Repeatability of a Magnetic Resonance Imaging-Based Method for Measuring Three-Dimensional Patellar Kinematics in Loaded Flexion

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INTRODUCTION

Prevalent and disabling knee conditions such as osteoarthritis and patellofemoral syndrome are widely believed to be associated with abnormal joint loads. Assessment of the cause and effect relationships between mechanics and clinical symptoms and the selection of mechanical objectives for treatment are limited by the poor accuracy of current *in vivo* measurements of knee mechanics. Measurements of knee kinematics are fundamental to assessments of joint loads because the relative positions of the bones dictate the lines of actions of the contact, muscle and ligament loads and the geometry of contact in the tibiofemoral and patellofemoral joints.

A new method for measuring three-dimensional patellar kinematics through a range of loaded knee flexion using magnetic resonance imaging (MRI) has been developed. The mean measurement error of this method, when compared to a reference standard in cadaver specimens, was less than 1.8^o for attitude and 0.9 mm for position [1]. The clinical utility of the method is not known, however, because it is not clear how tremor, gross subject movement and subject positioning affect measurements when it is used *in vivo*. Our research question was: how repeatable is the MRI-based method for assessing patellar tracking during loaded flexion *in vivo*?

METHODS

The patellar kinematics measurement method relies on registering bone models (with associated coordinate systems) developed from a high-resolution MR scan to low-resolution bone positions derived from fast, low-resolution MR scans [1]. Subjects were positioned supine in a GE Signa 1.5T MRI unit on a custom MRI compatible loading rig. A high-resolution MR image of each subject's knee in relaxed, full extension was obtained and segmented to create three-dimensional geometric models of the proximal tibia, distal femur and patella. Subjects then performed a cycle of loaded flexion in a rig that loaded the knee. For each cycle, fast (approximately 36 sec) low-resolution images were taken of the subjects' knee in 5 positions of loaded flexion between full extension and roughly 40^o of flexion. These low-resolution images were then segmented to identify outlines of the tibia, femur and patella. The relative positions of the geometric bone models at each loaded flexion position were determined by shape-matching the bone models to the segmented bone outlines using the iterative closest points (ICP) algorithm. Anatomical coordinate systems were assigned to each bone model and the kinematic parameters describing the position and orientation of the patella relative to the femur were represented using a joint coordinate system.

We assessed repeatability by measuring patellar tracking for four separate flexion cycles in each of three subjects [all left; 2 female/1 male; age: 28.67 (9.87) yr (mean (standard deviation)); height: 1.75 (0.09) m; weight: 60.23 (13.81) kg]. Subjects were removed from the rig and repositioned between each cycle. We described the intrasubject variability using the mean of the standard deviation of each patellar kinematic parameter (flexion, spin, tilt, proximal, lateral and anterior translation) at one degree increments over the four separate low-resolution cycles. Approval for this study was obtained from our Institutional Ethics Review Board.

We also assessed the variability associated with using two separate high-resolution bone models. We generated models from two separate high-resolution scans and measured patellar kinematics using both models by registering them to the low-resolution scans. The registration error was defined as the mean difference between each patellar kinematic parameter derived using the two different bone models through the range of each flexion cycle.

RESULTS

Across the four cycles of loaded flexion, the mean intrasubject variability (ISV) for all subjects through the range of flexion was less than 1.5 º for measurements of attitude and less than 1.0 mm for measurements of position (Table 1).Using two different high-resolution bone models (with the same axes) had relatively less effect on the repeatability of the procedure than the cycle-to-cycle variations (Table 2). The mean registration error for patellar spin was three times greater than other angular registration errors.

DISCUSSION

The intrasubject variability is equal to or less than the measurement error found in our study of cadaver specimens for all parameters except proximal patellar translation [1]. These results compare favourably to intrasubject variabilities of 1.6 º, 2.4 º, and 2.3 º for patellar flexion, tilt and spin respectively, for another non-invasive tracking protocol, Fast-PC [2]. While we have not assessed how assignment of anatomical axes affects the method's repeatability, a strength of the method is that axes need only be assigned once for intrasubject comparisons. The method is sufficiently accurate and repeatable to detect clinically significant changes in patellofemoral kinematics.

REFERENCES: 1) Fellows *et al* ORS 2003 2) Rebmann and Sheehan *J Magn Reson Imaging* 17(2) 2003

Subject	**Patellar Attitude ISV (degrees)**			**Patellar Translation ISV (mm)**		
	Flex.	Spin	Tilt	Prox.	Lat.	Ant.
1	1.78 (0.35)	0.88 (0.41)	1.52 (0.57)	1.34 (0.33)	0.65 (0.31)	0.52 (0.16)
2	1.07 (0.27)	0.64 (0.43)	0.69 (0.28)	0.47 (0.33)	0.12 (0.04)	0.21 (0.11)
3	1.39 (0.27)	1.57 (0.40)	0.96 (0.40)	0.67 (0.22)	0.53 (0.14)	0.24 (0.05)
Mean	**1.40 (0.29)**	**1.02 (0.40)**	**1.04 (0.35)**	**0.81 (0.37)**	**0.42 (0.23)**	**0.32 (0.14)**

Table 1: Intra-subject variability (ISV) [mean (standard deviation)] of the MRI-based patellar kinematic measurements.

Rotation Registration Error (degrees)			**Translation Registration Error (mm)**		
Patellar Flexion	Patellar Spin	Patellar Tilt	Patellar Proximal	Patellar Lateral	Patellar Anterior
0.44 (0.17)	1.40 (0.65)	0.36 (0.11)	0.25 (0.12)	0.30 (0.11)	0.14 (0.06)

Table 2 – Differences in kinematic measurements obtained between two high-resolution bone models.

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