Dynamic imaging produces different 3D knee kinematic information than static imaging

A. G. d'Entremont[1,2], J. Nordmeyer-Massner[3], C. Bos[4], D. R. Wilson[2,5], and K. P. Pruessmann[3]
[1]Mechanical Engineering, University of British Columbia, Vancouver, BC, Canada, [2]Centre for Hip Health and Mobility, Vancouver, BC, Canada, [3]Institute for Biomedical Engineering, ETH and University of Zurich, Zurich, Switzerland, [4]Philips Healthcare, Best, Netherlands, [5]Orthopaedics, University of British Columbia, Vancouver, BC, Canada

INTRODUCTION Osteoarthritis is generally believed to be initiated by, and its progression facilitated by, abnormal joint mechanics (Wilson 2008). In many *in vivo* studies, knee kinematics have been assessed using images acquired at a series of static positions over the range of motion (ROM). The limitation of these methods is that there may be differences between the kinematics estimated from sequential static poses of the joint and the kinematics of the joint moving at physiological rates.

The purpose of this study was to compare kinematic results from a validated 3D static MR kinematics technique (Fellows 2005) to a novel 3D dynamic MR kinematics technique (d'Entremont ISMRM 2010) to determine whether imaging during continuous movement produces different kinematic information than imaging a joint at sequential static positions.

METHODS Ten normal subjects (mean age 31, 8 male, 7 right knees) were imaged on a 3T Philips Achieva scanner using a novel stretchable 8-channel knee coil array which permits knee flexion while maximizing the SNR independently of the knee size and shape (Nordmeyer-Massner ISMRM 2008). A MR-compatible loading rig was created to allow free leg motion with a force of 15% body weight applied in the ankle-hip direction. A fast imaging protocol based on an ultrafast gradient echo sequence with water suppression was developed and used to image the knee in motion.

One high-resolution scan was taken (multi-slice T1-weighted FSE, 8:52 min), which provided detailed subject-specific bone models. Then three types of low-resolution loaded scans were taken: static standard (16 slices, 2D TSE, 23 seconds), static fast (8 slices, ultrafast gradient echo, 1.9 seconds) and dynamic (30 sets, 8 slices each, ultrafast gradient echo, 56 seconds) (Fig. 1). The two static scans were performed together at each of six flexion angles. During the dynamic scan, performed after the static scans, the subject was asked to move very slowly, but no specific rate of motion was required. Angles for the static scans were chosen to cover the same flexion range as the dynamic scan.

Parameter	Measure	Paired t-test p-value		
		DYN v. SF	DYN v. SS	SF v. SS
Patellar flexion	Slope	**< 0.0001**	**0.0005**	0.335
	Intercept	0.220	0.123	0.039
Patellar spin	Slope	0.945	0.985	0.951
	Intercept	0.702	0.685	0.928
Patellar tilt	Slope	**0.012**	0.025	0.424
	Intercept	0.040	0.073	0.525
Patellar proximal translation	Slope	**< 0.0001**	**0.0007**	0.685
	Intercept	**< 0.0001**	**< 0.0001**	0.039
Patellar lateral translation	Slope	**0.011**	**0.012**	0.411
	Intercept	0.021	0.018	0.148
Patellar anterior translation	Rate of change of slope	**0.015**	**0.006**	0.717
	Slope	0.212	0.046	0.548
	Intercept	0.416	0.270	0.456
Tibial abduction	Slope	0.823	0.696	0.300
	Intercept	0.030	0.092	0.448
Tibial internal rotation	Slope	**0.008**	**0.007**	0.920
	Intercept	**0.013**	**0.008**	0.894
Tibial proximal translation	Slope	**0.005**	**0.014**	0.245
	Intercept	0.828	0.097	**0.002**
Tibial lateral translation	Slope	0.388	0.589	0.055
	Intercept	**0.007**	0.200	**0.0004**
Tibial anterior translation	Slope	**0.003**	**0.014**	0.564
	Intercept	0.028	0.035	0.490

Table 1: Comparison between summary measures (Bonferroni adjusted $\alpha = 0.016$; bold values $p < \alpha$).

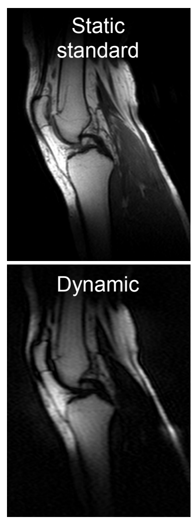

Figure 1: Sample images

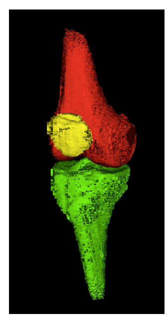

Figure 2: High-res segmentation

In each image, bones were segmented to create bone models (Fig. 2). Anatomical axes were added to the high-resolution models, and these models were then shape-matched to each low-resolution set (static standard, static fast, dynamic). Finally, translations and rotations for the tibia and patella were calculated with respect to the femur. Each kinematic parameter was plotted against tibial flexion, and, for each of the three low-resolution sets, linear least squares fits were performed to obtain summary measures of slope and intercept (quadratic fits for patellar anterior translation). Bonferroni-corrected paired t-tests were performed to compare summary measures for dynamic and both static results.

RESULTS Differences between dynamic and static results were seen for nine of the 11 kinematic parameters (Table 1, Fig. 3). For example, the average difference in patellar proximal translation between static and dynamic results at 15° tibial flexion was 4.3 mm. The subjects performed on average 2.75 knee flexion cycles dynamically, with an average rate of flexion of 0.9°/s.

Two tibial parameters showed statistical differences between the static methods in intercept, however actual differences were small (average difference of 0.6 mm for tibial proximal translation and 0.9 mm for tibial lateral translation).

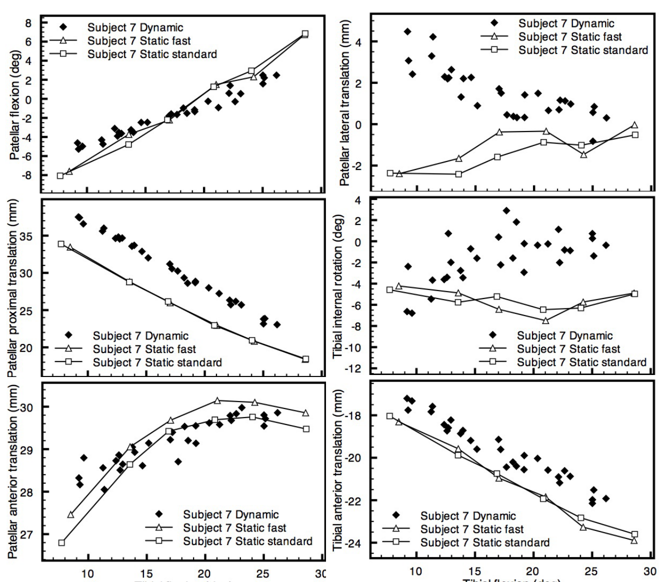

Figure 3: Representative results for kinematic parameters

DISCUSSION We observed differences between static versus dynamic 3D results in a majority of knee kinematic parameters. These differences are consistent with results from 2D measures of patellar tracking in both CT and MR (Muhle 1995, Dupuy 1997, Brossmann 1993). Although the motion was slow, there is likely a different muscle activation pattern when moving into a position actively than being passively positioned and subsequently loaded. Differences measured are on a clinically relevant scale; average differences in patellar kinematics of 2.25 mm between normal and pathological subjects have been reported (MacIntyre 2006).

For the two tibial parameters with statistical differences in intercept between the static methods, actual differences were on the order of the original static method error (0.88 mm, Fellows 2005). The differences, especially in tibial lateral translation, likely arise from fewer slices (medial-lateral truncation of the tibia) in the static fast scans.

Advantages of this study include using a validated static method, examining a clinically important ROM, and loading the joint. Limitations of this study include the restricted ROM of the dynamic scans and a difference in static and dynamic hip flexion angles due to the need to keep the knee in the center of the FOV.

In conclusion, dynamic-based 3D kinematics measures provide different information from static 3D measures, and may represent kinematic results closer to those in activities of daily living.