EXPANDING THE POTENTIAL OF CINE PC MRI IN TRACKING MUSCULOSKELETAL MOTION

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INTRODUCTION

The rising cost of musculoskeletal pathologies, disease and injury create a pressing need for accurate and reliable methods to quantify 3D musculoskeletal motion. For this reason, there has been a renewed interest in this area over the past few years [1-3]. Unfortunately, the majority of the current techniques available for studying skeletal kinematics are fluoroscopic in nature, which expose the patient to ionizing radiation and are incapable of measuring muscle function. Ultrasound eliminates the need for ionizing radiation and can track muscle motion, yet remains primarily 2D and cannot accurately track 3D skeletal kinematics. Cine-phase contrast (PC) MRI remains the only imaging technique with the ability to non-invasively track 3D musculoskeletal motion during volitional activity, but current scan times are long (~2.5 minutes). Minimizing these scan times will broaden the spectrum of potential patients that can be studied. Therefore, the purpose of this study was to validate the use of cine-PC MRI for quantifying musculoskeletal motion on a 3.0T platform and to determine if scan time can be reduced.

METHODS

The ability to track 3D musculoskeletal motion was assessed by quantifying the accuracy and precision of cine-PC MRI, using the 3.0T platform. To quantify accuracy a motion phantom, similar to one previously described [4], was constructed. The phantom moved a sample box containing 1:10 of CuSo4 in a 0.6% agarose gel solution, mimicking the T1 MRI properties of bone. Four holes were milled in the box and plastic rods were inserted through the holes to create MRI signal voids (fiducials). The motion phantom was placed in a 3.0T Philips MR scanner (Philips Medical Systems, Best, NL) and aligned with the scanner's axial plane. Standard 2-element flexible coils were placed left-right (LR) and anterior-posterior (AP) of the phantom, respectively. A pole extended from the phantom, which a single researcher used to move

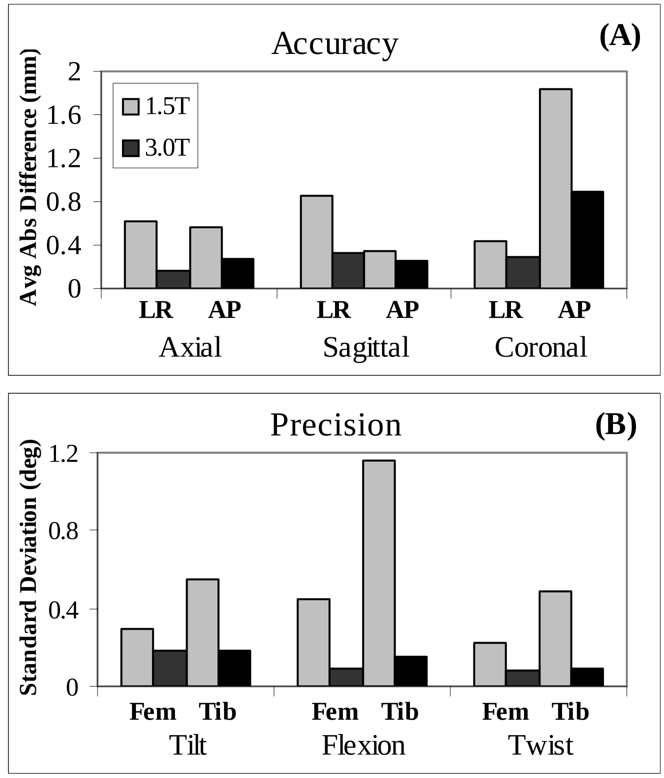

Figure 1: Comparison of in-plane accuracy and precision between 1.5T [6] and 3.0T platforms for two data averages.

the sample box in a circuitous path at 30 cycles/min (guided by an auditory metronome). Movement was confined to the axial plane [4].

Cine-PC images were acquired in all three cardinal planes using two data averaging and no data averaging (scan time = 2.06 and 1.08 minutes, respectively). All other imaging parameters [TR (6.8 msec), TE (3.4 msec), spatial resolution (0.47mm^2), flip angle (20 deg), temporal resolution = 81.6 msec] remained constant. Because phantom motion was confined to the axial plane, there were large out-of-plane motions when data was acquired in the sagittal and coronal planes. The corresponding out-of-plane directions were the RL and AP-directions. Regions of interest (ROIs) were visually identified within the boundaries of the sample box in the first frame. Their trajectories were then computed in 3D space through integration of the velocity data.

For comparison, high spatial and temporal resolution cine images (no velocity) were acquired in the axial plane [TR (4.1 msec), TE (1.2 msec), spatial resolution ($0.25mm^2$), temporal resolution = 4.1 msec]. Using these images, the centroid of each fiducial was visually identified in each frame using ImageJ (NIH, Bethesda, MD). Accuracy was defined as the average absolute difference in the ROI's trajectory calculated through: (1) integration of the velocity data and (2) visual tracking of the fiducials.

To quantify precision, a 3D dynamic cine-PC MR image set (x,y,z velocity and anatomic images using a sagittal-oblique imaging plane) was acquired during cyclic knee flexion/extension in 12 healthy subjects, placed supine in the same 3.0T MR imager [4]. Cine images were also acquired in three axial planes to establish anatomical coordinate systems. Kinematics of the femur, tibia and patella were quantified via integration of velocity data. Precision (the variability associated with tracking *in vivo* skeletal motion using velocity integration) was defined as the standard deviation of the kinematics, derived in 10 independent analyses of the same image set. The mean precision was calculated for the femur and tibia across subjects.

RESULTS

Using cine-PC on the 3.0T platform (2 data averages) reduced imaging time by 25% (42 seconds) over the 1.5T platform and improved accuracy, on average by 50% (0.41 mm, Figure and Table 1A). No data averaging reduced imaging time by 47% (100 seconds) over the 1.5T platform with improved accuracy (38% or 0.33 mm). Precision improved on average by 72% for both the femur and tibia for *in vivo* skeletal motion (Figure and Table 1B).

DISCUSSION

Given the variety of techniques that quantify skeletal motion *in vivo*, cine-PC MRI is ideal for this task due its ability to simultaneously quantify 3D skeletal and muscular motion. In addition, it is non-invasive and non-ionizing. The 3.0T platform further enhances cine-PC MRI by improving scan time, accuracy and precision. On the 3.0T platform, it is possible to reduce scan time to 1 minute while maintaining superior accuracy and precision [2].

For most musculoskeletal cine-PC MRI studies, using proper imaging alignment can create small out-of-plane rotations and translations (e.g. ~4.5° and ~5.1 mm for the knee). Yet, motion phantom excursions in the AP and RL directions are 25 mm and 18 mm, respectively [4]. Therefore, the phantom harshly represents the accuracy of tracking in vivo skeletal motion and the sagittal and axial plane data (accuracy < ~0.4 mm in all directions) is the best representation of realistic *in vivo* motion. Large out-of-plane motions, similar to the coronal plane data, were only seen in a few of the worst patellofemoral maltrackers [5].

With scan time reduced to only one minute and dramatic improvements in both accuracy and precision, 3.0T cine-PC MRI is a robust technique for tracking *in vivo* musculoskeletal motion. The reduced scan time of 1 minute broadens the potential patient population to include those with limited movement abilities.

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Table 1A: Accuracy (mm) for phantom motion.

	2 Averages		No Averages	
	Left-Right	Posterior-Anterior	Left-Right	Posterior-Anterior
Axial	*0.16	*0.28	*0.57	*0.38
Sagittal	0.33	*0.25	0.36	*0.14
Coronal	*0.29	0.89	*0.36	0.85

* in-plane directions of motion.

Table 1B: Precision (°) for in vivo skeletal motion.

	Flexion	Int / Ext Rotation	Varus / Valgus
Femoral Displacement	0.09	0.18	0.08
Tibial Displacement	0.15	0.18	0.09