The Width:thickness Ratio of the Patella

An Aid in Knee Arthroplasty

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Abstract Establishing the appropriate size of the patellar implant-bone composite is one of the important steps ensuring functional success in arthroplasty. Conventionally, the patella is measured intraoperatively and its thickness is used to guide the depth of resection. However, in a diseased joint, this may not reflect the native patellar thickness. We studied the relationship between the patellar thickness and various patellar dimensions on three-dimensional reconstructed computed tomographic scans from 37 normal adult knees. Patellar width correlated with thickness. The average patellar width:thickness ratio was 2.0 (standard deviation, 0.106; 95% confidence interval, 1.96–2.03). The cartilage thickness was on average 2.5 mm (standard deviation, 1.0). The width:thickness ratio was similar in 79 digital radiographs taken before TKA of knees without patellofemoral disease (mean, 2.1; standard deviation, 0.28). When compared with the two other methods for calculating patellar resection described in the literature, the width:thickness ratio was more reliable. The

width:thickness ratio appears anatomically constant and may be a useful guide for estimating pre morbid patellar thickness.

Introduction

For surgeons who choose to resurface the patella, establishing appropriate thickness of the patellar implant-bone composite during knee arthroplasty is important to optimize the patellofemoral joint kinematics and to balance its soft tissues [2]. Knee range of motion can be decreased by an increased thickness of the patellar prosthesis-bone composite after knee arthroplasty [5]. Other detrimental effects of overstuffing the patellofemoral joint, such as lateral patellar subluxation, increased patellofemoral contact pressure on the lateral condyle, and increased patellofemoral compression forces, have been reported in laboratory studies [8, 10, 21].

Surgeons tend to avoid overstuffing the patellofemoral joint by resecting the amount of bone that corresponds to the thickness of the patellar implant. In other words, the final patellar bone-prosthesis composite thickness is intended to match the original patellar thickness before surgery. However, the thickness is difficult to estimate when it has been reduced substantially by the wearing process. In advanced cases, the patella may be excavated and the median ridge altered. In the most severe cases, the patella will be quite thin and will not reflect the original thickness.

The preresection thickness of the patella typically is measured as the anteroposterior dimension from the anterior surface of the patella to the deepest part of the median ridge of the patella [18]. To address patellae with marked articular surface wear, two principal methods of reconstructing the

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patella without reference to the articular surface have been described: (1) the lateral facet subchondral bone thickness method [9, 18], in which all bone that is farther from the anterior surface than the shallowest part of the patella – typically on the lateral facet – is resected, and (2) the tendon-capsule method, in which all bone is resected deep to the posterior limit of the quadriceps tendon and the patellar tendon attachment [12, 13, 15] or the capsular attachment onto the patella [4].

We first asked whether a reliable relationship could be found between the thickness of the patella and any of its other dimensions that might allow the native thickness of a worn patella to be predicted from the nonarticular parts. Secondly we asked whether any predictive method we explored would be superior to the two described in the literature.

Materials and Methods

We obtained 37 computed tomographic (CT) scans of knees from 21 female and 16 male patients older than 55 years (range, 55–70 years) without patellofemoral disease from the contralateral knees of active people whose other knee was part of a study of unilateral medial compartmental arthritis. Computed tomographic scans were obtained using an established protocol that reduced the total radiation exposure to 0.7 mSv, the same radiation dose as for a long-leg standing film [7]. Three-dimensional images were reconstructed using computer software; the surface models enabled manipulation of the images and measurements.

A robust method for aligning the patella was necessary to produce reliable and reproducible measurements. The anterior surface of the patella was established by fitting a plane to multiple points on this surface. We aligned the patella with this plane vertically and the most posterior points in seven axial images from superior to inferior were used to define the deepest points on the median ridge. The patellar median ridge was simplified by fitting a line to these points. After aligning the patella with the anterior plane horizontal and the median ridge line in screen, the patellar thickness was measured from the anterior surface of the patella to the median ridge at the proximodistal center of the median ridge. At this level, the patellar width was measured. We also made measurements of the patellar length, lateral:medial facet ratio, and length of the median ridge (Fig. 1).

To establish precision of the measurements, we determined the agreement between two different observers for patellar width and thickness in 20 measurements. We assessed interobserver agreement by Bland-Altman graphs and intraclass correlation coefficient [11, 17] for 27 knees. The intraclass correlation coefficient was 0.95 and 0.97 for the thickness and width, respectively. We found no systematic biases between observers and the difference between the readings from both observers was 0.04 (standard deviation [SD], 1.07) and 0.2 mm (SD, 0.78) for width and thickness, respectively.

The patella can be resected at the level of the deep limit of the quadriceps tendon attachment and nearly posterior to the attachment of the patellar tendon (tendon method) [15] or at the level of the subchondral bone of the lateral facet (subchondral method) [9, 18]. However, neither of these

Fig. 1A–H Three-dimensional images were reconstructed from CT scans of the knees in extension; software generates all figures automatically. (A) Posterior reconstruction with the black arrow shows the length of the medial ridge; (B) the sagittal view with the white arrow shows the length of the patella; (C) axial and (D) coronal

views with two-headed arrows show the widths of the medial and lateral facets; (E) sagittal reconstruction is shown; (F) an axial view with a black line shows patellar width; (G) a coronal view shows...; and (H) this sagittal view with white line shows patellar thickness.

Fig. 2A–D These images illustrate the method of resecting the patella at the level of the quadriceps tendon attachments (tendon-capsule method). (A) A sagittal reconstruction is shown; (B) an axial image with the two-headed black arrow shows the amount to be resected; (C) a coronal view at the level of the patellar tendon is shown; and (D) a sagittal image with a two-headed black arrow shows the amount to be resected; the attachment of the patella tendon also can be seen.

methods is precise in relation to the depth of the patella. To virtually reproduce the tendon method, we used a sagittal image at the median ridge to locate the posterior (deep) limit of the quadriceps tendon by noting when the Hounsfield units just outside the bone changed from fat to fascia-tendon (Fig. 2). To virtually reproduce the subchondral bone method, after aligning the patella with the anterior surface horizontally, the axial image at the center of the median ridge was used to define a plane parallel to the anterior surface but just down to the subchondral bone of the lateral facet (Fig. 3). We then measured the thickness of the patellar bone to be resected using these two methods as references for the depth of patellar resection.

We determined the cartilage thickness at the point from which the patellar bony thickness was measured. This was possible on a CT scan because, in the extended relaxed knee, the articular surface of the patella rests on the supracondylar area with intervening fat between it and the underlying femur. Thus, the fat-cartilage junction was located where the Hounsfield unit changes from negative (fat) to positive (cartilage).

In addition, we studied the preoperative axial radiographs of 79 patients undergoing TKA. These patients had minimal radiographic changes of their patellofemoral joint. We measured the bony width and thickness of the patella on a digital axial radiograph using Centricity®

Fig. 3A–D These images show the method to simulate resection of the patella at the level of the subchondral bone of the lateral facet. (A) A sagittal reconstruction is shown; (B) an axial image with a two-headed black arrow shows the amount to be resected; (C) a coronal view shows the subchondral bone of the lateral facet; and (D) a sagittal image with a two-headed black arrow shows the amount to be resected.

Picture Archiving and Communication Systems (PACS) 3.0 software (GE Healthcare, Chalfont St Giles, UK).

We used Spearman's rho correlation to ascertain any relationships between patellar thickness and the other measurements (patellar width, patellar length, patellar ridge length). We used the Statistical Package for Social Sciences (SPSS) Version 13 (SPSS Inc, Chicago, IL).

Results

Patellar thickness correlated ($r = 0.89$, $p < 0.001$) with its width (Tables 1, 2; Fig. 4). The ratio of the width of the patella to the thickness was 2.0 ± 0.106 (mean $\pm$ SD) (95% confidence interval, 1.96–2.03). At the point from which the thickness of the patella was measured, the mean cartilage thickness was 2.5 ± 1.0 mm (95% confidence interval, 1.8–3.70 mm). However, we found no correlation between the length and width of the patella or the length and thickness of the patella (Table 2). The average ratio of the lateral facet to medial facet width was 1.3 (range, 0.8–1.6).

The width:thickness ratio was the most reliable of the three ways of restoring native thickness in normal knees. The alternative methods based on the lateral facet or the tendon attachments were substantially less reliable in

Table 1. Patellar dimensions of 37 knees

Dimensions	Mean	Standard deviation	Range	95% Confidence intervals
Width (mm)	44.8	4.8	36.8–53	43.2–46.4
Thickness (mm)	22.4	2.3	18.4–27.3	21.7–23.2
Length (mm)	34.3	3.8	24.3–39.2	33.0–35.5
Ridge length (mm)	23.7	2.3	18.7–28.6	22.9–24.5

Table 2. Correlation coefficients for patellar dimensions of 37 knees

Dimensions	Ridge length	Length	Thickness	Width
Width	0.68*	0.40	0.89*	1
Thickness	0.52*	0.22	1	
Length	0.65*	1		
Ridge length	1			

* Highly significant correlation.

Fig. 4 The regression line shows the relationship when patellar width was 2.0 times patellar thickness. There was a strong relationship between the patellar thickness and its width ($r = 0.89$, $p < 0.001$; thickness = 0.44 ; width + 2.8).

restoring normal patella thickness when a single thickness of patella implant was used (Fig. 6). When comparing the three methods, the width:thickness ratio allowed the native thickness to be restored with an average of 0.1 mm and a standard deviation of 1 mm. On average, the tendon method removed 7.5 mm of bone and the subchondral method removed 9.4 mm of bone (Table 3). The influence of these methods on the final thickness of the bone-prosthesis composite depends on the range of components available. The ratio of patellar width:thickness measured on axial radiographs was on average 2.1. The correlation between width and thickness of the patella was good ($r = 0.63$, $p < 0.001$) (Fig. 5). The variability of this ratio in the study group was small (SD, 0.28; 95% confidence interval, 2.07–2.19).

Discussion

The disadvantages of overstuffing the patellofemoral joint are well recognized [2, 5, 8, 10, 21]. In addition, a thin patella resulting from over-resection has had poor strain characteristics, which may contribute to early failure [14, 19]. Our primary aim was to investigate whether a reliable relationship could be found between the thickness of the patella and any of its other dimensions. Our secondary aim was to determine whether our predictive method was more accurate in reproducing patellar thickness than the two main methods previously described.

The major shortcoming of this study is the fact that these scans were obtained from patients whose other knee had medial compartment osteoarthritis. This potentially will bias our findings because medial osteoarthritis is a common variant that is usually symmetric. However, these knees had not yet succumbed to obvious osteoarthritis by their sixth decade, although some early changes may be developing. We measured only patellae whose articular cartilage remained of normal thickness in active people older than 55 years, so we believe the patellae were essentially normal. The study is essentially preclinical: we were not measuring these distances in the operating theater. We used CT scans rather than radiographs for clinical measurements. However, the method, based on reliably oriented patellae in three dimensions, is likely to be as accurate as any method using calipers because there is user variability in the use of manual measurement devices and intervening soft tissue can overestimate dimensions. Measurements obtained in this study, based on three-dimensional images and the use of Hounsfield units to correctly identify bony limits, further improve the repeatability of this observation. This is reflected in the agreement between observers.

The width of the patella appears to be a reliable indicator for predicting normal patellar thickness. We found, for normal patellae unaffected by erosive disease changes, the thickness was $\frac{1}{2}$ of the maximum width. This simple ratio is independent of damage to the articular surface and may help the surgeon when deciding on the thickness of the patella-prosthesis composite during arthroplasty. The relationship between patellar thickness and width has not been described, and the low variability in this measurement is surprising. Two other recent studies

Table 3. Thickness of the resected part of the patella

Method of resection	Mean (mm)	Standard deviation	Range	95% Confidence intervals
Subchondral bone of the lateral facet	9.4	1.4	13–6.3	8.9–9.8
Quadriceps tendon	7.5	1.4	5.3–10.3	7.0–7.9

Fig. 5 Patellar thickness and width were measured from digital axial radiographs of 79 knees. There was good correlation between the patellar thickness and its width ($r = 0.63$, $p < 0.001$; thickness = 0.40 ; width + 4.0).

that measured dimensions of the patella during surgery reported width and thickness [1, 20]. They did not report a ratio, but if one were to calculate a ratio based on their average measurements, it would be comparable to ours. Moreover, they did not emphasize the reliable and constant relationship nor did they highlight its usefulness.

The width:thickness ratio was more reliable than the two published conventional methods, especially when the median ridge is considerably worn away by disease, the feature most commonly used by surgeons to gauge the preresection thickness. The alternative methods based on the lateral facet or the tendon attachments were substantially less reliable in restoring normal patella thickness when a single thickness of patella implant was used (Fig. 6).

The simple 2:1 ratio for estimating the patellar thickness from its width does not take into account the thickness of the patellar cartilage. The patellar cartilage thickness is approximately 4 mm [3, 6], although there is progressive thinning after the age of 50 years [16], presumably a normal aging process. The cartilage thickness in patients in our CT-based study was on average 2.5 mm and one possible reason may be all of these patients were older than 60 years. This is more reflective of the population who undergo knee arthroplasty. Therefore, strictly speaking, to restore normal patellar thickness, 2.5 mm should be added to $\frac{1}{2}$ the width of the patella. However, if one considers the

Fig. 6 This box plot shows the postoperative thickness of the patella using each method and a 9-mm patella prosthesis.

ideal thickness of the cement mantle and the fact that cartilage is more compressible than the prosthesis, it may be more practical to use the original ratio [6, 7, 9, 12, 21]. The width:thickness ratio of the patella is not the only variable in reconstructing the patella during arthroplasty; it clearly will be impacted by different designs of femoral trochlea and patellar button, which more or less reproduce the natural morphologic features. In grossly abnormal patellofemoral joints, such as those with primary patellofemoral arthritis secondary to trochlea dysplasia, we do not yet know whether changing an abnormal patella into one with a normal width:thickness ratio is desirable or appropriate. In these difficult cases, there is a real risk of overstuffing the joint, but this ratio gives the surgeon some numeric ground rules to start from. However, the majority of patellae resurfaced in the course of total condylar knee arthroplasty will not have substantial morphologic disorders of the patellofemoral joint. For these cases, a width:thickness ratio of 2 may be a starting point on which to base decisions in reconstructive surgery of the patella.

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