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In vivo measurements of patellar tracking and finite helical axis using a static magnetic resonance based methodology

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ABSTRACT

Patellofemoral (PF) maltracking is a critical factor predisposing to PF pain syndrome. Many novel techniques of measuring patellar tracking remain research tools. This study aimed to develop a method to measure the *in vivo* patellar tracking and finite helical axis (FHA) by using a static magnetic resonance (MR) based methodology. The geometrical models of PF joint at 0°, 45°, 60°, 90°, and 120° of knee flexion were developed from MR images. The approximate patellar tracking was derived from the discrete PF models with a spline interpolation algorithm. The patellar tracking was validated with the previous *in vitro* and *in vivo* experiments. The patellar FHA throughout knee flexion was calculated. In the present case, the FHA drew an "L-shaped" curve in the sagittal section. This methodology could advance the examination of PF kinematics in clinics, and may also provide preliminary knowledge on patellar FHA study.

1. Introduction

Patellofemoral pain syndrome (PFPS) is a common disease in human knee joint. The incidence of PFPS could reach to approximate 25% in the general population, and could be even higher in sports [1,2]. PFPS could affect the daily activities, and chronically lead to knee instability and osteoarthritis [3]. However, the pathophysiology of PFPS remains still unclear [4].

PFPS is correlated with the abnormal patellofemoral (PF) alignment and tracking (malalignment and maltracking) [5]. Previous studies reported significant differences in patellar lateral translation, spin, and tilt between symptomatic and asymptomatic individuals [6,7]. PFPS is also more prevalent in patients with patella alta, whose patella is high positioned [8]. As a common cause of PFPS, PF arthritis is also associated with incongruent sliding between the patella and femoral sulcus [9].

Restoring PF tracking has been considered as a critical principle in the treatment of PF diseases. Minor alterations in PF alignment could change the mechanics in both PF and tibiofemoral joints [10]. In the treatment of lateral patellar instability and subluxation, lateral retinacular release was performed with the aim to correct patellar tracking [11,12]. The realignment of PF joint is also a major concern in total knee arthroplasty. The rate of PF complications after knee arthroplasty ranged from 4% to 41% [13]. To improve the success rate, the design of prosthesis is still developing in terms of restoring the physiological PF kinematics [14].

The complex geometry and motion of the patella remains challenging to clinicians and technicians [15]. The advances in imaging technologies better enabled the measurement of PF kinematics. Dynamic MR techniques have been used to investigate the associations between joint kinematics and joint pathology [16–20]; Nha et al. measured the *in vivo* weight-bearing PF and tibiofemoral motion with MR imaging and dual orthogonal fluoroscopy [21]. However, many of these novel techniques remained research tools. And majority of these studies cannot accommodate deep flexion ranges [15–20], while clinical diagnosis commonly relies on static MR and CT. An efficient and sufficiently accurate method to assess the patella tracking using conventional imaging techniques is demanding [22].

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Finite helical axis (FHA) is an important feature of joint kinematics. Although the method of calculating FHA has been mathematically well established and used in the kinematics analyses of tibiofemoral and ankle joints [23–26], the patellar FHA has not been thoroughly understood. The patellar FHA, which is closely associated with the quadriceps moment and knee extensor, plays an important role in the PF kinematics, and may serve as a potential reference in the PF realignment and replacement surgeries. Previous studies proposed the patella rotating around an approximate axis near the femoral epicondyle [27,28], yet no quantitative measurement has been conducted about the patellar FHA.

This technical note aimed to develop a methodology to quantify the *in vivo* patellar tracking and FHA by using the routine static MR scanning, which was of high practical and clinical relevance.

2. Materials and methods

2.1. MR scanning

A male subject (age: 30 years; mass: 65 kg; height: 172 cm) volunteered for this study. The knee pathology was ruled out with the physical and MR examinations. The right knee was scanned with the MR machine (Siemens, Sonata 1.5 T, Germany) at 0°, 45°, 60°, 90°, and 120° of knee flexion. To accommodate the flexed knee in the magnetic field, subject was required to lie on the right side under non-weightbearing condition. A knee brace of thermoplastic sheet (ORFIT Eco, ORFIT, Inc., Belgium) was utilized to maintain the right knee static in the certain flexion angle during the scanning. The left leg was out of touch with the right knee. The following scanning parameters were used: magnetic field = 1.5 T, field of view = 180.5 × 149.5 mm^2, pixel resolution = 0.47 × 0.47 mm^2, slice thickness = 2 mm, echo time (TE) = 43 ms, repetition time (TR) = 7170 ms. Ethical approval was granted from the authority and the subject signed the consent with the experimental procedures explained.

2.2. Geometry reconstruction

The geometries of the PF joint at different knee flexion angles were reconstructed from the MR images using the medical image processing software, Mimics (version 8.0 Materialise, Inc., Belgium). The segmentations of the patella and femur were performed based on different grayscales among tissues. The developed 3D models of PF joint were shown in Fig. 1(a)–(e). These five models were placed in a common coordinate system by matching the femurs through a geometry registration technique in Rapidform (version 2006, 3D Systems, Inc., Korea), as shown in Fig. 1(f).

2.3. Patellar tracking interpolation and validation

The approximate patellar tracking was derived from the abovementioned patella models. The patella in this study was considered rigid, and its position could be determined by three non-collinear points. Therefore, points at apex, medial, and lateral sites of patella were selected as the reference points (Fig. 2(a)). Since the positions of these reference points at 0°, 45°, 60°, 90°, and 120° of knee flexion were known (the red points in Fig. 2(b) and (c)), the approximate tracking of the points throughout knee flexion (the blue dash curves in Fig. 2(c)) could be calculated with the order-three spline interpolation method [29] (Supplementary material 1). With the tracking of the reference points, the patellar tracking can be determined as follows:

As shown in Fig. 2(d), let points A, B, C denote the three reference points on patella, A′, B′, and C′ denote their positions at θ degree of

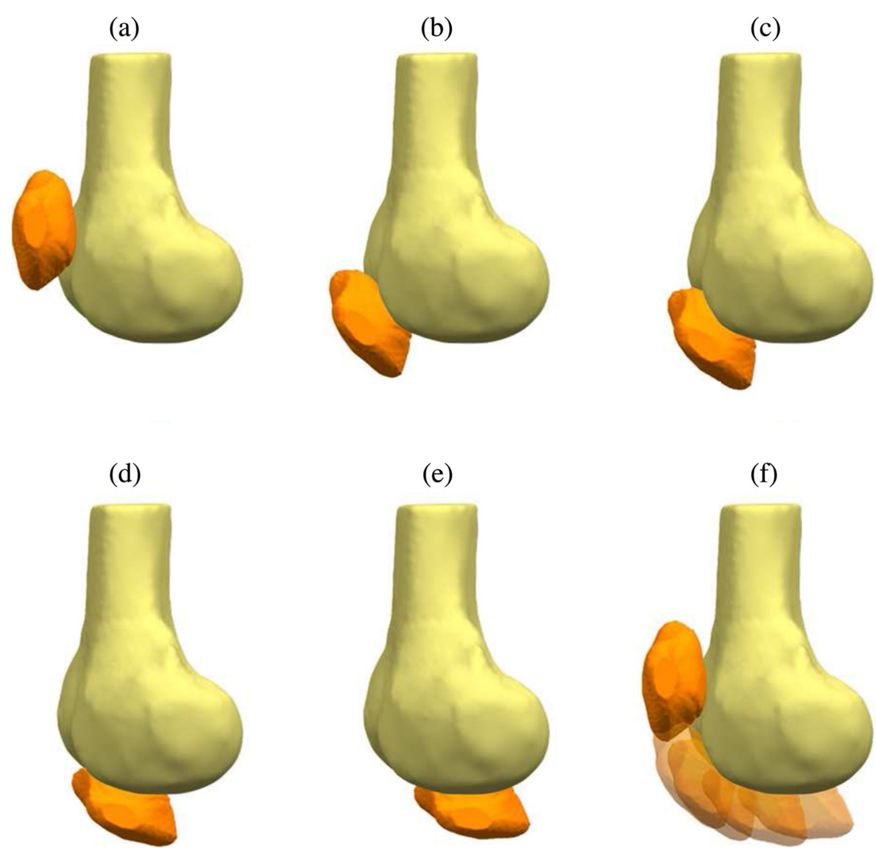

Fig. 1. 3D models of PF joint at different angles of knee flexion. (a–e) PF joints at 0°, 45°, 60°, 90°, and 120° of knee flexion. (f) Five models were placed in a common coordinate system by matching the femurs though a geometry registration technique in Rapidform (Version 2006, 3D Systems, Inc., Korea).