INTRODUCTION:
Recently, high-flexion knee replacements have been developed to accommodate a large range of motion (ROM > 120°) after total knee arthroplasty (TKA). Femoral rollback or posterior translation of the femoral condyles during knee flexion is essential to maximize knee flexion and to avoid posterior bone-implant impingement during deep knee bends [1]. The posterior cruciate ligament (PCL) has been described as the main contributor to femoral rollback [2].

Proponents of PCL conservation argue that sparing the PCL during TKA leads to more physiological knee kinematics, less bone resection, lower shear loads and maintenance of proprioception [3]. However, a more substantial and reproducible amount of femoral rollback has been reported for PCL-substituting (posterior-stabilized) knee replacements [4]. For adequate functioning the PCL should not be too tight or too lax after surgery. A tight PCL leads to more femoral rollback at the expense of a tighter flexion gap, a higher joint compression and potential polyethylene wear [5]. Hence, correct PCL functioning is a challenging surgical aim especially after cruciate-retaining high-flexion TKA requiring more femoral rollback than conventional TKA.

The objective of this study was to investigate the effect of PCL conservation on the biomechanical performance of a high-flexion knee replacement during deep knee flexion (ROM ≤ 150°). For this purpose, a finite element (FE) knee model was developed to analyze the implant loading of a cruciate-retaining high-flexion knee replacement. Both the polyethylene stress level and the amount of femoral rollback were evaluated. Furthermore, the mechanical performance of this implant type was compared to the behavior of both a cruciate-retaining conventional and a posterior-stabilized high-flexion TKA design. We hypothesized the posterior-stabilized high-flexion knee replacement to demonstrate lower polyethylene stresses and more femoral rollback during deep knee flexion compared to the cruciate-retaining TKA designs.

METHODS:
The polyethylene stress level and amount of femoral rollback were computed using a three-dimensional dynamic FE knee model which has been described in earlier studies [6,7]. The FE knee model consisted of a proximal tibia and fibula, TKA components, a quadriceps and patella tendon, collateral ligaments, a non-resurfaced patella and a PCL in case the cruciate-retaining TKA design was evaluated (figure 1). For use in this study, the prosthetic components of a newly designed cruciate-retaining high-flexion total knee replacement (PFC Sigma CR150, DePuy, J&J) were incorporated in the FE knee model. Subsequently, a cruciate-retaining conventional (PFC Sigma CR) and a posterior-stabilized high-flexion (PFC Sigma RP-F) implant design from the same manufacturer were incorporated in the same FE knee model to make a mechanical comparison between these implants. The three implant types analyzed in this study were all rotating platform designs. The PCL included in the FE knee model balanced prior to simulation and was able to wrap around the femoral and tibial component. The anatomy of the PCL was based on cadaveric measurements [8]. Visco-elastic material properties were used to model the polyethylene [10]. A weight-bearing squatting movement was simulated for all the knee replacements analyzed (ROM ≤ 150°).

RESULTS:
In the normal flexion range (ROM ≤ 120°), the three TKA designs demonstrated an equivalent peak contact stress of maximal 40 MPa (figure 2a). During high-flexion (ROM > 120°), the cruciate-retaining high-flexion design demonstrated a lower peak tibio-femoral contact stress (74.7 MPa) than the cruciate-retaining conventional design (96.5 MPa). The posterior-stabilized high-flexion design showed the lowest peak tibio-femoral contact stress at the condylar articulation (54.2 MPa), although the post was loaded higher (77.4 MPa). The polyethylene Von Mises stress distributions displayed similar trends (figure 3).

The knee designs analyzed in this study all produced a comparable amount of femoral rollback during normal knee flexion, whereas the cruciate-retaining designs showed a paradoxical anterior movement of the femoral condyles during high-flexion (figure 2b).

DISCUSSION:
The current study demonstrates a cruciate-retaining high-flexion knee replacement produces a lower prosthetic knee load than a conventional cruciate-retaining replacement during deep knee flexion. Compared to a posterior-stabilized high-flexion design, the cruciate-retaining high-flexion design demonstrated a similar prosthetic loading along with an inferior amount of femoral rollback during high-flexion. Obviously, the amount of femoral rollback depends on the PCL anatomy implemented and slightly varies between knee patients. The peak polyethylene stresses occurred at different locations for the posterior-stabilized and cruciate-retaining implant types (post vs. condylar contact area).

REFERENCES:

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