

Accuracy of Haptic Assessment of Patellar Symmetry in Total Knee Arthroplasty

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Abstract: Resection resulting in asymmetrically thick patellar arthroplasty in knee arthroplasty may lead to increased compression forces, wear, fracture, or loss of quadriceps power. Assessing the cut patella between the thumb and forefinger (haptic assessment) represents a convenient way to recognize asymmetry. In 2 test series, 8 orthopedic surgeons evaluated 24 precut solid foam patellae of varying asymmetric thickness by feeling the patella between thumb and forefinger, without visualization. Of 384 responses, in 73.2% asymmetry was underestimated, 10.4% assessments were exact, and in 16.4% asymmetry was overestimated. Specifically, 35.9% were correct within 1 mm, 60.7% within 2 mm, 81% within 3 mm, and 91.4% within 4 mm. The thickest half of the patella was correctly identified in 90.6% of responses. Haptic assessment of patellar symmetry is a useful technique in knee arthroplasty. **Key words:** haptic, patella, patellar asymmetry, patellar arthroplasty, surgical technique, tactile, total knee arthroplasty.

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Technical recommendations for arthroplasty of the patella during total knee arthroplasty include restoring appropriate patellar height [1–4], avoiding excessive thickness [5], medializing the patella [3], and providing a minimum thickness of 12 mm [6]. These recommendations are made to minimize shear strain and compressive forces that might lead to increased wear [7,8] and to avoid maltracking and the need for a lateral release [3]. Furthermore, excessive resection of the patella not only reduces the lever arm and power of the quadriceps mechanism [9], but also subjects the patient to potential

fracture through a structurally incompetent patella [4].

Also important is avoiding asymmetry in cutting the patella [3–5,10,11]. An asymmetrically cut patella is defined as one that is thicker on one side than on the other. Because either under-resection or over-resection of one half might lead to problems, a quick and convenient method of assessment of patellar symmetry should be an important consideration in total knee arthroplasty.

Techniques recommended to obtain an ideal patellar cut include applying “eyeballing” techniques in which a saw is simply taken across the underside of the patella [12], using a specialized jig that allows resection of a predetermined thickness [1,3], and performing an anatomic cut in which a saw is used to remove bone to within 1 mm of the patellar ligament and quadriceps tendon [3]. Techniques to assess restoration of patellar height often involve the use of calipers to measure the thickness of the remaining patella before resurfacing and after trial positioning of the patellar replacement [3,13].

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The senior author's (J.K.D.) technique has always been to initially cut less than the thickness of the prosthetic replacement and then to assess the symmetry of the patella between the thumb and forefinger. If the patellar thickness is judged symmetric, an additional amount of bone is removed symmetrically. Thus, ultimately, the amount of bone removed equals the thickness of the patellar component. However, more often than not, the initial cut has some asymmetry. If so, additional bone is taken off the thicker side until the patella is of a symmetric thickness and the amount of bone removed equals the patellar replacement thickness. Similar techniques have been described in the literature [3,9,13], but the subject has not been the focus of an independent analysis.

This study introduces the concept of "haptics" to orthopedic literature. Haptics is a field of research relating to or based on a sense of touch. The purpose of the study was to determine the validity and reliability of haptic techniques relying on tactile feedback to avoid an asymmetrically cut patella during total knee arthroplasty. We therefore tested the ability of orthopedic surgeons to use sense of touch in assessing the difference in millimeters between the thickest and thinnest parts of an asymmetrically cut patella and in judging the position of the thickest point.

Materials and Methods

Subjects

The subjects of the study were 8 orthopedic surgeons. The experience of the orthopedic surgeons ranged from 4–23 years in practice, with the junior author (J.P.P.) being in his fourth year of orthopedic residency.

Materials

We used 24 uniform, medium-sized (45 mm measured in a medial-to-lateral direction) solid foam models of the left patella designed for use in surgical training (Sawbones, Pacific Research Laboratories, Vashon, WA). We cut the undersurface of the specimens in an asymmetric random fashion using a patellar jig system (Johnson & Johnson; Raynham, MA). The patellae were then numbered, and the numbers of a clock were drawn on the cut surface of each patella, with the superior part labeled as 12 o'clock; the medial part, 3 o'clock; the inferior part, 6 o'clock; and the lateral part, 9 o'clock. Interval hatch marks were made to represent the numbers between (Fig. 1).



Fig. 1. Solid foam patellae were cut asymmetrically and numbered, and the face of a clock was drawn on each patella.

The thickness of the patella was measured at each mark to determine the difference between the thickest and thinnest parts. This difference represented the magnitude of asymmetry in millimeters. The 24 patellae were then placed into a bag and randomly distributed by shaking the bag several times.

Procedures

The test was designed to simulate the situation during total knee arthroplasty, when the patella is largely covered by soft tissue and cannot always be easily seen from the side. Therefore, the orthopedic surgeons were not allowed to see the patellae during testing. Testing was done individually, and the surgeon's dominant hand was double gloved. Each surgeon was asked to reach into the bag with the dominant hand, grasp one of the patellae with the thumb and forefinger, and feel the cut surface.

They were then asked to discriminate between the thickest and thinnest parts of the patella by estimating the number of millimeters of patella (if any) that would need to be taken off the thickest part of the cut surface to create a symmetric patella. Verbal responses were recorded by the experimenter (the authors). Subjects were then asked to bring the patella out of the bag with their thumb and forefinger gripping the perimeter of the patella at the point at which they estimated the cut side to be the thickest (Fig. 2). The results were recorded for each individual patella as the number of millimeters the surgeon thought needed to be removed to achieve symmetry and the number of the clock position under the thumb and forefinger.



Fig. 2. The surgeons drew each patella out of the bag using thumb and forefinger to grip the point on the perimeter of the patella that they thought had the greatest thickness.

After each patella was assessed, it was placed into a second bag to avoid visualization clues while the subjects assessed the remaining patellae in the first bag. After the first group of 24 patellae were evaluated, the patellae were remixed in the second bag for randomization, and each surgeon was asked to repeat the exercise. Thus, 24 patellae were evaluated twice, for a total of 48 responses per orthopedic surgeon.

The responses estimating the clock position of the thickest point were categorized as exact if the surgeon grasped the patella precisely at the thickest clock position (shown by premeasurement to be the highest peripheral point of the patella). The space between 2 "clock" numbers represented 1 twelfth of the patella. If the thumb and forefinger were placed within the 1 clock position on either side of the correct position (2 spaces), they were considered to be on the highest sixth of the patella. Similarly, if the thumb and forefinger were placed within 2 numbers on either side of the correct position (4 spaces), they were considered to be on the highest third of the patella. Finally, if the thumb and forefinger were within 3 clock numbers on either side of the correct position (6 spaces), they were considered to be on the highest half of the patella.

Statistical Analysis

The main outcomes of this study were accuracy and consistency of the surgeons' responses. Accu-

racy was estimated by taking the absolute value of the difference between each surgeon's estimate (of thickness and position) and the actual value for each patella. These absolute values were then averaged over round 1 and round 2. The accuracy values were estimated for the group of surgeons as a whole, as well as for each individual surgeon. Means are reported with 95% confidence intervals.

The consistency of the surgeons' responses was estimated by calculating intraclass correlation coefficients [14] and repeatability coefficients [15]. Specifically, intrarater agreement was estimated for each surgeon using data from the 2 repeated rounds of the experiment. Inter-rater agreement was estimated for each of the 2 rounds using data for all surgeons. Because patella thickness is a continuous variable, the consistency of the responses measuring this variable was evaluated using intraclass correlation coefficients and repeatability coefficients. The repeatability coefficient is expressed in the same units of measurements as the quantity being evaluated. The interpretation is that 95% of repeated observations will be within "x" units. Because patella position is an ordinal variable, the strength of agreement for patella position was evaluated by computing weighted κ statistics. For the intraclass correlation coefficients and κ statistics, the quality of agreement was classified according to Landis and Koch [16] as follows: slight (0-0.20), fair (0.21-0.40), moderate (0.41-0.60), substantial (0.61-0.80), and almost perfect (0.81-0.99).

Results

The accuracy of the orthopedic surgeons' estimates of patellar asymmetry and position of the thickest point are shown in Table 1. The surgeons consistently underestimated the amount of patella that would have to be removed to create a symmetric patella. Of the 384 responses, in 281 (73.2%) the amount of asymmetry was underestimated; 40 (10.4%) were exact; and in 63 (16.4%) the amount of asymmetry was overestimated. Specifically, 138 estimates (35.9%) were correct within 1 mm, 233 (60.7%) within 2 mm, 311 (81%) within 3 mm, and 351 (91.4%) within 4 mm.

Regarding the clock position of the thickest point of the patella, 22.7% of the responses were exact, 58.3% were within the highest sixth, 83.1% were within the highest third, and 90.6% were within the highest half.

As the trial progressed, almost all of the orthopedic surgeons developed carpal tunnel symptoms

because of the frequency of manipulation of the patella between their thumb and fingers. However, no surgeon's performance deteriorated in the second group of 24 specimens. Only 1 surgeon showed notable improvement from the first to the second trial.

Reliability data are presented in Table 2. Regarding estimates of the asymmetry (number of millimeters that would have to be removed to create a symmetric patella), intrarater agreement was generally within the substantial or almost perfect categories. However, considerably less intrarater consistency was found in assessing the position of the thickest part of the patella. The weighted κ values for position of the thickest point of the patella were in the slight to moderate categories.

Discussion

The ideal patellar resection should restore full flexion and function of the patellofemoral joint without compromising the structural integrity of the patella. In a biomechanical study in human cadaver knees, Reuben et al. [4] reported that patellar resurfacing leads to a significant increase in

Table 1. Accuracy of Surgeons' Estimates of Patellar Asymmetry and Clock Position of Thickest Point

Surgeon	N	Mean Error, mm*	95% Confidence Interval, mm
Asymmetry†			
1	24	2.82	2.1–3.55
2	24	3.29	2.58–4.01
3	24	1.57	1.09–2.06
4	24	1.67	1.19–2.14
5	24	1.77	1.28–2.26
6	24	1.98	1.41–2.55
7	24	2.33	1.68–2.99
8	24	1.69	1.1–2.27
All	192	2.14	1.92–2.36
Position‡			
1	23	1.26	0.94–1.58
2	20	1.23	0.86–1.59
3	24	1.21	0.91–1.51
4	24	1.08	0.82–1.35
5	24	1.27	0.93–1.61
6	24	0.96	0.6–1.32
7	23	1.41	1.06–1.77
8	24	1.08	0.73–1.44
Overall	186	1.19	1.07–1.3

*Difference between surgeon's estimate and actual measurement averaged over round 1 and round 2.

†Estimation of number of millimeters that would have to be removed to achieve a symmetric patella.

‡Estimation of clock position of thickest point on the perimeter of the patella.

Table 2. Repeatability of Surgeons' Estimates of Patellar Asymmetry and Clock Position of Thickest Point

Type of Agreement	Amount of Asymmetry*		Thickest Point, Weighted κ †
	ICC	Repeatability Coefficient, mm	
Intrarater			
Surgeon 1	0.93	1.3	0.41
Surgeon 2	0.97	0.8	0.49
Surgeon 3	0.58	2.5	0.13
Surgeon 4	0.60	2.4	0.24
Surgeon 5	0.75	1.8	0.50
Surgeon 6	0.75	2.1	0.47
Surgeon 7	0.85	1.8	0.28
Surgeon 8	0.84	1.7	0.23
Interrater			
First round	0.41		
Second round	0.49		

Abbreviation: ICC, intraclass correlation coefficient.

*Estimation of number of millimeters that would have to be removed to achieve a symmetric patella.

†Estimation of clock position of thickest point on the perimeter of the patella.

surface strain in the patella because of structural compromise when removal of bone results in a patellar thickness of less than 15 mm. However, a study by Greenfield et al. [12] reported no clinical problems after total knee arthroplasty, despite a residual patellar thickness less than 15 mm.

Conversely, overstuffing the patellofemoral compartment may have detrimental effects on total knee function. Star et al. [11] found significant increases in patellofemoral compression forces at higher knee flexion angles with increased patellar bone and implant thickness differences of as little as 10% over original thickness.

Current recommendations, therefore, generally suggest restoration of the original patellar thickness during resurfacing. This is why the senior author does not attempt a "perfect" cut with the first pass of the saw. Instead, he leaves some bone to be removed with a second cut, which either removes the asymmetric high side or, if the patella is symmetric, planes it down to match the full thickness of the patellar component.

Chan and Gill [17] reported that asymmetric patellar resection has a significant effect on postoperative lateral tilt. According to Dorr and Boiardo [9], an oblique osteotomy placing the patellar component on the lateral facet is a common error. However, Aglietti et al. [18] reported that 34% of their patients had a patellar tilt of at least 10° without a

negative effect or correlation with the need for a lateral release. Several factors play a role in patellar tilt, but because patellar tilt correlates with patellar asymmetry and thickness [3,19], we can use these data to infer the amount of asymmetry that may be acceptable clinically.

The solid foam patellae used in our study measured 45 mm in a medial-to-lateral direction. Thus, a 10° tilt is equivalent to approximately 8 mm of asymmetry ($\text{tangent of } 10^\circ = 0.176 \times 45 \text{ mm} = 7.92 \text{ mm}$). Given that 91.4% of the estimates in our study were within 4 mm of the true value, it would be well within the haptic ability of most orthopedic surgeons to detect an 8-mm difference. However, with a planar cut, every millimeter of patella left above the symmetric cut line will have an equal amount below the symmetric cut on the opposite side. Thus, if the first cut attempts to remove the equivalent of the patellar replacement but results in asymmetry, removing the high side with a second cut can leave an over-resected patella on the low side. Nonetheless, as Aglietti et al. [18] have shown, patients are relatively tolerant of asymmetry, and we are not aware of any data that show that asymmetric cuts of the patellae are a clinical problem in total knee arthroplasty.

Standard methods currently being used to assess symmetry involve the use of a caliper. However, because of soft tissue interposition, these techniques can overestimate patellar thickness [13]. Moreover, calipers measure thickness over a patellar plane but give no indication as to whether that plane is symmetrically oriented. Ultimately, these techniques depend on the surgeon's decision-making ability and surgical aptitude to achieve symmetric resurfacing of the patella. Our study appears to be the first of its kind to evaluate surgical aptitude using a haptic model.

Possibly, orthopedic surgeons are biased toward an underestimation of patellar asymmetry because of their surgical training. There is a conscious, and perhaps unconscious, effort by surgeons to avoid over-resection of the patella. The finding that 73.2% of the responses underestimated the amount of asymmetry, whereas only 16.4% overestimated, suggests that surgeons should also be aware of the potential for underestimation of patellar asymmetry when resurfacing patellae using tactile feedback. These findings are consistent with current haptic models. In a study on the ability of individuals to estimate the angle between 2 surfaces through touch alone, Lakatos and Marks [20] found a consistent underestimation of angular extent, which was inversely related to the size of the angle. The

addition of visual spatial cues did not significantly reduce the magnitude of haptic underestimation.

Symmetric cutting of the patella in total knee arthroplasty might avoid potential problems caused by wear, pain, maltracking, loss of range of motion, and decreased strength. Haptic assessment of symmetry is a simple technique that could avoid excessively asymmetrically cut patellae and potentially enhance the results of total knee arthroplasty. Furthermore, as the application of minimally invasive and arthroscopic techniques continues to rise [5,21], an understanding of haptic feedback will play an increasingly important role in surgical training and in the development of simulators that can accurately reproduce a tactile interface.

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