INTRODUCTION
Patellofemoral joint (PFJ) pain is a prevalent and disabling condition that may be associated with long term joint damage. Current treatment strategies are based on the hypothesis that pain results from patellar maltracking (particularly tilt and lateral translation) which produces an abnormal distribution of force across the facets. However tests of this hypothesis have been limited because accurate three-dimensional methods for assessing patellar tracking have only recently become available. Large-scale longitudinal studies will be required to assess whether maltracking causes PFJ pain and subsequent damage. To design these studies the consistency of normal patellar motion must be known. The objective of this study was to determine whether the in vivo patterns of patellar tilt and lateral translation are consistent from side to side and over one year in healthy knees.

METHODS
Three-dimensional patellar motion under load was assessed bilaterally in 10 male military cadets with no knee problems (20 healthy knees) at baseline, six months and 12 months. All participants provided written informed consent and the experimental protocol was approved by our institutional Research Ethics Board.

One operator acquired images of all 20 knees using a 1.5T clinical MRI scanner (GE Signa). A high resolution scan was obtained with the knee positioned in relaxed extension. Five low resolution scans were acquired at different angles of knee flexion (approximately 0 to 50º) while the subject applied force to a foot plate which provided 98 N of resistance.

Subject-specific three-dimensional geometric surface models of the distal femur, proximal tibia and patella were generated from the high resolution images using commercial software (Analyze 5.0, BIR Mayo Clinic). Orthogonal coordinate systems, based on anatomical landmarks, were assigned to each bone model.

The femur, tibia and patella were segmented in the low resolution images to generate bony outlines for each position of loaded knee flexion. Surface models extracted from the high resolution scan acquired at the six month time point were registered to the five bony outlines acquired at baseline, six months and 12 months using the Iterative Closest Points algorithm. Knee flexion angle and PFJ kinematics were found from the relative positions of the bone coordinate systems using a gyroscopic convention. Post-processing of all images was completed by the same investigator.

We tested the null hypothesis that patterns of patellar motion were not affected by time or limb (dominant or nondominant). The effects of time and limb (nested within subject) on patterns of patellar motion were determined using 3-level hierarchical linear and nonlinear modeling. That is, the data were modeled as clusters within three hierarchical levels: the first level described the measures of the kinematic variables obtained at five different angles of knee flexion, the second level described the assessment factors of time and limb, and the third level coded for subject.

RESULTS
The mean (SD) age, height and weight for the 10 subjects were 18.6 (0.49) years, 175.12 (9.78) cm and 73.25 (9.28) kg, respectively.

Patellar motion was consistent bilaterally across all three time points (p > 0.50). Two patterns were observed for tilt. In 14 of 20 knees, the patella tilted slightly medially (0.5º) until 10º of knee flexion, then tilted laterally 3º as the knee flexed to 50º (Fig. 1A). In six of 20 knees, the patella tilted medially approximately 10º as knee flexion increased (Fig. 1B). Similarly, two patterns were observed for lateral translation. In 15 of 20 knees, the patella shifted medially 1.5mm until 18º of knee flexion, then shifted laterally 2.5mm as the knee flexed to 50º (Fig. 1C). In five of 20 knees, the patella shifted medially approximately 6mm through the range of knee flexion assessed (Fig. 1D).

DISCUSSION
Within subjects, a consistent pattern of patellar motion was observed over the 12 month study period. A limitation of this study was the small sample size and the homogeneity of the subjects with respect to gender, age, body habitus and lifestyle factors. However, the primary normative patterns of patellar tilt and lateral translation observed in this study are in agreement with those reported in previous work using similar methodology in small numbers of healthy civilian subjects.

We thank Sue McKendry (Imaging Services, Kingston General Hospital), Dr. Crawford (Medical Officer, Royal Military College), the cadets, and Andrew Day (Senior Biostatistician, Kingston General Hospital). This work was supported by the NSERC-CHRP (DRW).

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ACKNOWLEDGEMENTS
We thank Sue McKendry (Imaging Services, Kingston General Hospital), Dr. Crawford (Medical Officer, Royal Military College), the cadets, and Andrew Day (Senior Biostatistician, Kingston General Hospital). This work was supported by the NSERC-CHRP (DRW).

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52nd Annual Meeting of the Orthopaedic Research Society
Paper No: 0534