Increasing posterior condyle cut for high-flex knee prosthesis may injure popliteus tendon origin: A comparison between real clinical setting and cadaveric study

Rit Apinyankul^a, Surachai Sae-Jung^a, Ong-art Phruetthiphat^{b,*}

^a Department of Orthopaedics, Faculty of Medicine, Khon Kaen University, Khon Kaen, Thailand

^b Orthopaedics Department, Phramongkutklao Hospital, Bangkok, Thailand

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ABSTRACT

Background: High-flex total knee prosthesis designs were proposed to improve flexion in total knee replacement (TKA). One of high-flex features is increasing posterior condyle cut which put popliteal tendon in higher risk of injury and may result in gap changes.

Methods: Prevalence of popliteus footprint injuries were compared between conventional and high-flex TKA in real clinical setting. Thirty-six popliteal origin sites from eighteen fresh cadavers were measured distances between the posterior rim of popliteal tendon origin and posterior border of the lateral femoral condyle (distance A) using digital “Vernier caliper”. The mean distances were compared to posterior condyle thickness of different prosthesis designs.

Results: The prevalence of posterior popliteus footprint injury was significantly higher in high-flex TKA compared to the conventional design TKA (17.8% vs 3.5%, $p = 0.005$). The mean of distance A on the right knee was 9.59 mm (6.03–12.70) while the mean of distance A on the left knee was 9.13 mm (5.80–11.07). Posterior condyle thickness of the femoral prostheses varies upon their design and size from 7.4 to 10 mm for conventional model and from 8.2 to 12.5 mm for high-flex design. Possibilities of popliteal tendon injury during posterior condyle bone cut was at least 16.7% for conventional model and 27.8% for the high-flex design.

Conclusion: High-flex TKA prosthesis with thicker posterior condyle relates to higher possibility of popliteal tendon origin injury compared to standard one.

1. Introduction

Total knee arthroplasty (TKA) surgery becomes standard treatment for advance-staged knee osteoarthritis for many decades. However, most of conventional design total knee prosthesis provide knee flexion not more than 115 degrees.¹ High-flex knee prosthesis design was proposed to improve knee flexion and provide a range of motion more than the conventional one by changing several features: reduced posterior femoral condylar radii with thickened posterior femoral condyles, reshaping the posterior contour of polyethylene liner and more posterior condyle bone cut to reduce impingement during deep flexion.

Popliteal tendon provides both static and dynamic stabilities in the normal knee.^{2–4} Previous studies have demonstrated gap changes in Posterior sacrifice (PS)TKA cadaveric surgery with popliteal tendon rupture⁵ and the popliteal tendon resection resulted in destabilizing of lateral and medial aspects of the knee.⁶ Additionally, we observed some

of popliteal tendon injuries during posterior condyle cutting step of high-flex TKA surgery (Fig. 1). To our knowledge, no study revealed relationships between popliteal tendon injury and posterior condyle cutting. The purpose of our study was to investigate the posterior femoral condyle to find out the risk of popliteal tendon injury associated with high-flex and standard model TKA.

2. Materials and methods

The study protocol was reviewed by the institute's Ethics Committee for Human Research, and deemed exempt from the institutional review board oversight because the study met the criteria of the Exemption Determination Regulations (research involving the collection of study of bone, the body of persons who donate to the hospital and subjects cannot be identified directly or through identifiers linked to the subjects).

* Corresponding author. Orthopaedics Department, Phramongkutklao Hospital, Bangkok, 10400, Thailand.

E-mail address: ongart-phr1@hotmail.com (O.-a. Phruetthiphat).

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Fig. 1. Popliteal tendon injury (yellow arrow) during knee flexion after posterior condylar bone cut in high-flex prosthesis design.

The study was classified into 2 phases: Phase 1 (A comparison of the prevalence of posterior popliteus footprint injury between Conventional and High-flex design TKAs in real clinical setting) and phase 2 (A cadaveric study to investigate anatomy of posterior femoral condyle and posterior popliteus footprint to find out the risk of popliteal tendon injury associated with high-flex and conventional model TKA).

2.1. Phase 1 (Clinical study)

132 patients with severe tricompartmental osteoarthritic knee underwent Total knee arthroplasty (TKA) between January 2016 until December 2018. Patients were classified into 2 groups: 87 patients underwent conventional design TKAs while 45 patients performed high-flex design TKAs.

2.2. Phase 2 (Cadaveric study)

The study was designed as cadaveric research to determine and measure popliteal tendon origin footprints accurately. Eighteen fresh cadavers were dissected to reveal thirty-six popliteal tendon origin sites and posterior border of the lateral femoral condyle. The distance between the posterior rim of popliteal tendon origin and posterior border

of the lateral femoral condyle was measured using a digital “Vernier caliper” (Distance A, Fig. 2). The distance A was measured three times and the average of them were calculated.

2.3. Data analysis

The data was collected and calculated using mean and standard deviation values including minimum and maximum to analyze data of distance A.

3. Results

Phase 1 study demonstrated that there was no difference in patient's demographics except age (65.3 vs 63.1 years old, $p < 0.001$) and the prevalence of posterior popliteus footprint between groups (3.5% vs 17.8%, $p = 0.005$) as shown in Table 1. The conventional group had 3 cases of popliteus footprint injury while the high-flex group had 8 patients with popliteus footprint injury.

Phase 2 study revealed a mean of distance A 9.38 mm (SD 1.68 mm). Details for each cadaver was shown in Table 2. The mean of distance A on the right knee was 9.59 1.66 mm (6.03–12.70) while the mean of distance A on the left knee was 9.13 1.78 mm (5.80–11.07).

Fig. 2. The Footprint of Popliteal Tendon (Yellow arrow).

A is the distance between the posterior rim of popliteal tendon origin and posterior border of the lateral femoral condyle. LCL is lateral collateral ligament, and POP is popliteal tendon.

Table 1

Demographics and popliteus tendon injury in Conventional and High-flex TKA groups.

Parameters	Conventional group (n = 87)	High-flex group (n = 45)	p-value
Age	65.3 ± 2.8 (60–71)	63.1 ± 3.6 (57–69)	< 0.001
Gender			0.571
Female	64 (73.56)	31 (68.89)	
Male	23 (26.44)	14 (31.11)	
Body weight (kg)	65.1 ± 10.4	64.5 ± 14.2	0.783
Height (cm)	158.4 ± 6.5	156.6 ± 8.1	0.169
BMI (kg/m ²)	26.8 ± 4.2	26.2 ± 5.5	0.486
Popliteus tendon injury (posterior footprint)	3 (3.45%) All were asymptomatic	8 (17.78%) Four cases were asymptomatic The rests had mild pain or tightness during knee extension and all were completely healed in 3 months	0.005

Table 2

The measurement of distance between the posterior rim of popliteal tendon origin and posterior border of the lateral femoral condyle.

Cadaver	Gender	A _R (mm)	A _L (mm)
1	Male	10.57	9.70
2	Male	11.27	10.73
3	Male	10.73	10.43
4	Male	9.90	10.47
5	Male	9.60	11.07
6	Male	10.33	9.47
7	Male	10.80	10.13
8	Male	10.27	10.17
9	Male	10.47	9.43
10	Male	6.73	6.37
11	Female	8.17	6.30
12	Male	10.07	10.70
13	Male	6.03	5.80
14	Male	12.70	7.70
15	Male	7.73	7.30
16	Male	9.97	11.07
17	Male	8.20	7.63
18	Male	9.03	9.93

Distance A is the distance between the posterior rim of popliteal tendon origin and posterior border of the lateral femoral condyle. A_R and A_L are the distance A of right and left knee, respectively. Average A_R was 9.59 ± 1.66 mm (6.03–12.70) and Average A_L was 9.13 ± 1.78 mm (5.80–11.07). The average of all cadavers was 9.36 ± 1.71 mm (5.80–12.70).

The possibility of popliteus injury when using a standard prosthesis and a high flex prosthesis were demonstrated in Table 3 and Table 4, respectively. The posterior condyle thickness of the femoral prostheses varies upon their design and size from 7.4 to 10 mm for standard model and from 8.2 to 12.5 mm for high-flex design. If the patient's distance of A is shorter than the posterior condyle thickness, there will be a risk for popliteus origin injury during posterior condyle cut. As a result, the possibilities of popliteal tendon injury during posterior condyle bone cut was 16.7%–66.7% for standard model and between 27.8% and 97.2% for the high-flex design.

The possibly popliteal injury was variable depending on the thickness of posterior condyle of each prosthesis and the distance between posterior rim of popliteal tendon origin and posterior border of the lateral femoral condyle as shown in Tables 3 and 4.

4. Discussion

Popliteal tendon provides both static and dynamic stabilities in the

Table 3

Comparison of posterior condyle thickness of prosthetic design (Conventional model), distance A and possibility of popliteal tendon injury.

Prosthetic Design	Thickness of posterior condyle (millimeters)	The average thickness of distance A (Cadavers)	Possibly popliteal tendon injury in clinical practice
Anthem PS and CR	9.5	9.36 ± 1.71 mm (5.8–12.7 mm)	38.9%
Legion PS, CR and CK	9.5		38.9%
Journey II PS design	7.4 (posterior lateral)		16.7%
Sigma PS	7.6 to 8.5		16.7%–30.6%
Attune PS and CR	9.0		30.6%
Nexgen PS	10.4		66.7%
Persona PS	9 to 10		30.6%–52.8%
CR	8 to 9		25.0%–30.6%
Triathlon PS and CR	8.5		30.6%
Vanguard PS and CR	9		30.6%
Columbus PS	8		25.0%
Vega PS	10		52.8%

normal knee.^{2–4} Previous studies demonstrated gap changes in PS-TKA cadaveric surgery with popliteal tendon rupture.⁵ Additionally, popliteal tendon resection resulted in destabilizing of lateral and medial aspects of the knee.⁶ During posterior condyle cutting step of high-flex TKA, we observed some of popliteal tendon injuries during high-flex TKA surgery. To our knowledge, no study revealed relationships between popliteal tendon injury and posterior condyle cutting. The purpose of our study was to investigate the posterior femoral condyle to find out the risk of popliteal tendon injury associated with high-flex TKA.

Our clinical study demonstrated that the prevalence of posterior popliteus footprint injury was significantly higher in high-flex TKA compared to the conventional design TKA (17.8% vs 3.5%, $p = 0.005$). In addition, phase 2 study showed that an average of distance of A was 9.38 ± 1.68 mm (range 5.80–12.70 mm) and they represent safe zone for posterior condyle cut without popliteus origin injury (Table 2). The average distance A on the right side was larger than the left side (9.59 vs 9.13 mm). It is possible that the injury to popliteal tendon when performing a standard designed or high flex designed TKA may be higher rate on left knee than right knee.

The results showed possibilities of popliteus injury when using a conventional prosthesis (Table 3) and a high flex prosthesis (Table 4). The posterior condyle thickness of the femoral prostheses varies upon their design and size from 7.4 to 10 mm for standard model and from 8.2 to 12.5 mm for high-flex design. Our result demonstrated that the possibilities of popliteal tendon injury during posterior condyle bone cut was 16.7% to 66.7% for standard model and between 27.8% to 97.2% for the high-flex design. A result from cadaveric study defined that the least possibility of popliteus footprint injury was 16.7% for conventional TKA and 27.8% for high flex design TKA, even though this prevalence was relatively high compared to posterior popliteus footprint injury from clinical study (3.5% and 17.8%, respectively). This may be caused by unawareness of popliteus injury during femoral bone

Table 4

Comparison of posterior condyle thickness of prosthetic design (High-flex model), distance A and possibility of popliteal tendon injury.

Prosthetic Design	Thickness of posterior condyle (millimeters)	The average thickness of distance A (Cadavers)	Possibly popliteal tendon injury in clinical practice
Anthem		9.36 ± 1.71 mm (5.8–12.7 mm)	
PS and CR	11.5		97.2%
Legion			
PS, CR and CK	9.4 (posterior lateral)		33.4%
Sigma			
RP-F	8.2 to 12.5		27.8%–97.2%
Nexgen			
PS (High flex)	12.5		97.2%

cut in real clinical setting. The information from this study is useful for counseling purpose for patients and their families who undergo TKA, especially with high-flex design. The authors believe that patient-specific or custom-designed prosthesis may help in reduction of popliteus footprint injury especially in Asian population who have smaller bodies and femoral condyles. This preliminary study would be useful for comparison to Western population in the future. The authors believe that the prevalence of popliteus footprint injury in the Western population should be lower than Asian people because the Western patients had the larger body and femoral condyle resulting in longer distance between posterior footprint and posterior condyle. Even though CT scan may help to measure a distance more accurate in some circumstances, it does not include the thickness of cartilage of posterior condyle that might be presented in real situations. In addition, popliteus footprint is difficult to be identified by CT scan. Finally, the authors need the further investigation assessed by metal artifact reduction sequence-Magnetic Resonance Imaging (MARS-MRI) for evaluate the correlation of popliteal injury, clinical outcome and their recovery.

Study limitation: A cadaveric study came from Thai people may represent only for Asian population who has smaller bone and smaller popliteal tendon. This may imply that the distance A may be shorter than another population (Caucasian, Hispanic, etc). Therefore, the possible rate of popliteal tendon injury when perform high-flex design TKA may be lower in Non-Asian population compared to Asian population.

5. Conclusion

Thai patients representing an Asian population are variable in popliteal tendon origin footprints and have a chance of its origin site injury during high-flex TKA surgery. The thicker posterior condylar prosthesis, the higher chance of popliteal origin site injury. Additionally, High-flex TKA prosthesis with thicker posterior condyle relates to higher possibility of popliteal tendon origin injury compared to standard one.

Author contributions

All authors designed the protocol. Rit Apinyankul collected the data. Surachai Sae-Jung and Ong-art Phruetthiphat supervised the study and analyzed the data. All authors participated in the manuscript

preparation.

Disclosure

This is original work from the Department of Orthopaedics, Faculty of Medicine, Khon Kaen University, Thailand. It has not been presented elsewhere nor is it under consideration by another journal. The authors participated in the design, execution, analysis and writing up of the research.

Declaration of competing interest

The authors have no competing interests. No funds were received in support of this study. The manuscript submitted does not contain information about medical device(s)/drug(s). No benefit(s) in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

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