CLINICAL ARTICLE

Relationship between the Patellar Ridge and the Femoral Trochlea in the Patellar Tracking

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Objective: To investigate the anatomic morphology of the patellar ridge and how it matches the femoral trochlea in patellar tracking.

Method: We selected 40 volunteers, 20 males (age, 28 ± 5 years) and 20 female (age, 27 ± 6 years), who were completely asymptomatic with normal knee structures. We measured the right or left legs of volunteers, and the region from the distal femur to the tibial tuberosity was scanned by computed tomography (CT) with flexion at 0° , 30° , 60° , and 90° . CT data was reconstructed using image analysis software (Mimics). Variables such as the angle between the patellar ridge and patellar long axis, the tibial external rotation angle, as well as the best matching position between the patellar ridge and femoral trochlea at different knee flexion angles were measured. A single experienced orthopedic surgeon performed all the measurements, and the surgeon was blinded to the subject identifying information. We analyzed the differences between the various angles using a one-way analysis of variance. The differences between genders were analyzed using the *t* test.

Results: The intraclass correlation coefficient (ICC) values were greater than 0.81 for all measurements, and the ICC value is almost in perfect agreement. The angle between the patellar ridge and the patellar long axis was $11.13^\circ \pm 4.1^\circ$. The angle in male participants was $10.87^\circ \pm 4.5^\circ$ and it was $12.09^\circ \pm 3.7^\circ$ in female participants. There were significant differences between each angle (0° , 30° , 60° , and 90°). The angles between the patellar ridge and femoral trochlear groove did not greatly increase with the knee flexion. The tibial internal rotation angle also showed a gradually increase at knee flexion of 0° – 60° , and a gradually decrease at 60° – 90° . The best-fit point between the patellar ridge and femoral trochlear groove gradually increased along with the knee flexion. There were no significant differences between male and female participants at all angles ($P < 0.05$).

Conclusion: The anatomic morphology of the patellar ridge allows better matching between the patellar ridge and femoral trochlea during knee flexion, which is an important mechanism for the regulation of patellar tracking.

Key words: Femoral trochlear groove; Knee; Patellar ridge; Patellar tracking; Patellofemoral joint

Introduction

Patellar tracking is critical for knee joint function, and the understanding of which is significant for diagnosing patellar instability and maltracking. Patellar tracking is defined as the motion of the patella relative to the femur or femoral groove during knee flexion and extension. The knee extensor apparatus is a complex system, and its normal functioning requires controlled interplay among joint geometry, muscle tension, and passive soft-tissue restraints. In conjunction with the rise in the number of cases of patellofemoral joint disease, there have been increased studies on patellar

tracking, and numerous investigations have attempted to evaluate the significance of the associated factors using different experimental approaches^{1,2}.

Findings have indicated that patellar tracking is very complex with respect to the femur, because it involves shift, rotation, and tilt, and it depends on various dynamic and static structures around the patella^{3–5}. Previous studies have identified several anatomic parameters involving bone and soft tissue that contribute to patellar tracking. Among the primary parameters that influence patellar tracking, the femoral trochlea and patella are the most important bone

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structures. Understanding the role and significance of the femoral trochlea and patella across the whole range of knee flexion has been a major aim in biomechanical research. Some authors have studied the role of the femoral trochlear groove in patellofemoral joint instability^{6,7}. Senavongse and Amis examined the effects of groove geometry on the stability characteristics of the patellofemoral joint⁵. However, among the various patellofemoral stabilizing factors, the articulating geometry of the patella was not taken into consideration by biomechanical researchers.

In the coronal plane, the patella has a rounded triangular shape, which is concave on its superficial surface. The articular surface of the patella contains a vertical central ridge, which separates the broader lateral facet from the medial facet and a smaller, more medial “odd” facet. Kim *et al.*⁸, Baldwin and House⁹, and Yoo *et al.*¹⁰ investigated the thickness of the patella and location of the patellar ridge on the patella, and they found that the patellar ridge was located 34%–44% laterally from the medial border^{7–10}. However, no study has investigated the patellar ridge or the long axis and tendency of the patella and no report has ever covered the relationship between the patellar ridge and the femoral trochlea in patellar tracking.

Using clinical imaging diagnosis and surgical procedures, the patellar ridge occupies an oblique line from the proximal patella to the distal medial patella. The patellar ridge and femoral trochlear groove did not have a parallel alignment but were aligned at a particular angle. With the change in the flexion angle, the best-fit point between the patellar ridge and femoral trochlea likewise changes. We hypothesized that the anatomic features of the patellar ridge and angle relation with the femoral trochlear groove were important factors in patellar tracking. However, there is a general lack of information on the effects of the patellar ridge on patellar tracking or the relationship to symptoms of patellofemoral disease. Understanding the morphology and dimensions of the patella is clinically significant in designing prostheses and developing surgical techniques, and the relative position of the patellar ridge is an important variable in patellar tracking in the trochlear groove.

The objective of this study was to investigate the importance of the patellar ridge in patellar tracking by means of computed tomography (CT) scans and 3-D reconstruction technology. We aimed to measure the angle of the patellar ridge, determine that angle with different knee positions, and assess the position change of the best-fit point between the patellar ridge and femoral trochlea so as to study the role of anatomic morphology of the patellar ridge in patellar tracking regulation, to arrive at a better understanding of the function of the patellar ridge as well as provide a basis for clinical diagnosis and treatment.

Methods

Inclusion and Exclusion Criteria

The inclusion criteria were as follows: (i) age ranges from 18 to 40 years; (ii) height ranges from 165 to 180 cm; and

(iii) $18.5 \text{ kg/m}^2 < \text{body mass index (BMI)} < 43.3 \text{ kg/m}^2$. The exclusion criteria were as follows: (i) history of knee joint injury; (ii) history of patellar instability; (iii) patellar grinding test and apprehension test positive upon physical examination; and (iv) abnormal knee joint imaging examination.

Participants

The participants signed an informed consent form, and the study was approved by our institutional review board. We recruited 20 male (age, 28 ± 5 years) and 20 female (age, 27 ± 6 years) volunteers who were completely asymptomatic with normal knee structures. One knee of each subject (24 left knees and 16 right knees) was randomly selected and imaged.

Computed Tomography Protocol

We obtained the CT scans by the same technician operating a slice CT scanner (Somatom Sensation 16; Siemens Medical Solutions, Erlangen, Germany) with 100–120 kV, 150 mA, rotation time 1 s, 1.0-mm thickness, and 1.0-mm slice gap. During imaging, the subject lay supine, and a knee joint fixed bracket was used to support the knee at predetermined flexion angles and maintain the forefoot in the vertical position. We undertook the imaging with the quadriceps muscle relaxed and the knee flexed at 0°, 30°, 60°, or 90°. The scanned area was 10 cm from the femoral condyle toward the tibial tubercle. We reconstructed the CT data using image analysis software (Mimics; Materialise NV, Leuven, Belgium). A single experienced orthopedic surgeon (JHN) performed all the measurements, and the surgeon was blinded to the subject identifying information (name, age, and sex).

Parameter Definitions

The stability of the patellofemoral joint is theoretically affected by the patellar ridge and by the femoral trochlear groove and tibiofemoral rotation. We choose to measure several indexes to elaborate the relationship between the patellar ridge and the femoral trochlea, as follows:

Patellar Ridge

The patellar ridge is defined by positioning one point at the proximal end and one point at the distal end of the patellar ridge and then connecting them by means of a straight line (Fig. 1).

Femoral Trochlear Groove

The trochlear anteroposterior (Whiteside) line, a line to the axis of the center of the trochlea, represents the anatomic form of femoral trochlear groove, which connects the deepest point of the trochlear groove to the top of the femoral notch (Fig. 2).

Angle of the Patellar Ridge

The angle of the patellar ridge represents the anatomic features of the patellar ridge, which is defined as the angle

Fig. 1 3-D reconstruction image depicting the patellar ridge, which is defined as positioning points at the proximal and the distal end of the patellar ridge, respectively, and then connecting them in a straight line (line a).

between the patellar ridge and the long axis of the patella (by selecting the proximal and distal poles of the patella and connecting them by a line) (Fig. 3).

Angle between the Patellar Ridge and Femoral Trochlear Groove

The angle between the patellar ridge and femoral trochlear groove is used to elaborate the relationship between the patellar ridge and the femoral trochlear groove, and is

Fig. 2 3-D reconstruction image depicting the anatomic reference for Whiteside's line, which is defined as the femoral trochlear groove line (line b).

defined by using the Patellar ridge (a line connecting one point at the proximal end and another point at distal end of the patellar ridge) and Whiteside's line (a line to the axis of the center of the femoral trochlea) in the same plane (Fig. 4).

Tibial Rotation Angle

The tibial rotation angle is defined as the relative rotational difference between the distal part of the femur and proximal part of the tibia at the knee joint level by measuring the twist angle of each posterior condylar line of the proximal part of the tibia and distal part of the femur¹¹ (Fig. 5).

Measuring Method

Measurement of Tibial Rotation Angle

We selected the axial slice of the distal part of the femur from the level of the deepest point of the trochlea as well as the axial slice of the tibial plateau from the clearly recognized posterior condylar notch of the tibia. The axis of the distal part of the femur was a tangent line connecting the most posterior aspect of the medial femoral condyle and the lateral femoral condyle and tibial plateau. The axis of the proximal part of the tibia was a tangent line connecting the most posterior aspect of the tibial plateau. We measured the femoral rotation angle as the angle between these two axes. A positive angle indicated external rotation of the tibia relative to the femur (Fig. 5).

Fig. 3 3-D reconstruction image depicting the angle of the patellar ridge. The angle (α) is between the patellar ridge (line a) and the long axis of the patella (line b), which is a line connecting the proximal and distal pole of the patella.

Fig. 4 3-D reconstruction image depicting the angle between the patellar ridge and the femoral trochlear groove. The angle (β) between the patellar ridge (a line connecting one point at the proximal end and another point at the distal end of the patellar ridge: line b) and the femoral trochlear groove (Whiteside's line, a line to the axis of the center of the femoral trochlea: line a) in the same plane.

Fig. 5 Computed tomography images depicting the tibial rotation angle. The angle (γ) is defined as the relative rotational difference between the distal part of the femur (line b) and proximal part of the tibia (line a) at the knee joint level by measuring the twist angle of each posterior condylar line of the proximal part of the tibia and distal part of the femur (F, femur; T, tibia).

Measurement of Angle between the Patellar Ridge and Femoral Trochlear Groove

After 3-D reconstruction of the patellofemoral joint, we located the two end points of the patellar ridge and connected them by a straight line, and two end points of the femoral trochlear groove (Whiteside's line) were also located and connected by a straight line; we then measured the angle between them (Fig. 4).

Measurement of Best-fit Point between the Patellar Ridge and Femoral Trochlear Groove

After 3-D reconstruction, we drew the linear track of the patellar ridge and femoral trochlear groove, and we measured the position of the point that was the shortest distance between the two lines (Fig. 6).

Statistical Analysis

We used SPSS version 21.0 (IBM, Armonk, NY, USA) for statistical analysis. All the measured variables and data are expressed as mean $\pm$ SD. A typical interpretation of an intraclass correlation coefficients (ICC) value is as follows: 0.00–0.20 (poor agreement); 0.21–0.40 (fair agreement); 0.41–0.60 (moderate agreement); 0.61–0.80 (substantial agreement); and 0.81–1.00 (almost perfect agreement)¹². We analyzed the differences between the various angles using a one-way analysis of variance. The differences between genders were analyzed with the *t*-test. We considered $P < 0.05$ statistically significant.

Results

Intraclass correlation coefficient values were greater than 0.81 for all measurements. Therefore, the ICC value is almost in perfect agreement (0.89–0.93). The measurement result reliability has been confirmed. The angle of the patellar ridge and the patellar long axis was $11.13^\circ \pm 4.1^\circ$. The angle in male participants was $10.87^\circ \pm 4.5^\circ$, and in women it was $12.09^\circ \pm 3.7^\circ$ (Fig. 7). The χ^2 -test was used for comparison of the means, and the measurement results are shown in Table 1.

Angle of the Patellar Ridge and with the Femoral Trochlear Groove

There was statistically significant difference between each angle. At the knee flexion 0° , the angle between the patellar ridge and the femoral trochlear groove was $22.42^\circ \pm 3.8^\circ$, and the angles were $24.46^\circ \pm 2.8^\circ$, $23.57^\circ \pm 2.5^\circ$, and $25.27^\circ \pm 3.2^\circ$ at 30° , 60° , 90° , respectively. In the process of knee flexion, the angle between the patellar ridge and the femoral trochlear groove gradually increased between the knee flexion of 0° – 30° and 60° – 90° , but it is decreased between 30° and 60° ($P < 0.05$). The most obvious numerical change occurred at the knee flexion of 0° – 30° , and the average angle was 2° .

The angles in male participants were $21.31^\circ \pm 2.5^\circ$, $24.27^\circ \pm 1.7^\circ$, $23.32^\circ \pm 2.7^\circ$, and $24.67^\circ \pm 2.6^\circ$, and in females these values were $22.72^\circ \pm 3.1^\circ$, $25.21^\circ \pm 3.1^\circ$,

Fig. 6 3-D reconstruction image depicting the best-fit point between the patellar ridge and femoral trochlear groove. We drew the linear track of the patellar ridge (line a) and femoral trochlear groove (line b), and we measured the position of the point that was the shortest distance (red line) between the two lines.

$24.17^\circ \pm 2.6^\circ$, and $25.48^\circ \pm 2.3^\circ$, at the knee flexions of 0° , 30° , 60° and 90° . Their changed trend was the same as the overall trend. There were no significant differences between men and women at all angles ($P < 0.05$) (Fig. 8).

Tibial Internal Rotation Angle

Between 0° and 60° , the tibial internal rotation angle also showed a gradual, though conspicuous, increase. The most obvious change occurred between 0° and 30° , from $10.50^\circ \pm 3.2^\circ$ to $15.59^\circ \pm 4.2^\circ$, and the average angle was 5.09° ($P < 0.05$). However, a gradually decrease occurred at the knee

Fig. 7 Bar chart illustrates the long axis angle of the patellar ridge and the patella at knee joint flexion from 0° to 90° .

flexions of 60° – 90° , and the angles were from $18.24^\circ \pm 2.7^\circ$ to $16.30^\circ \pm 3.6^\circ$ ($P < 0.05$).

The angles in male participants were $10.30^\circ \pm 2.5^\circ$, $14.68^\circ \pm 1.7^\circ$, $18.66^\circ \pm 2.1^\circ$, and $16.01^\circ \pm 1.5^\circ$, and in female participants these values were $11.29^\circ \pm 1.6^\circ$, $15.62^\circ \pm 2.7^\circ$, $17.73^\circ \pm 2.1^\circ$ and $16.72^\circ \pm 2.3^\circ$, at the knee flexions of 0° , 30° , 60° and 90° . Their changed trend was the same as the overall trend. There were no significant differences between men and women at all angles ($P < 0.05$) (Fig. 9).

The Best-fit Point between the Patellar Ridge and Femoral Trochlear Groove

The best-fit point between the patellar ridge and the femoral trochlear groove gradually decreased along with the knee flexion ($P < 0.05$). The points were $90.08\% \pm 4.5\%$, $61.58\% \pm 3.6\%$, $40.45\% \pm 5.4\%$, and $24.90\% \pm 6.7\%$ at the knee flexions of 0° , 30° , 60° , and 90° , respectively.

The points in male participants were $88.47\% \pm 3.5\%$ to $23.62\% \pm 3.7\%$, and in female participants they were $91.58\% \pm 3.7\%$ to $25.15\% \pm 5.1\%$ between the knee flexion 0° – 90° . The points gradually decreased along with the knee flexion. There were no significant differences between male and female participants at all angles ($P < 0.05$) (Fig. 10).

Discussion

Patellar tracking, involving shift, rotation, and tilt, is a very complicated motion, and complex interplay of components contributes to its biomechanical characteristics^{3,4}. Among other factors, the statics and dynamics of this articulation involve the geometries of the patella and femoral trochlea, the passive soft-tissue restraints of the capsule and retinaculum, and coordination of the quadriceps. Although these changes would have affected the results of the present study, we did not study all these factors.

Patellar geometric characteristics play an important role in patellar tracking and its matching to the femur. Using sagittal and axial magnetic resonance images, Yoo *et al.*¹⁰ confirmed that the central ridge was located 19.9 mm (or 43%) lateral from the medial border¹⁰. Some authors have considered that the patellar ridge can act as a fulcrum for patellofemoral tracking, thereby influencing normal kinematics⁸. Using cadavers, Gaurav *et al.* assessed the position of the patellar ridge from the proportion of the medial facet width within the whole width¹³. They determined the patellar lateral and medial facet width ratio to be 1:3; the patella ridge was located in the medial facet. Several authors have reported the location of the patellar ridge: it was located 34%–44% lateral from the medial border^{8–10}. We found the patellar ridge to be an oblique line from the proximal to the distal medial patella, located in the medial patellar facet. This special structure is essential in maintaining patellofemoral stability.

Numerous studies have attempted to evaluate patellar tracking using various approaches^{14–17}. We examined the patellar joint using CT and 3-D reconstruction. At low flexion angles, our observations on patellar displacement are

TABLE 1 The measurement results at knee joint flexion from 0° to 90° (mean ± SD)

Index	Angle of knee joint flexion (°)				Statistic value		
	0	30	60	90	F	P	ICC
Long axis angle of the patellar ridge and the patella (°)	11.1 ± 4.1	11.1 ± 4.1	11.1 ± 4.1	11.1 ± 4.1	—	—	0.93
Angle between the patellar ridge and the femoral trochlear (°)	22.4 ± 3.8*	24.5 ± 2.8*	23.6 ± 2.5*	25.3 ± 3.2*	168.52	0.000	0.91
Tibial rotation angle (°)	10.5 ± 3.2*	15.6 ± 4.2*	18.2 ± 2.7*	16.3 ± 3.6*	257.24	0.000	0.90
The best fit point of the patellar ridge and the femoral trochlear (%)	90.1 ± 4.5*	61.6 ± 3.6*	40.5 ± 5.4*	24.9 ± 6.7*	307.45	0.000	0.89

*, differences with other groups, $P < 0.05$; ICC, intraclass correlation coefficients.

Fig. 8 Bar chart illustrates the angle between the patellar ridge and the femoral trochlea at knee joint flexion from 0° to 90°.

Fig. 9 Bar chart illustrates the tibial rotation angle at knee joint flexion from 0° to 90°.

consistent with those in the literature¹⁸. However, tibial internal rotation may also affect patellar tracking. Because with knee flexion, the tibia rotates internally, the tibial tubercle, to which the patellar tendon is attached, will be displaced medially¹⁹. This will pull the patella in a medial direction. When the patella is properly seated in the trochlear groove, however, tibial rotation will have reduced influence on its traction (medial translation)²⁰. The result of patellar tracking

Fig. 10 Bar chart illustrates the best fit point of the patellar ridge and the femoral trochlea at knee joint flexion from 0° to 90°.

in another study indicated that with the femur as reference, the largest change in patellar traction occurred during knee joint flexion of 0°–30°¹⁶. In the present study, we found that the tibial internal rotation angle increased gradually in the process of knee flexion at 0°–60°. From 0° to 30°, the angle varied most significantly. This finding is in accordance with that of other investigations¹⁶.

The literature indicates that the patella flexes with the knee, but at a lower magnitude. One study found that when the knee was maximally flexed (90°), the patella flexed only to approximately 66.1°¹⁷. This tendency has also been reported in other investigations for different knee motions using various measuring methods²¹. Some studies have suggested that the contact area of the patella and femoral trochlea increases gradually during flexion^{22,23}. This indicates that during knee flexion, the patella is better at matching the femoral trochlear groove. Our results confirmed this conclusion. The present study determined that the best-fit point of the patellar ridge and femoral trochlear groove changed from 90.08% ± 4.5% to 24.90% ± 6.7% in knee flexion at 0°–90°. The results of our study confirm that the best-fit point of the patellar ridge and femoral trochlear groove moves to the proximal side of the patella.

In the present study, we investigated the anatomic characteristics of the patellar ridge and its matching relationship with the femoral trochlear groove. Our results indicate that patellar tracking was affected by patellar articular geometry. In the process of patellar movement, all measurements obviously change; however, the angles between the patellar ridge and the femoral trochlear groove did not greatly increase. This phenomenon demonstrates that as a special convex structure to match the femoral trochlear groove, the patellar ridge must have great significance. Thus, our study on the anatomic morphology of the patellar ridge and the matching relationship between the patellar ridge and femoral trochlear groove underlines the important role of regulatory patellar tracking. We found the angle between the patellar ridge and femoral trochlear groove to be $22.42^\circ \pm 3.8^\circ$ to $25.27^\circ \pm 3.2^\circ$ at knee flexions of 0° – 90° . In the patellar tracking, irrespective of patellar motion, a small change remains for the angles between the patellar ridge and the femoral trochlear groove.

It is in the knee flexion range of 0° to 30° that patellar maltracking is most prevalent since the patella is then least stable²⁴. The general consensus is that the patella translates medially as the knee flexes 20° to engage the trochlear groove³. The stability of the patellofemoral joint is achieved through a complex interaction of a range of factors during knee joint flexion of 0° – 30° . However, we maintain that the anatomic morphology of the patellar ridge is of greater importance in knee joint flexion, especially at 0° – 30° . In other words, patellar instability has a direct relationship with

the patellar ridge being unable to match the femoral trochlear groove. The present study demonstrates that the patellar ridge is an oblique line from the proximal patella to the distal medial patella and that the angle between the patellar ridge and patellar long axis is $11.13^\circ \pm 4.1^\circ$. The anatomic morphology of the patellar ridge allows the patella to engage with the trochlear groove. If the patellar ridge and femoral trochlear groove had a parallel relationship, that would impede the engagement of the patella into the trochlear groove. Thus, when treating patellar instability, as well as restoring the anatomic morphology of the femoral trochlear groove and soft tissue balance, it is necessary to restore the normal shape of the patellar ridge.

The present study has some limitations. We did not specifically investigate the kinematic distribution among the participants because their number was small. In addition, we measured patellar tracking only during knee flexion, which is not a dynamic motion. Despite these limitations, our study provides quantitative measures of the patellar ridge during flexion of the knee in living subjects. Our prime finding is that the patellar ridge is located in the medial patellar facet in an oblique line. The anatomic morphology of the patellar ridge is essential in maintaining patellofemoral stability.

Conclusion

The anatomic morphology of the patellar ridge allows better matching of the patella and femoral trochlear groove in knee joint movement, and has great significance in patellofemoral instability.

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