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Patellar Component Design Influences Size Selection and Coverage

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Abstract

Background: Patellofemoral (PF) complications following total knee arthroplasty continue to occur. Outcomes are influenced by implant design, size and alignment in addition to patient factors. The objective of this study was to assess the effect of implant design, specifically round versus oval dome patellar components, on size selected and bony coverage in a population of 100 patients.

Methods: Intraoperative assessments of patella component size were performed using surgical guides for round and oval designs. Digital images of the resected patellae with and without guides were calibrated and analyzed to measure bony coverage. Lastly, the medial-lateral location of the median ridge was assessed in the native patella and compared to the positioning of the apex of the patellar implants.

Results: In 82% of subjects, a larger oval implant was selected compared to a round. Modest, but statistically significant, differences were observed in selected component coverage of the resected patella: 82.7% for oval versus 80.9% for round. Further, positioning of the apex of oval patellar components reproduced the median ridge of the native patella more consistently than for round components.

Conclusions: These findings characterized how implant design influenced size selection and coverage in a population of patients. The ability to “upsized” with oval dome components led to increases in bony coverage and better replication of the median ridge compared to round components. Quantifying the interactions between implant design, sizing and coverage for a current implant system in a population of patients supports surgical decision-making and informs the design of future implants.

Keywords

patellar component; implant design; implant size; bony coverage; patellofemoral; total knee replacement

1. Introduction

Total knee arthroplasty (TKA) using a posterior-stabilized (PS) prosthesis has demonstrated excellent pain relief, high functional scores, and excellent long-term prosthesis survivorship exceeding 95% at 10 years [1,2]. However, patellofemoral (PF) complications, ranging from anterior knee pain, maltracking, patellar crepitus or clunk syndrome, loosening, and patellar fracture, continue to occur [3-8]. Prior studies have reported incidence rates of up to 12% for patellar pain, from 0.68% to 5.2% in TKA for patellar fracture and up to 14% for crepitus [6-8]. The etiology of some complications, e.g. anterior knee pain, is not well understood, while others, e.g. patellar crepitus, have been linked to implant size and design. Patellar crepitus occurs secondary to the development of fibrosynovial hyperplasia on the posterior aspect of the distal quadriceps tendon resulting in frictional irritation of the tendon during knee flexion as it traverses the intercondylar box of the posterior-stabilized femoral component [9-11]. This condition has a greater incidence with use of smaller patellar and femoral component sizes and decreased composite patellar thickness [5]. Recently, Panni et al. reported PF complications in 7% of TKA patients: 13 patients with anterior knee pain, five with symptomatic maltracking and one with loosening in a cohort of 280 patients at 96 month follow-up [4].

When resurfacing the patella, surgeons will determine the implant design, size and alignment considering multiple factors related to the patient's anatomy. Patellar implant design, size, and position are selected to maximize osseous coverage with minimal overhang of the implant on the resected surface, to assure facet symmetry and to facilitate central patellar tracking. When the composite thickness of the implant and resected patella reproduces the thickness of the native patella, the efficiency of the extensor mechanism is maintained [12].

Related to patellar tracking, the patellar component is positioned to replicate the anatomy of the native patella, in particular, the apex of the implant with the median ridge of the native patella.

PF mechanics and the incidence of complications are dependent on implant design [13-18], as well as sizing and surgical technique (resection thickness, under/overstuffing the joint, thickness symmetry of the remaining medial and lateral facets) [5,19-21]. However, sizing of the patellar component, and specifically investigating how component shape influences the selected size for a cohort of patients, has not been previously evaluated. Accordingly, the objective of this study was to determine the effect of patellar component shape (round versus oval dome) on selected patellar component size, osseous patellar coverage and the ability to “upsized” or select a larger-sized oval implant compared to round. Lastly, the medial-lateral location of the median ridge was also assessed in the native patella and compared to the positioning of the apex of the patellar implants.

2. Methods

Following institutional review board approval and informed consent, 100 primary TKA subjects were evaluated during patellar resurfacing using a single posterior-stabilized prosthesis (PFC Sigma; Depuy Synthes, Warsaw, IN). The patient cohort consisted of 45 males and 55 females with an average age of 65 years and mean BMI of 28.02. All procedures were performed by surgeons fellowship-trained in TKA using a gap balancing technique. The patella was prosthetically resurfaced in all cases. Surgical approach consisted of a medial parapatellar approach for all knees. After exposure of the knee joint, a portion of the retropatellar fat pad was excised, and the lateral patellofemoral ligament released. Femoral and tibial bone resections

and appropriate soft tissue balancing were performed to assure gap balance and alignment along the mechanical axis.

The patella was addressed by initially measuring the maximal thickness by hand-held caliper. The median ridge was drilled with a 2 mm drill bit to a level below the predicted articular surface resection to mark its anatomic position. The patellar articular surface was resected either freehanded or with a patellar cutting guide by experienced, fellowship-trained total arthroplasty surgeons with a goal of removing a thickness of bone equal to the thickness of the selected patellar component and to assure symmetric patellar facet thickness. Following patellar osteotomy, the remaining patella was again measured and adjustments in patellar resection performed if necessary to confirm the desired patellar thickness and facet symmetry were attained. For patients with small patellae, the resection would never result in less than 12 mm of remaining bone on the anterior aspect of the patella. As a result, this scenario may result in a small amount of overstuffing. All peripheral osteophytes were then removed, and the periphery of the bone surface and the median ridge location were outlined with a surgical marker. The synovium on the undersurface of the quadriceps tendon in the suprapatellar region was also sharply excised. Digital photographs were taken of the resected surface and the surface covered with the best-fit round and oval patellar lug guides (Figure 1A-C); care was taken to ensure that the camera was aligned parallel to the resected surface. The selected size for the round and oval dome patellar implant was recorded. During this intraoperative assessment, the resected surface was not modified to account for differences in thickness associated with the selected implant sizes. While sized for both types of patellar components, patients received the implant preferred by the surgeon in the procedure, which provided the best osseous coverage without excessive component overhang.

Each digital photograph was calibrated based on the known dimensions of the surgical guides. Specifically, the size of a pixel was determined by setting the length in pixels equal to the dimension of the guide. Using the scaled images, the area of the resected patellar surface and the percent coverage with the round and oval patellar components were determined (Figure 1D). All of the image analyses were performed by one individual. To assess accuracy of the image calibration and area measurement process, the measurement process was repeated for 5 patients selected at random and differences were evaluated. The medial-lateral position of the median ridge was determined as the distance from the medial edge to the center of the drilled hole. The apex of the round and oval patellar components were reported relative to the medial aspect of the resected surface and compared to the native anatomic position of the median ridge. A statistical comparison was performed to evaluate difference in coverage and position of the median ridge between the round and oval implant groups using a paired student t test with a 5% level of significance. A repeated measures ANOVA was also performed to assess differences in these measures between operating surgeons.

3. Results

The distribution of patellar component sizes showed that the selected oval patellar component was typically larger in size than the selected round component for the cohort of 100 patients (Figure 2). Compared to a round component, a larger sized oval patellar component was selected for 82% of patients. Analyzing the data by operating surgeon, larger oval components were selected: 85.0% for 40 cases (surgeon a), 78.9% for 38 cases (surgeon b) and 81.8% for 22 cases (surgeon c); all of the upsizing rates were within 1 case (2.5 to 4.5%) of the mean.

A greater percentage of the resected surface of the patella was covered with the selected oval component (mean 82.7%, standard deviation (SD) 10.7%) than with a round component (mean 80.9%, SD 9.7%; Figure 1 and Table 1). Differences in the percent coverage were statistically significant (p value = 0.019) in a paired 2-tail t test. The repeated measures ANOVA confirmed the statistically significant differences in coverage between selected implant designs (p = 0.01) and showed no effect of operating surgeon (p = .325). The image calibration process measured the size of the guide in pixels, which ranged from nominally 388 to 689 pixels, and then by equating this dimension to the actual dimension in mm, the resulting pixel sizes ranged from nominally 0.05 mm to 0.09 mm. Repeated measurements of the resected area were on average within 1%, with a maximum difference of 2.3%.

Anatomic variation in the resected patellae is shown by representative images (Figure 3), which illustrate various combinations of round and oval sizing. Patellae that would receive the same-sized round and oval components are shown along the major diagonal and then by moving to the right, examples are shown for patellae that would be upsized to a larger oval compared to the round component. Further, for each size of round component, the likelihood of upsizing to a larger oval component was computed (Figure 4). An increase of one size with the oval design (e.g. from 32 mm round to 35 mm oval) was selected the majority of the time: 75% for 32 mm round, 72% for 35 mm round, and 92% for a 38 mm round, with smaller percentages of selecting the same size or upsizing 2 sizes (e.g. from 32 mm round to 38 mm oval). As the largest-sized component (41 mm) was the same for both the round and oval designs, there was no opportunity to upsize a 41 mm round.

The medial-lateral position of the median ridge of the patella relative to the medial aspect of the resected surface was measured and found to be normally distributed (Figure 5). The oval

patellar components better reproduced the position of the natural median ridge than the round component; for the 100 subjects, 58 of the oval components versus 48 of the round components had the implant apex positioned within ± 2 mm of the median ridge of the native patella (Figure 5). Averaged across all subjects, the round component resulted in a more medial placement of the apex relative to the natural median ridge, while the oval was closer and slightly lateral to the natural median ridge. The mean position of the apex of the round patellar component was 1.16 mm (SD 2.54 mm) medial to the anatomic median ridge or 2.53% (SD 5.67%) of patellar medial-lateral width. The apex of the oval component was located 0.25 mm lateral (SD 2.45 mm) to the anatomic median ridge or 0.75% (SD 5.64%) of patellar medial-lateral width. Differences in apex position between the oval and round components were statistically significant ($p < 0.001$) in a paired 2-tail t test.

4. Discussion

The current study utilized intraoperative assessments and image analysis of intraoperative photographs of the resected patella to assess the impact of patellar component shape on sizing and bony coverage in a cohort of 100 TKA patients. Compared to a round component, use of an oval patellar component resulted in selection of a larger patellar component in 82% of cases and provided a modest, but statistically significant, improvement in component coverage of the resected patellar surface. Upsizing the patellar component can influence the composite thickness of the resurfaced patella, which has been related to the incidence of crepitus [5,22] and impacts PF joint loading [23,24] and the mechanics of the extensor mechanism [12, 20, 25]. In addition, apex position for the oval patellar component was closer to the native median ridge than for the round component. It is noted, however, that this comparison assumed a medial placement of the

patellar component on the resected surface, whereas a surgeon may adjust sizing and/or placement to optimize apex positioning and patellar tracking during the operative procedure.

When considering bony coverage, the size selection of the component was influenced by the discrete nature of the sizing line and the shape of the resected surface. For the same-sized implant, the area of the oval component was 11-13% percent smaller than the round design, depending on size. For an oval design that was one size larger, the area is 3-8% larger than the round component (e.g. 38 mm oval vs. 35 mm round). So, compared to a round component, selecting the same-sized oval component resulted in decreased coverage, while an upsized oval component provided greater coverage, with the clear caveat that the component must ultimately fit the resected surface of the patella. Given the discrete nature of the sizing line, it is important to note that 7 of the subjects would have received a size 41 round component and were not eligible for upsizing. Understanding the variation in geometry of the resected patella is an important consideration in determining the shape, fit and sizing of implant components.

Limitations of the current study were that three surgeons performed the operative procedures, although each surgeon was fellowship-trained in TKA and considered to be a high volume surgeon. The findings of component size, bony coverage and apex positioning were consistent between operating surgeons, but individually did not yield statistically significantly differences given the limited population size. Further, in the intraoperative evaluation, the resection thickness was not adjusted to optimize the thickness of the bone-component construct for each of the selected implant designs. In most cases, this composite thickness would be within 1 mm of the thickness of the native patella. Another limitation is the lack of measured clinical outcomes or biomechanical assessment for this patient cohort. While the intraoperative assessment considered two component designs, the patient ultimately received the implant

preferred by the surgeon; accordingly, it was not possible to measure a variety of clinical outcomes (e.g. functional measures, strength, knee pain). The study performed the comparisons based on the optimally-sized implants selected by the surgeons, and did not consider whether other implant sizes would have led to improved coverage or apex position. Lastly, the authors note that the difference in percent of bone coverage (~1.8%) and duplication of native median ridge position (~1 mm) are relatively small and recognize the limited clinical significance.

The image quality (pixel size of 0.05 to 0.09 mm) and repeatability of the area measurement (average error less than 1%) provided confidence in the accuracy of the imaging measurements. The images showed minimal shadowing around the guides, which is indicative of good alignment between the camera and the resected patella. Errors in the reconstruction of geometry from radiographic images or CT scans are typically comparable to the resolution of the x-ray or scan (pixel size and slice thickness). While not a direct comparison, other studies have reported segmentation errors for CT and MRI scans of 0.163 mm for interobserver and 0.105 mm for intraobserver [26].

The modest increase in coverage of the resected surface with selection of an oval (82.7%) compared to a round patellar component (80.9%) results in a larger surface area to transmit loads and lower strains. In addition, use of an oval patellar component led to more implant contact with cortical bone around the periphery in the majority of the patellae evaluated. The increased area for load transfer may be important as the implant contacts lower modulus bone on the resected surface. In a computational model, the volume of bone experiencing strains near yield was approximately 2x greater in the implanted patella than in the natural patella [24]. The greater strained volume was due to the altered loading through bone of lower modulus, and while

the bone will likely remodel, it does represents the conditions immediately following the surgical procedure.

In the patellar implants utilized, the component thickness scales with component size (i.e. 38 mm component thickness is 9.5 mm versus 11.4 mm for a size 41 mm component). If the goal is for the composite thickness of the resected bone and implant to reproduce the original thickness of the bone, the amount of bone resected is based on the thickness of the initial component size selection. During the surgical procedure, the patella was resected based on the initial estimate of component size and the evaluation was performed on images of the resected surface for each patient. To accommodate a larger or smaller component size, the amount of bone resection would likely be varied; however, these adjustments were not considered in this study. Overstuffing of the PF joint may lead to tightness of the ligaments and muscles, which has been shown to limit flexion [19, 20], and changes in the effective moment arm of the quadriceps. Patella fracture can occur due to excessive resection of the native patella [23, 27]. With links to patellar fracture and potentially anterior knee pain, Fitzpatrick et al. have investigated the distribution of bone strain and the effects of varying resection thickness [24, 25]. Using a series of subject-specific models, mechanical changes in the extensor moment arm, kinematics, and distribution of bone strain were evaluated with changes in resection depth [25]. Regions of high strain in the patella bone are related to fracture, particularly in the thinnest patellae, while more generally, highly-strained regions may be linked to postoperative anterior knee pain [28].

Among other patient and implant design factors, smaller patellar and femoral component sizes, and decreased composite patellar thickness have been associated with a higher incidence of patellar crepitus [5]. While focused on the patellar component, the current study did not assess

femoral component design, sizing or positioning, which influences PF kinematics and contact mechanics [22, 29]. The etiology of crepitus has been linked to increased contact between the quadriceps tendon and the upper aspect of the intercondylar box of the femoral component. Clinical observations have demonstrated that the quadriceps tendon may contact the anterior border of the femoral component intercondylar notch during deep flexion [8-9, 11]. Computational models have confirmed the clinical findings, showing increased tendofemoral contact in the intercondylar box region with a smaller (thinner) patellar implant size and with a decreased composite thickness [22]. The ability to upsize to a larger oval component gives the surgeon options to increase composite thickness and lessen tendofemoral contact with the intercondylar box, especially for patients with patella baja or shorter patellar tendon lengths who are also at greater risk for development of patellar crepitus [5]. In a control-matched analysis of subjects with and without postoperative patellar crepitus [5], no statistically significant differences in the incidence of patellar crepitus were observed between those implanted with round versus oval patellar components, although the study was underpowered statistically due to the very small number of round components that were implanted.

5. Conclusions

In summary, using a novel intraoperative evaluation, the findings of this study assessed the effect of implant design (oval versus round) on selected patellar implant size in a cohort of 100 patients and supports usage of an oval patella to improve coverage and better duplicate the position of the anatomic median ridge. Greater coverage has the potential to improve load transfer and reduce bone strains, while reproducing the median ridge has implications for patellar tracking. The use of a larger (and thicker) component may help reduce the incidence of

quadiceps tendon irritation and the subsequent development of patellar crepitus; however, the authors also recognize the implications of composite thickness in avoiding excessive ligament and muscle tightness and maintaining enough of the resected patella to prevent fracture.

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Figure Captions

Figure 1. Photographs of the resected patella showing the drilled location of the native median ridge (1A). Round (1B) and oval (1C) sizing paddles were used for image calibration and show sizing and coverage. Imaging processing (1D) was used to determine resected area and medial-lateral (ML) location of the median ridge. This patient would be upsized from a 38 mm round to a 41 mm oval patellar component to maximize osseous coverage.

Figure 2. Distribution of patellar component sizes (% usage) for round and oval components for the 100 subjects.

Figure 3. Representative resected patellae for subjects who would receive the implant sizes for the round (row) and oval (column) combinations. For example, the first row shows the anatomy for subjects who would receive a 32 mm round or a 32 mm, 35 mm and 38 mm oval component. Patellae along the major diagonal with same size round and oval components are more circular in shape, while patellae to the right of the diagonal had larger oval than round components and were more elliptical in shape.

Figure 4. Percentage of oval component sizes corresponding to each round component size indicates the likelihood of upsizing with use of an oval component. For example, subjects with a 32 mm round component, 75% would receive an oval component one size larger, and 9% would receive an oval component two sizes larger.

Figure 5. Distribution of medial-lateral position of the median ridge for the natural patella (top). Oval patellar component more closely reproduced the position of the natural median ridge than the round component (bottom).

Table 1. Measured surface area and medial-lateral position of the median ridge for the natural patella. Comparison of coverage and difference in apex position for the round and oval patella. Data shown with mean (standard deviation). P value reported for comparison of round versus oval results using a paired 2-tail t test.

	Resected Surface Area (mm ²)	Natural Median Ridge Position (mm from medial edge)
Natural	1219.8 (SD 221.7)	18.73 (SD 2.70)
	Coverage (%)	Difference in Apex Position (mm)
Round	80.92 (SD 9.72)	1.16 (SD 2.54)
Oval	82.65 (SD 10.67)	-0.25 (SD 2.45)
P value	0.019	<0.001

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