Effects of patellar resurfacing on contact area and contact stress in total knee arthroplasty

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Abstract

The objective of this study was to examine the effects of patellar resurfacing on patellofemoral joint contact pressure and contact area in total knee arthroplasty. We tested seven fresh-frozen cadaveric knees using a custom knee jig which permits the simulation of physiologic quadriceps loading. Before patellar resurfacing, the mean peak contact pressure of medial and lateral patellofemoral joints was less than 10 MPa at knee flexion angles of 30°, 60° and 90°, that of medial and lateral patellofemoral joints were 11.63 MPa and 11.42 MPa at a knee flexion angle of 120° respectively, and the mean contact area of patellofemoral joint ranged from 70 to 150 mm2. After patellar resurfacing, the mean peak contact pressure of medial and lateral patellofemoral joints ranged from 50 to 100 MPa (P < 0.05), which exceeds the yield strength of ultrahigh molecular weight polyethylene, and the mean contact area of patellofemoral joint reduced to 10–15 mm2 (P < 0.05). The contact pressure of patellofemoral joint was lower than the yield strength of articular cartilage before patellar resurfacing. Our results indicate that the yield stress of UHMWPE is exceeded after patellar resurfacing.

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Keywords: Patellar resurfacing; Contact area; Pressure; Patellofemoral joint; Total knee arthroplasty

1. Introduction

Initially, knee replacement did not include patellar resurfacing. Instead, the native patella was maintained, regardless of its condition or underlying disorder. When patellar resurfacing during total knee arthroplasty (TKA) was introduced in the 1970s, it aroused initial enthusiasm because of a resultant decrease in anterior knee pain, but new complications emerged, which included fracture, component failure, osteonecrosis, instability, tendon rupture, and patellar clunk syndrome [1–4]. Most of these early complications were attributable to poor surgical technique and inferior implant design [5,6]. The clinical results have improved significantly with improvement on these surgical and design flaws [7–10]. But the decision on whether to resurface the patella during TKA remains controversial. Proponents of resurfacing state that it reduces the incidence of postoperative anterior knee pain and gives a better clinical outcome [11–14]. Those who do not favor resurfacing argue that it does not add any benefit [15,16] and may bring about unexpected complications. Volumetric wear is proportional to normal load and sliding distance and depends upon the factors related to the articulating surfaces, including hardness, real contact area [17]. Volumetric wear is also a major obstacle limiting the long-term performance of implanted UHMWPE components [18]. So we attempted to examine the contact area and pressure generated between patellofemoral joints (PFJ) before and after patellar resurfacing in TKA to clarify the biomechanical effects of patellar resurfacing on PFJ.

2. Materials and methods

Seven (four men, three women) fresh-frozen unmatched knees from cadavers were used in the current study. All knees were macroscopically intact and radiologically normal with no previous history of surgery. During
Fig. 1. Two intramedullary shafts are inserted into femoral and tibial medulla, and then the specimen is loaded with 30 kg (about half of the body weight of an adult) perpendicular to the ground by Instron machine.

dissection, the cartilage surface was inspected for wear. Any specimen with greater than Grade 2 chondromalacia was excluded from the study [19]. The cadaveric specimens ranged from 30 to 40 years of age. The tibia and femur were cut to approximately 20 cm long for mounting. The skin and subcutaneous fat were removed while the joint capsule and the surrounding retinaculum were carefully preserved. All musculature was dissected and removed from the tibia and the posterior femur. The fibula was cut near the level of its articulation with the tibia, and then the fibula was fixed to the tibia with the insertion of the lateral collateral ligament preserved.

A clamp, cable and pulley system was used to apply loads to the quadriceps tendon. The quadriceps tendon was clamped to ensure even loading of all muscle fibers. The muscles were wrapped in saline moistened gauze before clamping to prevent drying during testing and ensure even force distribution to the clamp through the tissue. The muscle was clamped as close to its tendinous insertions as possible, so tendinous fibers could be incorporated within the clamp. Clamping was applied in such a way that the muscle fibers were perpendicular to the clamp to further ensure even loading of the muscle fibers.

Two intramedullary shafts were inserted into the femoral and tibial medullae respectively. With the aid of a Model 8501 Instron machine (Instron Corporation, Canton, MA), the specimen was positioned at variable knee flexion angles while allowing translation in the x, y, and z axes and independent rotational freedom for the femur and the tibia. The physiologic Q angle was maintained, which was determined with a standard goniometer and defined as the angle between the axis of the femur and a line drawn between the midpoint of the patella and the tibial tubercle. Then the specimen was loaded with 30 kg (about half of the body weight of an adult) perpendicular to the ground with the help of the Instron machine. The muscles were loaded simultaneously to prevent shear force on the Fuji Prescale pressure sensitive film (Fuji Photo Film Co, Tokyo, Japan), and the specimen was balanced at the desired angles. The film remained in place for 2 min, then the muscles were unloaded simultaneously. The intraarticular contact area and pressure of the PFJ were measured at 30°, 60°, 90° and 120° knee flexion.

2.1. Measurements of contact area and pressure

The Fuji Prescale pressure sensitive film was cut to 5.0 × 5.0 cm. The film was composed of two parts, a transfer sheet and a developer sheet, both of which were approximately 0.10 mm in thickness. The film sheets were placed in a polyethylene bag to protect the film from fluid contamination. The Fuji Prescale pressure sensitive film was placed in the PFJ via the suprapatellar pouch arthrotomy. The transfer sheet contained a microcapsule layer of a translucent color-forming substance. When pressure was exerted on the film, the microcapsules broke, releasing their substance onto the developer sheet. The density of the shade of color was proportional to the amount of pressure experienced between the two sheets. Low type Fuji film with a range of 2.5 to 10 MPa was used before patella resurfacing, and medium type Fuji film with a range of 10 to 50 MPa or high type Fuji film with a range of 50 to 130 MPa was used after patellar resurfacing. Low type film was also used after patellar resurfacing for patellofemoral contact area. Films with any evidence of crumbling artifact were discarded and measurement was repeated.

Then photos of the Fuji Prescale pressure sensitive film were taken by Nikon 4300 digital camera to calculate the patellofemoral joint contact area (mm²) by Auto-cad software, and the peak contact pressure (MPa) was analyzed by Prescale density reader (FPD-305E) and Prescale pressure reader (FPD-306E).

2.2. Total knee arthroplasty

After the preoperative kinematics measurements, the specimens underwent total knee arthroplasty using the Nexgen® Complete Knee Solution system (posterior cruciate substituting). Total knee arthroplasty was performed using the company’s recommended surgical protocol by a senior doctor (WU Haishan, MD) with the assistance of an orthopaedic surgery resident. After the components were implanted (patella unresurfaced), the knees were taken through a full range of motion to assess soft tissue balance. No soft tissue release was required after implantation of the components. The knees were closed in anatomic layers.

Each specimen (patella unresurfaced) was subjected to the same test procedures as before total knee arthroplasty to determine the contact area and contact pressure at each knee flexion angle. Then the patellae were resurfaced and a dome-shaped patellar component was implanted, and the contact area and contact pressure at each knee flexion angle were repeated (Fig. 1).

All tests were run at 24 °C.

Table 1

<table>
<thead>
<tr>
<th>Contact area of patellofemoral joint (mean values) (mm²)</th>
<th>Unresurfaced</th>
<th>Resurfaced</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°</td>
<td>77.45 (34.34–118.37)</td>
<td>11.84 (6.43–22.33)</td>
</tr>
<tr>
<td>60°</td>
<td>117.08 (58.99–260.67)</td>
<td>14.27 (6.12–30.34)</td>
</tr>
<tr>
<td>90°</td>
<td>126.62 (66.51–194.52)</td>
<td>12.48 (5.94–18.94)</td>
</tr>
<tr>
<td>120°</td>
<td>154.51 (98.48–270.19)</td>
<td>13.91 (11.64–16.99)</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>Contact pressure of lateral patellofemoral facet (mean values) (MPa)</th>
<th>Unresurfaced</th>
<th>Resurfaced</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°</td>
<td>3.17 (0.92–8.27)</td>
<td>49.77 (13.2–97.3)</td>
</tr>
<tr>
<td>60°</td>
<td>3.39 (0.75–7.50)</td>
<td>77.59 (39.7–110)</td>
</tr>
<tr>
<td>90°</td>
<td>3.24 (1.09–5.79)</td>
<td>94.69 (46.4–122)</td>
</tr>
<tr>
<td>120°</td>
<td>11.42 (1.79–31.9)</td>
<td>107.83 (89.7–125)</td>
</tr>
</tbody>
</table>

Table 3

<table>
<thead>
<tr>
<th>Contact pressure of medial patellofemoral facet (mean values) (MPa)</th>
<th>Unresurfaced</th>
<th>Resurfaced</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°</td>
<td>2.92 (0.633–8.27)</td>
<td>62.84 (31.9–99.6)</td>
</tr>
<tr>
<td>60°</td>
<td>3.24 (0.62–7.5)</td>
<td>59.57 (31.8–104)</td>
</tr>
<tr>
<td>90°</td>
<td>3.57 (1.46–5.21)</td>
<td>95.59 (48.6–120)</td>
</tr>
<tr>
<td>120°</td>
<td>11.63 (2.87–22.5)</td>
<td>109.71 (90–127)</td>
</tr>
</tbody>
</table>
2.3. Statistical analysis

Each specimen acted as its own control. The measurements before and after patellar resurfacing were compared using the paired Student’s t-test.

3. Results

Before patellar resurfacing, the mean peak contact pressure of medial and lateral patellofemoral joints was less than 10 MPa at knee flexion angles of 30°, 60° and 90°, and the mean peak contact pressures of medial and lateral patellofemoral joints were 11.63 MPa and 11.42 MPa at a knee flexion angle of 120° respectively, and the mean peak contact pressures of medial and lateral patellofemoral joints ranged from 70 to 150 mm². After patellar resurfacing, the mean peak contact pressure of medial and lateral patellofemoral joints ranged from 50 to 100 MPa ($P<0.05$), and the mean contact area of patellofemoral joint reduced to 10–15 mm² ($P<0.05$). The data represent 6.5-, 8.2-, 10-, and 11-fold reduction in PFJ contact area after patellar resurfacing for the respective knee flexion angles (Tables 1–3).

Typical patellofemoral contact patterns before and after patellar resurfacing are shown in Figs. 2 and 3. Native patella contact patterns varied widely but in general had a round to oval shape. The contact pattern for each patella did not change significantly at 30°, 60°, 90° and 120° knee flexion. Of note is the two-point patellofemoral contact seen throughout the range of motion tested in the patella resurfaced specimens.

4. Discussion

In the past two decades, progress has been made in surgical technique and design of prostheses, making TKA more successful in terms of patient satisfaction [20]. Nevertheless, certain problems related to TKA remain unresolved, including the problem of patellar resurfacing during TKA. Options available for the patella during TKA include: resurfacing in all patients [11,13], nonresurfacing in all patients [16], and selective resurfacing [21,22]. These options have been based mainly on clinical outcomes, and there is little information concerning the biomechanical effects of patellar resurfacing or not on PFJ in TKA.

Lee et al. [23] reported that the average patellofemoral joint contact area in a normal knee was $189±83$ (mean±standard deviation), $231±80$, $232±80$, and $191±51$ mm² at 30°, 60°, 90° and 120° knee flexion, respectively. The contact area seen between PFJ before patellar resurfacing in our study demonstrated an oval footprint which did not significantly change in shape at any flexion angles. The mean contact...
area before patellar resurfacing was 77.45±29.41 (mean ± standard deviation), 117.08±76.25, 126.62±55.15 and 154.51±55.01 mm² at 30°, 60°, 90° and 120° knee flexion, respectively. In the patella resurfaced specimens, the two-point patellofemoral contact was seen throughout the range of motion. The mean contact area after patellar resurfacing was 11.84±6.67, 14.27±7.88, 12.48±5.81 and 13.91±1.96 mm² at 30°, 60°, 90° and 120° knee flexion, respectively. These data represent 6.5-, 8.2-, 10-, and 11-fold reduction in PFJ contact area after patellar resurfacing for the respective knee flexion angle (P<0.05).

After patellar resurfacing, the contact area and shape of the PFJ found in our study were similar to the findings of previous reports [24,25]. In 1995, Takeuchi et al. [25] demonstrated low contact area in six prosthetic knee systems ranging from 13 mm² to 68 mm². Szivek et al. [24] and Takeuchi et al. [25] also demonstrated high contact pressure, in excess of 20 MPa, at the patellofemoral interface consistent with the findings in our study.

Lee et al. [23] reported that the peak PFJ contact pressure in a normal knee was 1.48±0.48, 1.44±0.45, 1.66±0.50, and 1.63±0.64 MPa at 30°, 60°, 90° and 120° knee flexion, respectively. Our results showed that a statistically significant change in lateral PFJ peak contact pressure after patellar resurfacing (P<0.05). The mean peak contact pressure of PFJ before patellar resurfacing was less than 10 MPa at 30°, 60° and 90° knee flexion, respectively. At 120° knee flexion, the mean peak contact pressure of PFJ was only 11 MPa. So the mean PFJ peak contact pressure before patellar resurfacing was below the yield stress of articular cartilage in most of the cases, which is reported to be 10 MPa [26]. In contrast, the mean peak contact pressure of lateral PFJ after patellar resurfacing was 49.77±34.69, 77.59±31.66, 94.69±23.46 and 107.83±13.71 MPa at 30°, 60°, 90° and 120° knee flexion, respectively, which is above the yield strength of UHMWPE [25,27]. Similar change was observed in mean medial PFJ peak contact pressure. Elevation in contact pressure at the patellofemoral joint after TKA inevitably results in the wear of UHMWPE [28] and increased patellofemoral joint contact stress after total knee arthroplasty has been implicated as the primary cause of component wear and failure [29,30].

This study presents some comparative objective data with respect to contact area and pressure between patellofemoral joints before and after patellar resurfacing in TKA. The results, however, should be viewed with the following limitations in mind. First, a single knee system was used during testing and the data obtained in this study may not be
applicable to other knee systems. Second, the yield strength for the articular cartilage used in this study (10 MPa) is the value determined in healthy human articular cartilages. The cartilage present in knees undergoing arthroplasty routinely demonstrate a diseased cartilage and it is probably reasonable to assume that the yield strength of this tissue may be less than that of normal hyaline cartilage.

In summary, our results indicate that patellofemoral contact pressure before patellar resurfacing is below the yield strength of normal articular cartilage and the yield stress of UHMWPE is exceeded after patellar resurfacing.

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References