Flexible real-time imaging of highly-dynamic knee joint motion

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Introduction: Of the recent advancements in musculoskeletal MRI, the most remarkable is the imaging of functional movements. Cine phase contrast (CPC MRI) was the first technique to accurately quantify *in vivo* 3D musculoskeletal kinematics non-invasively. Unfortunately, CPC and Cine MRI suffer from the necessity of imaging multiple repetitions of the same movement, typically 30 at a minimum. Thus, X-ray fluoroscopy has been the conventional modality in joint mechanics imaging, given its high acquisition speed and spatial resolution. Yet, these classes of techniques are limited by their use of ionizing radiation, an inability to quantify muscle kinematics, and low accuracy (only a few biplane systems can come close to the accuracy of CPC MRI). Real-time MRI offers practicality and ultimate flexibility for the capture of dynamic movement tasks. Draper et al [2] showed real-time acquired axial knee images from which slow joint motion could be measured. Yet, display (image monitoring) was not available in real-time. For physicians, such ability is crucial. Further, to truly make real-time MRI a practical clinical tool, imaging frame rate must be increased, enabling larger field-of-views for motion tracking in other slice directions with adequate in-plane resolution. Thus, the purpose of this work was to resolve these issues by utilizing a highly-accelerated radial MRI sequence in order to image the freely moving knee in real-time with low-latency.

Methods: For this IRB-approved study, two healthy subjects were imaged (after providing informed consent) using a 3.0T System (Trio, Siemens Medical Systems, Erlangen, Germany) with the standard body phased-array and spine coils. Radial sampling was adopted for faster imaging, which enabled sub-sampling rates as high as R=12 to be achieved via radial GRAPPA. As an improved GRAPPA weight calibration method, the recently developed through-time radial GRAPPA calibration was employed [3]. A real-time version of self-calibrating GRAPPA operator gridding was preferred over convolution gridding [4].The processing of raw k-space data for both calibration and accelerated (actual) scans were carried out on a remote server using a hybrid multi-CPU and a GPU approach [5], enabling low-latency radial GRAPPA reconstructions for real-time monitoring. The product BEAT_IRTTT imaging sequence was utilized for acquisition with the gradient-echo (GRE) kernel (FOV: 300 mm, 1.56x1.56 mm^2, slice thickness: 8.0 mm, TR: 4.2 msec, BW: 789 Hz/Px). Sets of fully-sampled (192 projections) calibration images (~1 min) were first acquired, during which the subjects were encouraged to move freely inside the FOV. Then, 12-fold sub-sampled (16 projections) were acquired and reconstructed in real-time on the inline display of the MRI scanner's host PC with latencies as low as 9 msec. The accelerated imaging protocol was completely flexible as the volunteers were able to move their legs/knees anywhere within the defined FOV and no constraints were placed on the speed of motion.

Results: The motion of the knee (patellofemoral and tibiofemoral) joint (Fig 1) was captured over a large range of motion with equal image quality. The temporal footprint of each image was 68 msec (15 frames/sec), with no view sharing applied, making it possible to image unconstrained movement. Muscle kinematics (Fig 1) were also captured, as there was adequate imaging speed and contrast.

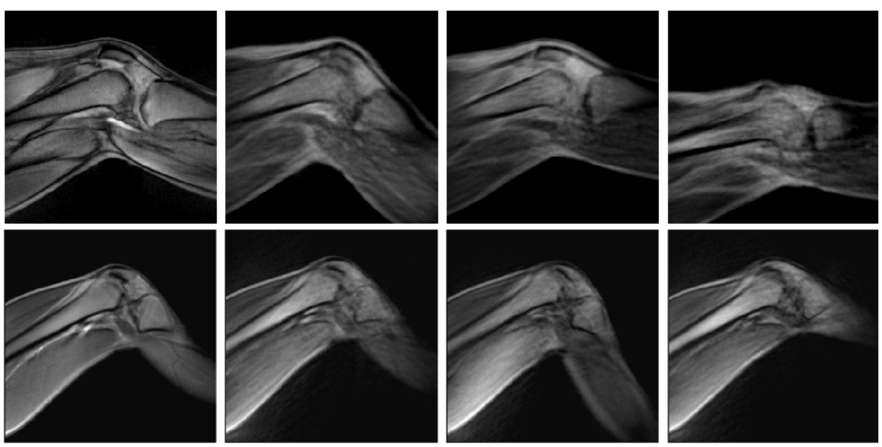

Figure 1: Calibration (1st column) and 12-fold sub-sampled reconstructions in two separate subjects. Subjects were placed in right or left decub positions and the lower knee was given free motion by suspending the body-matrix coils array over the joint.

Discussion: Though current real-time acquisitions yield only magnitude images suitable for 2D structure tracking, integration of phase-contrast imaging, at the expense of frame rate, is still needed for true quantitative kinematic analysis, without the lengthy (and less accurate) process of imaging segmentation and model matching. Use of a 32-channel coil array should improve radial GRAPPA acquisitions and permit higher degrees or radial sub-sampling, while use of SSFP should further increase frame rate.

Conclusion: The highly-accelerated radial GRAPPA reconstruction with low-latency will likely advance clinical diagnosis/treatment of various musculoskeletal pathologies by allowing real-time imaging and display with improved spatial and temporal resolution.

References: [1] Asakawa et al, *Journal of magnetic resonance imaging*, vol. 18, no. 6, pp. 734–9, Dec. 2003. [2] Draper et al, *Journal of magnetic resonance imaging*, vol. 28, no. 1, pp. 158–66, Jul. 2008. [3] Seiberlich et al, *Magnetic resonance in medicine,* vol. 65, no. 2, pp. 492–505, Feb. 2011. [4] Saybasili et al, *Magnetic resonance in medicine*, vol. 64, no. 1, pp. 306–12, Jul. 2010. [5] Saybasili et al, *ISMRM 20th Annual Meeting,* vol. 20, p. 2554, 2012.