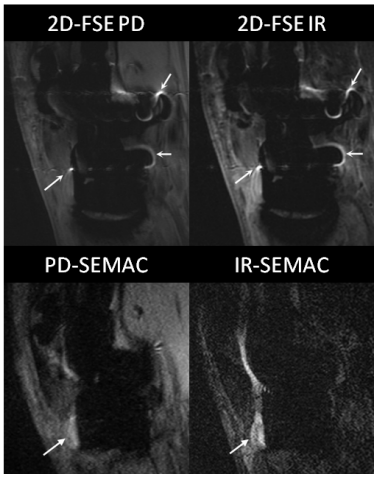

Figure 2: Bright signal pile up on FSE images (*curved arrows*) may be confused with bright fluid signal in the SEMAC images (*wedge-shaped arrows*) used to diagnose a near-complete patellar tendon tear.

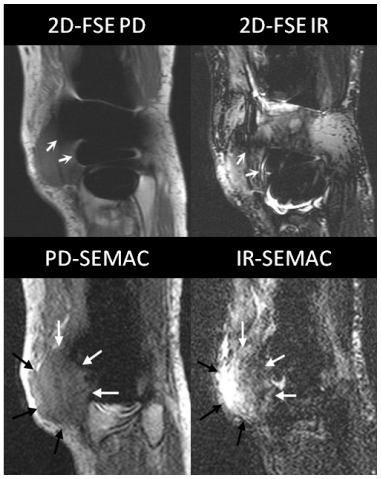

Figure 3: Signal loss in FSE images (*curved arrows*) obscures the full extent of recurrent osteosarcoma visible on SEMAC images (*wedge-shaped arrows*).

CONCLUSION

SEMAC and MAVRIC accurately measure implant rotation in the knee. SEMAC is a promising method for imaging around metal, as it is able to significantly reduce artifact for a variety of metallic hardware in the knee, changing symptomatic patient management.

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