Influence of total knee arthroplasty on patellar kinematics and contact characteristics

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Abstract

Purpose Femoro-patellar complications are one of the most common problems after total knee arthroplasty (TKA). TKA components that reduce patellar loads and preserve physiological patellar kinematics should reduce these problems. Therefore, we evaluated the patellar kinematics and the retro-patellar contact characteristics in both the intact knee and in the TKA-knee.

Methods Eight Thiel-embalmed cadaver knees were tested first intact and then after TKA using rotating as well as gliding inlay and with additional patellar resurfacing while flexing the knee from 0° to 100°. During the examination quadriceps and hamstring forces were applied.

Results TKA with additional patellar resurfacing led to an increased retro-patellar pressure, a decreased contact area and an increased lateral movement. Although patellar kinematics could not be changed by using a gliding inlay compared to a rotating inlay, the gliding inlay improved retro-patellar contact characteristics by reducing the pressure and increasing the contact area, especially in higher flexion.

Conclusions The increased retro-patellar pressure together with the increased lateral movement of the patella after TKA may be one important cause for anterior knee pain appearing after TKA. In view of the improved retro-patellar contact characteristics using a gliding inlay this inlay should be preferred, providing that the posterior cruciate ligament is intact.

Introduction

Total knee arthroplasty (TKA) has become a highly successful surgical procedure, with patient satisfaction of nearly 90% [1]. The most common complications after TKA are related to femoropatellar problems [2, 3], with residual anterior knee pain in 5–45% of patients [4, 5]. Therefore, the question of whether or not to resurface the patella remains controversial [6, 7]. Several in vitro studies found a change in patellar kinematics in TKA-knee compared with the native knee [8, 9]. Because excessive loads and altered kinematics [2] potentially contribute to patellar complications, it may be possible to reduce the complication rate by selecting TKA components that minimise patellar load and preserve physiological patellar kinematics. Although mobile-bearing designs have been shown to cause lower retropatellar pressure, previous studies evaluating the influence of TKA on patellar kinematics and retropatellar contact characteristics used fixed-bearing or rotating-platform inlay (RP). To our knowledge, no studies exist using a mobile inlay providing anteroposterior gliding (APG) that enables anatomical adaption during movement and the potential for improved patellar kinematics. Therefore, the objective of our study was to evaluate the kinematics of an APG inlay under physiological loads. We evaluated patellofemoral contact

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area and pressure as well as patellar kinematics in the intact knee and in the TKA knee with additional resurfacing the patella, both with an RP inlay and an APG inlay. Our hypothesis was that a TKA with patellar resurfacing increases retropatellar pressure and alters patellar kinematics, whereas an APG inlay reduces retropatellar pressure and improves patellar kinematics compared with an RP inlay.

Materials and methods

Experimental setup

Eight cadaver knees were obtained from the Anatomical Institute of the University Ulm, Germany. The specimens were embalmed in Thiel solution [10], and had a mean age at the time of death of 80.8 (range 75–84) years. Knees with previous surgery or metastatic lesions were excluded. The specimens were transected 30 cm proximal to the knee joint. Skin, subcutaneous tissue and muscles were removed, except for the quadriceps and hamstring muscles. Care was taken to keep all capsular and retinacular tissues intact. The components of the quadriceps muscle were separated from each other and individually clamped with special aluminium pins. The femur was embedded with polymethylmethacrylate (PMMA) into an aluminium tube and mounted into a specially designed rig (Fig. 1). The amount of flexion–extension was secured with a variable fixture.

During measurements, static muscle loads were applied, and loading direction simulated physiological conditions.

We chose a total quadriceps load of 150 N. The load distribution was chosen according to the physiological cross-sectional area (PCSA) of the muscles [11]:

- rectus femoris: 15%=22.5 N
- vastus intermedius: 20%=30 N
- vastus lateralis: 40%=60 N
- vastus medialis: 25%=37.5 N

Hamstring load was simulated with one third of the quadriceps load: 50 N [12]. Rectus femoris, vastus intermedius and hamstrings were simulated along the longitudinal axis of the femur. Vastus medialis loads were applied at 25° medial and 18° posterior and vastus lateralis loads at 18° lateral and 7° posterior relative to the femoral axis. The experiment was performed on the intact knee first to provide a baseline reference. A standard TKA was performed using the low-contact stress (LCS) complete primary system (DePuy, Warsaw, IN, USA), which offers different mobile bearing inlays (Fig. 2):

- rotating platform (RP): has a highly conforming articular surface and enables free rotation of the tibial insert;
- anteroposterior glide (APG): enables rotation via the cone-shaped insert of the tibial stem and AP gliding on a control arm.

TKA implantation was performed according to the manufacturer's guidelines using a medial parapatellar approach.

Measurements were performed first with the APG inlay and then with the RP inlay. The patella was also resurfaced according to the manufacturer's guidelines. We chose the

Fig. 1 Rig with mounted specimen

Fig. 2 Anteroposterior gliding (APG) inlay (*left*) and rotating-platform inlay (RP) inlay (*right*). The APG inlay offers the possibility of glide in the AP direction on the control arm

metal-backed patella, which allows the articular surface to rotate up to 30° from neutral to either direction, achieving an optimal movement in the trochlear groove at each flexion angle. To ensure that the amount of bone resection was equal to the thickness of the patellar component, a patellar cutting guide was placed on the patella with its jaws located medially and laterally on the patella at the level of the subchondral bone of the lateral facet. All measurements were performed at 0°, 20°, 40°, 60°, 80° and 100° knee flexion. After mounting the specimen in the custom knee jig, the muscle forces were applied via load cells, and the measurement was performed for each flexion angle. Every test cycle (from 0° to 100°) was performed three times.

Patellofemoral kinematics

Patellar movement in relation to the femur was measured using an optical three-dimensional motion analysis system (Pontos: GOM; Braunschweig, Germany). Markers were attached to the patella and the tibia by Kirschner (K) wires. Femur markers were fixed to the aluminium tube (Fig. 1), and marker positions were tracked in three dimensions with an accuracy >0.05 mm. Relative patellar movement with respect to the femur was described as patellar tilt [rotation about the longitudinal axis (X-axis)] and patellar translation [shift along the mediolateral axis (Y-axis)].

Patellofemoral contact areas and pressures

Patellofemoral contact pressure and contact area were measured using a capacitive-based pressure system (S2039 patellar sensor, Novel; Munich, Germany), containing 5 mm × 5 mm sensor elements, covering a total area of 1,988 mm². After calibration according to the manufacturer's guidelines, the sensor was placed between the femur and patella using a medial parapatellar approach.

Statistical analysis

All measurements were recorded three times, and median values were calculated. Statistical comparisons were per-

formed with SPSS Statistics, 17.0, using a multifactorial (implant, flexion angle) repeated measures analysis of variance (ANOVA) and a post hoc analysis for the effect of implant type, with Bonferroni adjustment.

Results

Retropatellar pressure in the native knee remained <0.5 MPa for the full range of motion (Fig. 3). After TKA and patellar resurfacing, a significant increase in retropatellar pressure was observed (RP inlay: $p=0.002$; APG inlay: $p=0.013$). The highest retropatellar pressure (four-fold increase) occurred at 100° knee flexion with the RP inlay. Retropatellar pressure tended to be lower when using the APG inlay beyond 60° knee flexion ($p>0.05$).

The retropatellar area in the native knee increased continuously between 0° and 60° of knee flexion, from 2.2 cm² to 6.0 cm², and remained elevated up to 100° of flexion (Fig. 4). For both TKAs the retropatellar area was significantly reduced ($p<0.01$). With TKA, the area only increased between 0° and 20° to remain constant afterwards for the APG inlay, or to even slightly decrease for the RP inlay. The RP inlay produced lower retropatellar contact areas compared with the APG inlay for knee flexion >20° ($p<0.05$).

In the native knee, the patella started to tilt laterally from 40° and higher (Fig. 5). Maximum tilt was observed at full flexion. After TKA and patellar resurfacing, a lateral tilt was seen as early as 20°. During the full range of knee flexion, the tilt tended to be greater for the TKA knee ($p=$

Fig. 3 Mean retropatellar pressure under the various tested configurations. Retropatellar pressure increased significantly for the rotating-platform (RP) inlay ($p=0.002$) and the anteroposterior gliding (APG) inlay ($p=0.013$). Comparing the two inlays, no significant differences occurred

Fig. 4 Mean retropatellar area under the various tested configurations

0.09), whereas no difference was observed between the RP and APG inlay. The lateral translation of the patella in the native knee started at 40° and increased up to 9.0 mm at 100° (Fig. 6). After TKA, the lateral translation began earlier, at 20°. Additionally, in early flexion (< 60°) TKA knees translated more laterally than the native knee. Overall, patellar translation did not change significantly after TKA compared to the native knee ($p=0.08$). However, the RP inlay tended to result in less patellar translation when compared with the APG inlay.

Fig. 5 Mean patellar tilt under the various tested configurations (negative value = medial tilt). In early flexion, total knee arthroplasty (TKA) tended to have greater lateral tilt

Fig. 6 Mean patellar translation under the various tested configurations (positive value = lateral translation). In early flexion, total knee arthroplasty (TKA) led to a greater lateral translation

Discussion

The findings of this study supported our hypothesis that TKA increases retropatellar pressure and affects patellar kinematics. Using a gliding inlay (APG) instead of an RP inlay did not influence patellofemoral kinematics but did produce a larger retropatellar contact area. Our finding of increasing retropatellar pressure with increasing knee flexion confirms the results from previous in vitro studies [3, 13]. TKA implantation with additional patellar resurfacing significantly increased retropatellar pressure. Comparing the RP and the APG inlays, no significant difference occurred. The intact knee shows a femoral rollback during flexion, whereas most posterior cruciate ligament (PCL)-retaining TKAs exhibit a paradoxical anterior translation [14]. Loss of femoral physiological rollback induces abnormally high patellofemoral forces in flexion [14, 15]. The LCS TKA with the APG inlay is a PCL-retaining TKA. The APG inlay was developed to approximate the kinematics of the natural knee more closely by incorporating unlimited anteroposterior translation and rotation. A previous study showed a physiological rollback between 80° and 120° of knee flexion with this inlay [16], reducing the retropatellar pressure. In contrast, PCL-sacrificing TKAs, such as the LCS-TKA with RP inlay, exhibited the least amount of femoral rollback [15], leading to an increased retropatellar pressure. In our study, we found the tendency to lower retropatellar pressure beyond 60° of knee flexion when using the APG inlay, but this was not significant.

Concerning the retropatellar contact area, we found an increasing contact area with increasing flexion in initial and

midflexion, followed by a slight decrease in further flexion. These findings are in good agreement with other *in vitro* studies [13, 17]. After TKA, the retropatellar contact area significantly decreased beyond 40° of knee flexion. Other *in vitro* studies observed a comparable decrease of contact area after arthroplasty with various TKA systems [19]. The RP inlay produced lower retropatellar areas compared with the APG inlay for knee flexion >20°. This can be explained by the femorotibial motion, which influences the contact points between femur and patella. The physiological femoral rollback observed with the APG inlay in higher flexion might have increased the contact area, whereas a paradoxical anterior movement might have reduced this area.

Considering patellar kinematics, we found the native patellar to translate and tilt laterally for flexion angles >40°, which is in accord with other *in vitro* and *in vivo* studies [17, 18, 20, 21]. After TKA and patellar resurfacing, a lateral tilt and translation was observed in early flexion and confirmed the findings from previous *in vitro* studies [8, 9, 17]. Changes in patellar movement after TKA may be explained by the anatomy of the femur and the design of the femoral component. In the native knee, the lateral condyle is larger than the medial, forcing the patella to move medially. Although the medial anterior flange of the LCS femoral component is narrowed, the femoral component is much more symmetrical than the native femur. Therefore, the effect of forcing the patella to move medially is reduced. This effect occurred especially near extension. In deep flexion, the patella seats deeply in the trochlear groove, and its kinematics are predominantly controlled by the geometry of the groove. Comparing the RP and APG inlays, no significant differences were found. In so far as the trochlea is the main determinant for the patellar position at flexion angles >30° [22], the choice of inlay has no significant influence on patellar kinematics. Instead, the design of the femoral component plays an essential role. In particular, an anatomical patellar groove orientation seems to be important [22]. The patellar groove of the LCS complete knee system extends perpendicularly from the intercondylar notch and rises into an anatomically shaped anterior flange. However, although the patellar groove is anatomically shaped and the gliding patella can rotate up to 30° from neutral in either direction, physiological patellar kinematics could not be achieved. The altered patellar kinematics after TKA may be one cause for postoperative anterior knee pain. MacIntyre et al. examined patients with anterior knee pain and healthy individuals and found in the symptomatic group a higher lateral tilt [20]. Similar results were found in other *in vivo* studies [23].

The study presented here has several strengths but also limitations. One essential strength is the physiological direction of muscle simulation. The quadriceps load was distributed according to muscle PCSA, and the direction of

the different components was simulated physiologically. Most *in vitro* studies only simulated the quadriceps parallel to the femoral axis. However, the load distribution is important. Powers et al. evaluated the effects of axial and multiplane loading of the extensor mechanism on the patellofemoral joint and showed an increased contact area as well as an increased lateral movement of the patella under multiplane loading [24]. Sakai et al. also proved that patellar tracking is very sensitive to quadriceps loading [25]. Furthermore, we simulated hamstring co-contraction, which has been shown to increase patellofemoral contact pressure and change patellar translation [26, 27]. In addition, we measured patellofemoral kinematics before and after TKA within the same specimen.

One limitation of this study was that we were unable to simulate physiological load levels for the muscles, nor did we include a weight-bearing component. The quadriceps load of 150 N ensured that the muscles would not fail before all configurations were tested. However, Nagamine et al. showed that in native knees, increasing quadriceps load did not affect patellar movement [28]. Nevertheless, the applied quadriceps load in our experiment was clearly below the quadriceps force achieved during daily activity. Thus, contact pressure *in vivo* will be higher than the pressure measured in our study. However, absolute contact forces are difficult to extrapolate from cadaver models. Another limitation of the study was that the knees were only moved to 100° of flexion. Some knees were relatively stiff, so that 100° of knee flexion was the largest flexion achievable for all native knees. Considering the fact that we found a slight increase in pressure with increasing knee flexion, we assume that greater flexion would have further raised the retropatellar pressure. Furthermore, only one type of implant was tested. Therefore, we could not clearly verify the influence of the femoral component shape on patellar kinematics. Nevertheless, an initial lateral tilt and translation after TKA was observed in other *in vitro* studies [8, 9, 17]. In these studies, different types of prosthesis were used, but the femoral components were always more symmetrical than the native femur, assuming an influence of the femoral shape on patellar kinematics.

In conclusion, our data showed that TKA with additional patellar resurfacing led to increased retropatellar pressure, decreased contact area and increased lateral movement. The increased retropatellar pressure and lateral movement of the patella after TKA may be one important cause for the anterior knee pain appearing after TKA. Although patellar kinematics could not be affected by using an APG inlay compared with an RP inlay, the APG inlay improved retropatellar contact characteristics by increasing the contact area, especially in higher flexion. Therefore, if the posterior cruciate ligament is intact and can be preserved, the APG inlay should be preferred.

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