Predictive Formula for the Length of Tibial Tunnel in Anterior Crucitate Ligament Reconstruction

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Background: *The anterior cruciate ligament (ACL) reconstruction using bone-patellar tendon bone graft is a common procedure in orthopedics. One challenging problem found is a graft-tunnel mismatch. Previous studies have reported the mathematic formula to predict the tibial angle length and angle to avoid graft-tunnel mismatch but these formulas have shown limited predictability.*
Objective: *To propose a predictive formula for the length of tibial tunnel and to examine its predictability.*
Material and Method: *Thirty six patients (26 males, 14females) with ACL injury were included in this study. The preoperativemedial proximal tibial angle was measured. Intraoperatively, the tibial tunnel length and tibial entry point were measured. The postoperative coronal and saggital angle of tibial tunnel were measured from knee radiograph. The data were analysed by using trigonometry correlation and formulate the predictive formula of tibial tunnel length.*
Results: *we found that tibial tunnel length (T) has trigonometric correlation between the location of tibial tunnel entry point (w), coronal angle of tibial tunnel (b), saggital angle of tibial tunnel (a) and the medial proximal tibial slope (c) by using this formula T = Wcos(c)tan(b)/sin(a)*
Conclusion: *This proposed predictive formula can well predict the length of the tibial tunnel at preoperative period to avoid graft-tunnel mismatch.*

Keywords: *ACL reconstruction, New formula, Angle, Length, Tibial tunnel*

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One common hurdle encountered during the reconstruction of endoscopic anterior cruciate ligament is the graft-tunnel mismatch which is the mismatch of the length of the bone-patellar tendon-bone graft and the length of the tibial tunnel[1]. There are varied methods to minimize the consequences of this graft-tunnel mismatch including the recession of the femoral tunnel, free bone block transfer, bone block flip, and graft rotation up to 62° degrees[2-4]. Furthermore, previous studies have shown many mathematic formulas to predict the length of the tibial tunel with an aim to avoid the graft-tunnel mismatch[5-9]. However, these formulas still have limited predictability.

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If the length of the tibial tunnel can be precisely predicted, then the determination of the choice of graft and fixation device at preoperative planning can be effectively done. To date, there is no formula which can predict the length of the tibial tunnel preoperatively. This study is aimed to present a formula to predict the length of tibial tunnel and examine its predictability.

Material and Method

Data were collected prospectively in a case series of 36 patients consisting of 22 males and 14 female with acute or chronic anterior cruciate ligament injury. They were admitted to the department of orthopaedics, Faculty of Medicine,Thammasat university during March 2005 and December 2006. The physical examinations of each patient were analyzed on date of admission by using Lachman

test, anterior drawer test and pivot shift test. The proximal tibial flaring angle and tibial entry point were clinically measured by using goniometer (Fig. 1). After the operation, the plain radiography of the involved knee was taken in true AP and true lateral view in full extension with measurement scale on the film. The coronal angle (b) was measured in anteroposterior view (AP view) and the saggital angle (a) was measured in true lateral as shown in Fig. 2.

Coronal angle of tibial tunnel measurement

An AP view was obtained postoperatively to measure the angle of the tibial tunnel in the coronal plane. The angle of the tibial tunnel in the coronal plane was measured as the angle subtended by the axis of the tibial tunnel and a line drawn parallel to the medial articular surface of the tibia. Howell SM et al found that the surgeons do not drill the tibial tunnel at the same angle in the coronal plane[10]. The average angle of the tibial angle varied 11 degree (69-80 degrees) between surgeons, indicating that the angle of tibial tunnel was not drilled accurately. He concluded that loss of flexion and anterior laxity were greater when the angle of the tibial tunnel was drilled at 75 degrees or more in the coronal plane and gave recommendation to drill the tibial between 65-70 degrees in the coronal plane.

Sagittal angle of tibial tunnel

Patients were positioned in supine on the x-ray table. Their heels were placed on a foam bolster so that the popliteal fossa was suspended 10 cm above the table. Patients were instructed to relax the leg and allow gravity to maximally extend the knee. Roentgenograms were repeated until the lateral projection of the medial and lateral condyles were superimposed. Measurements were made from films in which the offset of the medial and lateral condyle was 6 mm or less as recommended by Howell SM et al[10]. A lateral radiograph of the knee in maximum extension was obtained preoperatively to measure the angle of the tibial tunnel in saggital plane parallel and the sagittal intercondylar roof (Blumensat line), as shown in Fig. 3. To avoid the roof impingement, we placed the tunnel in a position that was posterior to a line tangent to the roof of the notch with the knee in full extension. The angle of the tibial tunnel in the sagittal plane was measured as the angle subtended by the axis of the tibial tunnel and a parallel line to the tibial plateau of the tibia.

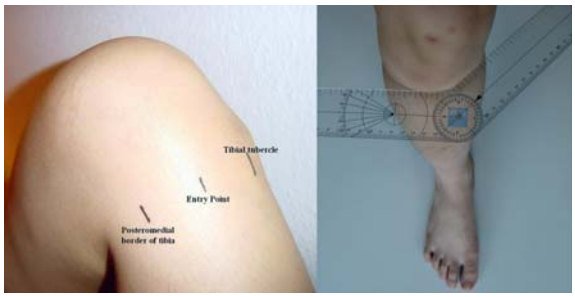

Fig. 1 (Left) the entry point of the tibial tunnel as in the middle between the medial border of tibial tubercle and posteromedial border of the tibia, (Right) the medial proximal tibial slope

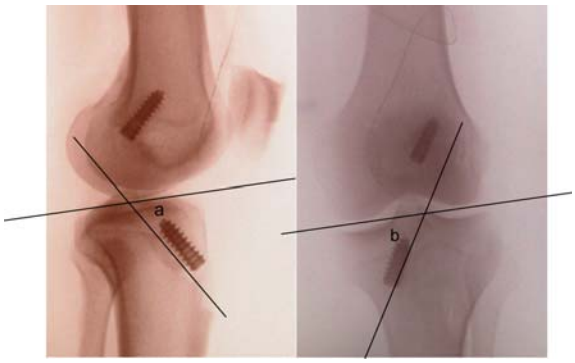

Fig. 2 Saggital angle (a) and coronoal angle (b) of the postoperative radiographs

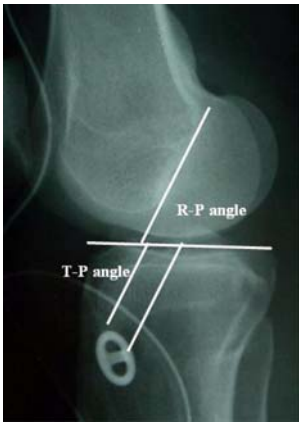

Fig. 3 The joint line was defined the most superior points of the anterior (A) and posterior (P) margins of the tibia. The sagittal roof-plateau angle (R-P) was drawn and measured. A 9 mm wide tibial tunnel was drawn with the anterior border of the tibial tunnel in the line with the slope of the sagittal intercondylar roof

Tibial entry point

Theoretically, the tibial tunnels begin at 1 cm above the superior (sartorial) border of the pes anserine insertion and 1.5 cm posteromedial to the medial margin of the tibial tubercle on the antermedial tibial cortex. The extra-articular entrance to the tibial tunnel is positioned midway anterior-to-posterior along the medial (subcutaneous) surface of the tibia as figure (Olszewski AD 1998, chaba).

Length of tibial tunnel

Arthroscopic examination of the knee was performed in the usual fashion and the associated intra-articular pathology was addressed in appropriate manner. The diagnosis of a significant ACL tear was confirmed. The torn ACL stump was debrided. ACL reconstruction using middle-third patella tendon autografts and endoscopic fixation were performed. The surgical procedure consisted of graft harvesting using double transverse incision technique to avoid injury of the infrapatella branch of saphenous nerve. Graft preparation involved the sizing the bone blocks to 8-9 mm in diameter. Drill holes were then placed in the bone blocks. Sutures with Ethibond no. 2 were passed through both of the femoral bone plug and tibial bone plug. The total graft length (TGL), patella tendon length (PTL), femoral bone block length (FBBL) and tibial bone block length (TBBL) were measured.

The tibial tunnel was measured in saggital plane and in coronal plane, as shown in Fig. 4. The guide was placed in the posterior medial footprint of the ACL, 7 mm in front of the crossing posterior cruciate ligament (PCL), adjacent to the slope of the medial tibial spine, and along a line extending from the posterior aspect of the anterior horn of a lateral meniscus (Jackson et al 1994, Kenna et al 1993, Miller et al 1996, Morgan et al 1995).

The length of the tibial tunnel center axis was measured twice. Firstly, the distance from the medial tibial cortex which was adequately subperiosteally exposured, to the entry point in the ACL foot print was measured by using the tibial tunnel drill guide calibrated guide pin canula. Secondly, the length of tibial tunnel was measured by direct measurement of the calibrated guide pin. The length from the tibial tubercle to the tibial entry point was also measured. The center of the femoral tunnel was positioned at 10.30 (right knee) or 01.30 (left knee) exactly 6-7 mm anterior to the over- the-top position.

Development of predictive formula

The mathematical formula was developed based on triangular prism shape of the proximal tibia. Using the simple trigonometry we produce a simple formula as shown in Fig. 5. We developed this formula based on the established correlations of the following variables: sagittal tibial angle, coronal tibial angle, location of the entry point, shape of the proximal tibia.

Tibial tunnel legth (T) = W cos (c) tan (b)/sin(a)

H/W1 = tan b
H = W1 tan (b) 1
W1/w2 = cosα
W1 = w2 cos (c)

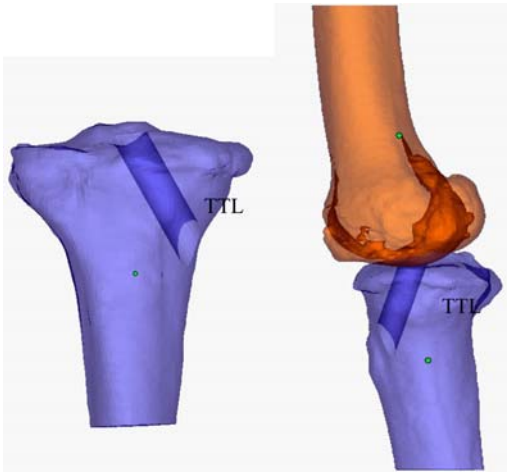

Fig. 4 Direction and the length of the tibial tunnel (TTL)

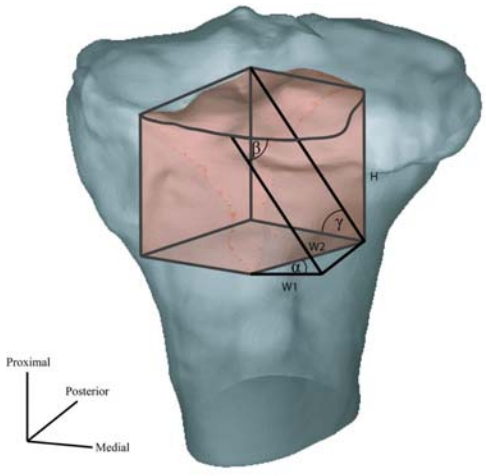

Fig. 5 Triangular prism of the proximal tibia

Substitute W1 in the formula 1

H = w2 Cos (c) tan (b) 2

H/T = sin (a)

T = H/sin (a)

Substitute H with w2 Cos (c) tan (b) from the formula 2

T = w2 Cos (c) tan (b)/sin (a)

Where

T = Tibial Tunnel length (TTL)

H = Height from the joint line to the tibial tunnel entrance

W2 = Width from the center of tibial tubercle to tibial tunnel entrance

c = Medial tibial Slope

b = Coronal angle of the tibial tunnel

a = Sagittal tibial tunnel-plateau angle (T-P) = Sagittal roof-plateau angle (R-P)

For example, if the width from the tibial tubercle to the entry point was 20 mm, the slope of proximal tibia was 45 degrees, the coronal angle of tibial tunnel was 70 degrees, and the saggital angle of tibial tunnel was 55 degrees, then the 47.5 mm must be taken into account for the tibial tunnel length according to the following calculation results of this formula = 20 cos 45 tan 70/sin 55 = 20 x 0.71 x 2.74/0.819 = 47.5 mm.

Statistical analysis

Descriptive statistics (mean and standard deviation) were used for the patients' characteristics. T-test was used to determine if the mean of predicted TTL and actual TTL was significantly different at significant level of p-value < 0.05. The accuracy is calculated with 5 mm error acceptable.

Results

Of the 36 patients in the study population, 14 were female and 22 were male. The average age of the study group was 36 years (range 15-60). The average IAL from tibial origin to femoral ACL insertion measured 23.3 $\pm$ 1.6 mm (range 20-28). The average proximal tibial angle (c) Coronal angle of the tibial tunnel (b) and Sagittal angle of tibial tunnel (a) were 45.2 $\pm$ 2.4 degrees (range 41-50), 67.5 $\pm$ 2.9 degrees (range 61-72) and 68.3 $\pm$ 4.5 degrees (range 55-74) respectively. The average calculated tibial tunnel length (TTL) was 46.83 $\pm$ 4.9 mm (range 40-55) and the true tibial tunnel length was 46.89 $\pm$ 4.4 mm (range 36.5-57.5). Establishment of the calculated tibial tunnel length was achieved in 31 cases (86%) (no graft-tunnel mismatch). Graft-tunnel mismatch, in which the tibial tunnel could not be established to the length calculated necessary to accommodate a minimum of 15 mm of bone graft, occurred in five cases (14%). Graft-tunnel mismatch occurred more frequently in patients whose patellar lengths were > or = 50 mm ($p < 0.005$), but was not found to correlate specifically to IAL.

Discussion

One of the common problems in the reconstruction of anterior cruciate ligament with bone-patella tendon-bone graft is the graft tunnel length mismatch. This problem occurs because the tibial tunnel length was unknown at preoperative period until we measured it intraoperatively. Various measurement techniques and mathematical formulas have been proposed to assist in avoiding this problem. There are several methods published in the recent literature showing the formula to predict tibial tunnel length and angle of tibial tunnel. One of the most popular methods of determining the appropriate tunnel angle is the "N+7 rule"[9]. The length of the tendinous portion of the graft is measured in millimeter and 7 is simply added. This resulted in the tunnel angle in the sagittal plane. This rule created acceptable tunnel in 89% of the specimens. This method is based on the clinical observation that the patellar tendon length is directly proportional to the size of the proximal tibia. However, there are some variability in this relationship because of the shape of the proximal tibia, possibility of patella baja and alta and difference of coronal angle. Base on this study, this variability resulted in an error rate of 11%. Pagnano et al. reported the difficulty with the "N+7 rule" in endoscopic ACL reconstruction[9]. They reported a 50% success rate using this method. He also found that the application of the "N+7 rule" to an individual surgeon's practice may be altered by l varied operative technique.

The "graft-50" method considered the length of the entire graft and subtracts the length of the femoral bone plug and the length of the ACL[6,7]. This method resulted in acceptable tunnel of 44%[13].

The "N+2 mm" is a direct measurement method. It is based on the more accurate intertunnel distance resulted in acceptable tunnels in all specimens[13]. This formula was calculated using the fixed intertunnel distance (23 mm) and fixed tibial bone plug (25 mm). However, similar to other direct measurement methods, this technique is considered technically difficult and may require several adjustments before the ideal angle is selected for the guide.

Table 1. Patients' characteristics, predicted TTL and actual TTL

Patient	Age	Sex	IAL	W	α	β	γ	Predicted TTL	Actual TTL
1	24	M	20	20	45	70	55	47.50	55
2	26	M	22	24	46	71	68	52.2	55
3	41	F	23	20	40	65	74	36.8	40
4	49	M	21	20	50	70	55	43.3	40
5	45	M	24	21	48	72	60	50.2	50
6	38	F	24	23	42	67	74	42.6	45
7	37	M	22	26	47	71	65	56	50
8	20	M	28	25	48	70	72	48.3	45
9	60	M	23	24	45	70	71	48.9	45
10	37	F	24	29	45	76	69	57.5	55
11	17	M	23	28	44	67	71	50.8	45
12	40	F	22	25	48	69	73	45.8	48
13	20	M	20	28	46	65	67	44.1	42
14	44	M	25	24	42	70	71	51.7	48
15	22	M	23	25	44	68	74	46.2	44
16	22	F	23	28	45	62	67	41	43
17	15	F	22	23	48	64	65	36	40
18	26	M	23	29	45	66	68	49.2	50
19	41	M	26	28	45	67	70	48.4	50
20	28	M	24	25	48	70	70	48.6	45
21	42	M	25	28	44	66	73	46.3	50
22	34	F	24	23	43	69	72	45.9	44
23	32	F	23	25	48	69	73	46	48
24	43	M	23	23	47	65	65	36.5	40
25	34	F	22	27	42	66	70	47.2	52
26	40	M	24	24	48	67	68	40.2	46
27	53	F	23	25	47	66	68	43.6	46
28	48	F	23	26	41	69	70	51	47
29	46	F	23	30	42	61	66	43.9	48
30	37	M	26	32	45	64	68	51.1	48
31	38	F	24	34	48	66	72	52	58
32	58	M	23	28	47	66	66	46	46
33	49	F	24	26	48	71	71	53.7	50
34	45	M	26	26	45	67	70	46.4	43
35	28	M	23	28	46	66	65	48	43
36	40	M	22	25	43	65	64	43	44
Mean	36.64		23.33	25.69	45.42	67.58	68.33	46.83	46.89
SD	11.23		1.60	3.13	2.4	2.96	4.56	4.96	4.46

Although there are a lot of formulas to calculate the tibial length, there is no yet formula based on the correlations of the amount of tibial flare (proximal tibial slope), coronal angle and sagittal angle with the tibial tunnel length. In addition, the existing formulas cannot well predict the length of the tibial tunnel preoperatively. Based on the formula presented in this study, we found that the tibial tunnel length well correlated with the width of the extra-articular opening of the tibial tunnel to the center of tibial tubercle, slope of the proximal tibia, and sagittal and coronal angle of the tibial tunnel. We also presented the pilot study in 36 knees and the results showed that the predicted TTL was acceptable tunnel at 86%. The average difference of the tibial tunnel length shows no statistical significance (p-value = 0.66).

There is more variability in making the tibial tunnel. The selected point of the intraarticular opening of the tibial tunnel is also fixed, but the length to the starting (entry) point on the tibia may vary. This is the key factor. The length of the tibial tunnel is easily varied by moving the starting point proximally or

distally. The length of the tunnel prior to drilling may be measured using one of several commercially available calibrated tibial guides.

Conclusion

In summary, using preoperative template together with this proposed predictive formula, we can effectively determine how long the tibial tunnel is with an aim to avoid the mismatch of graft tunnel.

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สูตรที่ใช้ในการคำนวนความยาวของโพรงกระดูกทิเบีย ในการผ่าตัดเพื่อซ่อมแซมเอ็นไขว้หน้าบริเวณหัวเข่า

บัญชา ชื่นชูจิตต์, โทมัส บาเทล

ภูมิหลัง: *การผ่าตัดเพื่อซ่อมแซมเอ็นไขว้หน้าบริเวณข้อเข่า ด้วยเอ็นสะบ้านั้นเป็นวิธีการผ่าตัดที่มาตราฐาน และได้รับการนิยมในปัจจุบัน ปัญหาที่พบได้บ่อยขณะผ่าตัดด้วยเทคนิคนี้ คือ ความยาวของเส้นเอ็นและความยาวของโพรงกระดูกที่ทำการใส่เส้นเอ็นเข้าไปนั้นไม่ได้สัดส่วนกัน ทำให้ศัลยแพทย์หลายท่านพยายามเสนอวิธีการคำนวณเพื่อให้ความยาวของเส้นเอ็น และความยาวของโพรงกระดูกที่จะทำการใส่เส้นเอ็นนั้นได้สัดส่วนกันพอดี แต่จนปัจจุบันก็ยังไม่มีสูตรคำนวนใดที่ให้ความแม่นยำอย่างสูง*

วัตถุประสงค์: *เพื่อเสนอสูตรคำนวณในการใช้คำนวณความยาวของโพรงกระดูก และตรวจสอบความถูกต้องในการคำนวณความยาวดังกล่าวโดยรายละเอียดของสูตรคำนวณนี้จะแสดงความสัมพันธ์ระหว่างตำแหน่งของทางเข้าของรูเจาะบริเวณกระดูกทิเบีย, มุมของโพรงกระดูก, รูปร่างของกระดูกทิเบีย*

วัสดุและวิธีการ: *การศึกษานี้กระทำในผู้ป่วยซึ่งได้การบาดเจ็บบริเวณเอ็นไขว้หน้า จำนวน 36 ราย ประกอบด้วย ชาย 26 ราย และหญิง 14 ราย ทำการเก็บข้อมูลของผู้ป่วยแบ่งเป็น 3 ขั้นตอนคือ ก่อนผ่าตัดผู้ป่วยทุกรายได้รับการวัดมุมเอียงของกระดูกทิเบียด้านบน (c) ขณะผ่าตัดทำการเก็บข้อมูลความยาวของโพรงกระดูก และตำแหน่งของทางเข้าของรูเจาะบริเวณกระดูกทิเบีย หลังผ่าตัดทำการเก็บข้อมูลโดยการวัดมุม ของโพรงกระดูกทิเทียในแนวโรนอล และในแนวแซกจิทอล ทำการวิเคราะห์ข้อมูลโดยใช้ความสัมพันธ์ทางตรีโกณ ระหว่างค่าตัวแปลต่าง ๆ เพื่อสร้างสมการในการทำนายความยาวของโพรงกระดูกทิเบีย*

ผลการศึกษา: *จากการศึกษาพบว่า ความยาวโพรงกระดูกทิเบีย (T) มีความสัมพันธ์กับตำแหน่งของทางเข้าของรูเจาะบริเวณกระดูกทิเบีย (W), มุมของโพรงกระดูกในแนวโซโรนอล(b), มุมของโพรงกระดูกในแซกจิทอล(a) และมุมเอียงของกระดูกทิเบียด้านบน โดยมีความสัมพันธ์ ดังสมการ* $T = W\cos(c)\tan(b)/\sin(a)$

สรุป: *ประโยชน์ที่ได้รับจากงานวิจัยนี้ศัลยแพทย์สามารถคำนวณความยาว ของโพรงกระดูกได้อย่างแม่นยำก่อนผ่าตัดเพื่อวางแผนการรักษา และหลีกเลี่ยงปัญหาที่เกิดจากความยาวของเส้นเอ็นและโพรงกระดูกไม่ได้สัดส่วนกัน*