



Evaluation of the permissible maximum angle of the tibial tunnel in transtibial anatomic posterior cruciate ligament reconstruction by computed tomography

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Received: 10 October 2018 / Published online: 8 December 2018
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Abstract

Introduction Excessive angle of the tibial tunnel may cause breakage of the posterior cortex in transtibial anatomic posterior cruciate ligament (PCL) reconstruction. However, a few studies have determined the permissible maximum angle of the tibial tunnel. The purpose of this study was to determine the permissible maximum angle of the tibial tunnel relative to the tibial plateau in transtibial anatomic PCL reconstruction and characterize the anatomic parameters of the tibial PCL attachment position.

Materials and methods Computed tomography (CT) scans of a consecutive series of 408 adult knees with normal PCL attachment were measured. The parameters measured were the permissible maximum angle (PMA) of the 10 mm-diameter tibial tunnel relative to the tibial plateau, the distance from the anterior orifice of the tibial tunnel to the tibial tuberosity (OTD), the anterior–posterior diameter (APD) of the tibial plateau, the distance from the center of PCL attachment site to the posterior edge of the tibial plateau (PPED), and the angle between the tibial plateau and the posterior tibial slope where the PCL insertion site was (PSA). Subgroup analysis was performed to determine the correlations between parameters, and sex, age, and height. The measurement reliability was evaluated by intraclass correlation coefficients (ICCs).

Results The average value of PMA was $48.2 \pm 5.4^\circ$, and it was not affected by sex, age, and height ($P > 0.05$). The values of OTD, APD, PPED, PSA, and height were significantly higher in males than females (OTD, $P < 0.01$; APD, $P < 0.01$; PPED, $P < 0.01$; PSA, $P = 0.019$; height, $P < 0.01$). With regard to age, we stratified the cases into three groups: the young (18–30 years old), the middle-aged (31–45 years old), and the elderly (46–60 years old). The mean value of OTD, APD, and height were significantly lower in the elderly than that in the middle-aged ($P < 0.01$, $P < 0.01$, $P < 0.01$, respectively). With regard to height, we stratified the cases into three groups: ~1.65 m (1), 1.66–1.75 m (2), and 1.76 m ~ (3). The mean value of OTD, APD, and PPED significantly increased with height, $P < 0.05$. The mean value of PSA was significant higher in II group than that in I group ($P = 0.034$).

Conclusions There should be a limit to the angle of the tibial tunnel in transtibial anatomic PCL reconstruction to prevent the fracture of posterior tunnel wall. The permissible maximum angle (PMA) of the 10 mm-diameter tibial tunnel relative to the tibial plateau was 48.2° . Besides, the determination of the value of OTD, APD, PPED, and PSA could provide a clinical reference to insertion site, depth, and angle of the tibial drill guide in PCL reconstruction.

Keywords PCL reconstruction · Tibial tunnel · Maximum angle · Computed tomography

Yuanjun Teng and Xiaohui Zhang have contributed to the work equally and should be regarded as co-first authors.

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s00402-018-3092-9>) contains supplementary material, which is available to authorized users.

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Introduction

Posterior cruciate ligament (PCL) is an essential structure for the stability of the knee. Biomechanical studies have demonstrated that PCL acts as the primary role to restrain tibial translation, producing 95% restraint to posterior displacement in the intact knee [1–4]. PCL injuries commonly occur in trauma population with multiple ligament injuries,

and the incidence varies from 1 to 44% in multiple knee ligament injuries [5, 6]. Several studies suggested that patients with severe posterior laxity (more than Grade II) might suffer from chronic instability, associated pain, worse knee function, and accelerated articular degeneration [7, 8]. Therefore, PCL reconstruction was strongly recommended for severe ruptures and multiple ligament injuries [1, 8, 9].

Of various surgical techniques available for PCL reconstruction, the transtibial tunnel technique has been commonly used [10]. Unfortunately, clinical outcomes were not as satisfactory as that in anterior cruciate ligament reconstruction [1, 6, 11, 12]. Because of the special position of PCL attachment site on proximal tibia, an acute graft angle is produced around the proximal posterior tibial aperture, which is termed as the “killer turn”. This acute angle causes repetitive abrasion on the graft, which could enlarge the tunnel inlet and weaken the graft, leading to poor clinical outcomes [13–16]. Currently, the “killer turn” was considered to be the main source of the recurrent posterior laxity in PCL-reconstructed knees [8, 15–17]. To relieve the “killer turn”, clinically surgeons tend to choose a large angle of the tibial tunnel relative to the tibial plateau. Depressingly, we have found some breakage of the posterior cortex during clinical PCL reconstruction when a large angle was adopted, and some researchers also noticed this phenomenon [18]. The most possible explanation was that the excessive tunnel angle could thin the proximal tibial tunnel wall; meanwhile, because of a fossa on the proximal tibia between PCL attachment slope and posterior cortex, there would be a high fracture risk of the posterior tunnel wall. Lee et al. [18] reported that the maximum possible angle of the tibial tunnel relative to the line which was perpendicular to the tibial shaft was 52° by measuring ten fresh cadaveric tibias on CT. However, their study was limited by small sample size and the power was not strong. Furthermore, the cadaveric study not considers patient sex, age, and height.

The purpose of this study was to (1) evaluate the permissible maximum angle (PMA) of the tibial tunnel relative to the tibial plateau in transtibial anatomic PCL reconstruction and (2) characterize anatomic parameters of the tibial PCL attachment position through computed tomography (CT) measurements.

Materials and methods

Patient selection

This study protocol was approved by the regional ethics committee of our institution. Computed tomography scans of a consecutive series of 408 adult knees with normal PCL attachment were retrospectively analyzed in this study. CT indications were different from the purpose of the current study. Inclusion criteria: (1) the age range of patients is 18–60 years;

(2) the date of examination from January 2015 to August 2017; (3) the selected sagittal section contained the widest PCL tibial attachment site. Exclusion criteria: congenital skeletal dysplasia, inflammation or tuberculosis of bone and joint, previous knee surgery, displaced fractures involving knee, tumor around the knee joint, and other abnormal knee joint in imaging.

Computed tomography imaging

All the included patients accepted clinical routine knee CT performed on a 64-multi-detector-row CT (SOMATOM Sensation, Siemens AG, Wittelsbacherplatz 2, Muenchen, Germany). Scanning parameters included a gantry rotation speed of 1.00 s/rotation, 0.3 mm collimation width × 12 detectors, a CT pitch factor of 0.90, and a field of view of 25–30 cm. CT dose index (CTDI) volume was 20.9 mGy.

Measurements of the tibial anatomic parameters

Using the ST-PACS CDMedical software Vision 3.1 (Cre-alife, Beijing, China), several measurements of the tibial anatomic parameters were taken on sagittal image that provided the most inclusive and wide PCL tibial attachment. The partial parameters were described by the previous study on magnetic resonance imaging (MRI) [2, 19], including the anterior–posterior diameter (APD) of the tibial plateau, the distance from the center of PCL attachment site to the posterior edge of the tibial plateau (PPED), the angle between the tibial plateau, and the posterior tibial slope where the PCL insertion site was PSA. In addition, the permissible maximum angle (PMA) of the tibial tunnel and the distance from the anterior orifice of the tibial tunnel to the tibial tuberosity (OTD) were evaluated emphatically.

APD was measured along the tibial plateau from the anterior edge to the posterior edge. PPED was measured from the center of PCL attachment site to the posterior edge of the tibial plateau. PSA was the included angle between the tibial plateau and PCL attachment slope (Fig. 1). PMA was the included angle between the tibial plateau and the extension cord that connecting the center of PCL attachment site with a point 5 mm anterior from the fossa vertex beneath the tibial slope (Fig. 2). We used the point 5 mm from the fossa vertex, because we usually use the 10 mm-diameter tibial tunnel in transtibial PCL reconstruction, as performed by Lee et al [18]. OTD was measured from the anterior orifice of the tibial tunnel of PMA to the tibial tuberosity (Fig. 2).

To determine the intra- and inter-observer reliability, the measurement was conducted by two independent and blinded observers. Author 1 measured all CT images; author 2 measured 100 cases randomly selected from all CT images and blinded to results from author 1. After 1 month, author 1 measured 50 cases again randomly selected from all images in another occasion.



Fig. 1 Sagittal CT images illustrate how measurements were taken: APD was measured along the tibial plateau from the anterior edge to the posterior edge. PPED was measured from the center of PCL attachment site to the posterior edge of the tibial plateau. PSA was the included angle between the tibial plateau and PCL attachment slope

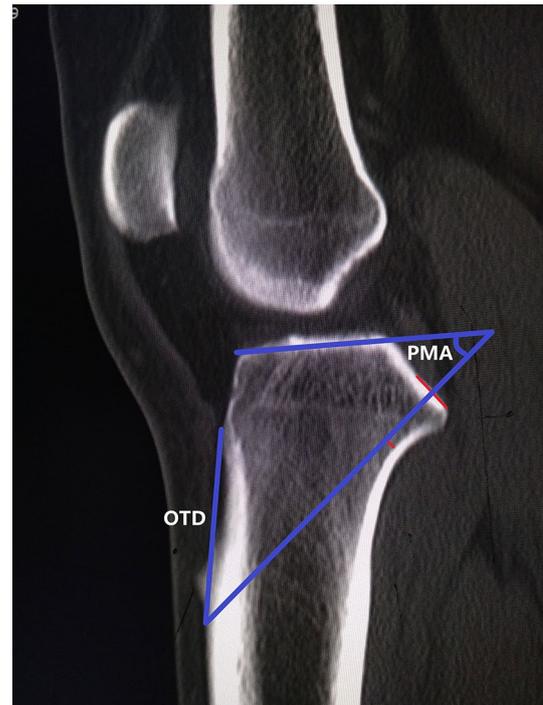


Fig. 2 Measurements of PMA and OTD on CT sagittal plane: PMA was the included angle between the tibial plateau and the extension cord that connecting the center of PCL attachment site with a point 5 mm anterior from the fossa vertex beneath the tibial slope. OTD was measured from the anterior orifice of the tibial tunnel of PMA to the tibial tuberosity

Statistical analysis

The calculation of intra- and inter-observer reliability was analyzed using the intraclass correlation coefficients (ICCs). The ICCs range from 0.00 (no agreement) to 1.00 (perfect agreement). Subgroup analysis was performed to determine the correlations between parameters and sex, age, and height. Comparison between male and female results was made using independent *t* test, while one-way analysis of variance (ANOVA) was used to assess anatomic parameters in age cohorts and height cohorts. The results were presented as arithmetic mean \pm standard deviation. All data processing was performed using the SPSS software (version 22.0, Inc., Chicago, IL, USA). $P < 0.05$ was considered statistically significant.

Results

Of the 408 knees CT images examined, 225 were from male patients and 183 were from female patients, including 230 left knees and 178 right knees. The average age at the time of CT was 38.3 ± 14.1 years (range 18–60 years).

Table 1 shows the anatomic parameters according to sex. The average values of PMA, OTD, APD, PPED, and PSA were

$48.2 \pm 5.4^\circ$, 46.6 ± 4.2 mm, 33.2 ± 3.1 mm, 18.1 ± 3.0 mm, and $123.4 \pm 5.7^\circ$, respectively. The values of OTD, APD, PPED, PSA, and height were significant higher in males than females (OTD, $P < 0.01$; APD, $P < 0.01$; PPED, $P < 0.01$; PSA, $P = 0.019$; height, $P < 0.01$, respectively). However, the value of PMA was no significant differences between sex groups ($P > 0.05$).

With regard to age, the cases were stratified into three groups: the young group (18–30 years old), the middle-aged group (31–45 years old), and the elderly group (46–60 years old) (Table 2). The average values of PMA, PPED, and PSA were no differences in age cohorts ($P > 0.05$). The mean values of OTD, APD, and Height were significant lower in the elderly than that in the middle-aged ($P < 0.01$, $P < 0.01$, $P < 0.01$, respectively).

With respect to height, the cases were also stratified into three groups: ~ 1.65 m (1), $1.66 \sim 1.75$ m (2), and 1.76 m \sim (3), as shown in Table 3. The average value of PMA showed no significant differences among three height groups ($P > 0.05$). The mean values of OTD, APD, and PPED significantly increased with height, $P < 0.05$. The mean value of PSA was significant higher in II group than that in I group ($P = 0.034$).

For each measurement, Table 4 shows that the values of ICCs were range from 0.677 to 0.912; good inter- and intra-observer reliability was evident.

Table 1 Results including measurements of both males and females

Parameter	Mean standard \pm deviation			<i>P</i> value
	Total (<i>n</i> =408)	Male (<i>n</i> =225)	Female (<i>n</i> =183)	
PMA ($^{\circ}$)	48.2 \pm 5.4	48.1 \pm 5.2	48.4 \pm 5.7	0.604
OTD (mm)	46.6 \pm 4.2	48.1 \pm 3.8	44.7 \pm 4.0	0.000
APD (mm)	33.2 \pm 3.1	34.4 \pm 2.7	31.7 \pm 2.9	0.000
PPED (mm)	18.1 \pm 3.0	18.9 \pm 2.1	17.2 \pm 3.7	0.000
PSA ($^{\circ}$)	123.4 \pm 5.7	124.0 \pm 5.3	122.7 \pm 6.0	0.019
Height (m)	1.68 \pm 0.07	1.72 \pm 0.05	1.62 \pm 0.05	0.000

PMA the permissible maximum angle of the tibial tunnel, *OTD* the distance from the anterior orifice of the tibial tunnel to the tibial tuberosity, *APD* the anterior–posterior diameter of the tibial plateau, *PPED* the distance from the center of PCL attachment site to posterior edge of the tibial plateau, *PSA* the angle between the tibial plateau and the posterior slope

Discussion

The most important finding of the present study was the determination of the permissible maximum angle (PMA) of the 10 mm-diameter tibial tunnel relative to the tibial plateau in transtibial anatomic PCL reconstruction. Meanwhile, the normal PCL insertion position and anatomic parameters of the proximal tibia were also measured on CT sagittal plane with normal PCL anatomy.

The previous studies have demonstrated that the recurrent posterior laxity is primary explanation, and the “killer turn” was the main causes of the recurrent posterior laxity [8, 15–17]. To relieve the “killer turn”, many surgeons tend to increase the angle between the tibial tunnel and plateau. However, the fracture risk of posterior tunnel wall would increase with the angle because of the unique anatomy of proximal tibia. Our study adds clinically important data to prevent the fracture of posterior tunnel wall and to provide a reference for positioning of the tibial PCL attachment during transtibial anatomic PCL reconstruction.

The present study suggested that the average values of PMA and OTD were 48.2 \pm 5.4 $^{\circ}$ and 46.6 \pm 4.2 mm, respectively. In other words, there would be a high fracture risk of the posterior tibial tunnel wall if the angle beyond PMA limit. Lee et al. [18] reported that the maximum angle of the tibial guide was 52 $^{\circ}$ \pm 5 $^{\circ}$ by measured cadaveric tibias on CT. In the present study, PMA was slightly lower to that of Lee et al. Differences with PMA values were resulted from the fact that the different measurements' technique was used in our study. We measured PMA between the tibial tunnel and the plateau, differently; they defined the maximum angle of the tibial tunnel was relative to the line that was perpendicular to the tibial shaft. Interestingly, the value of PMA was not influenced by sex, age, and height in the present study. With the value, we should limit the angle of the drill guide not more than 48.2 $^{\circ}$ relative to the tibial plateau in

Table 2 Parameters of the proximal tibia among three age groups

Age group (years)	PMA ($^{\circ}$)	Mean standard \pm deviation (<i>P</i> value)					
		OTD (mm)	APD (mm)	PPED (mm)	PSA ($^{\circ}$)	Height (m)	
Total	The young 18–30 (<i>n</i> =153)	47.4 \pm 5.9	46.7 \pm 5.1	33.3 \pm 3.6	18.4 \pm 4.1	123.5 \pm 5.6	1.68 \pm 0.08
	The middle-aged 31–45 (<i>n</i> =104)	47.6 \pm 5.0	47.1 \pm 3.8	33.8 \pm 2.1	18.6 \pm 2.1	123.6 \pm 5.2	1.69 \pm 0.06
	The elderly 46–60 (<i>n</i> =151)	49.4 \pm 5.1	45.5 \pm 3.6 (0.004 †)	32.6 \pm 2.9 (0.000 †)	17.6 \pm 2.1	123.2 \pm 6.0	1.67 \pm 0.07 (0.011 †)

Compared to the young, **P* < 0.05; compared to the middle-aged, † *P* < 0.05

PMA the permissible maximum angle of the tibial tunnel, *OTD* the distance from the anterior orifice of the tibial tunnel to the tibial tuberosity, *APD* the anterior–posterior diameter of the tibial plateau, *PPED* the distance from the center of PCL attachment site to posterior edge of the tibial plateau, *PSA* the angle between the tibial plateau and the posterior slope

Table 3 Parameters of the proximal tibia among three height groups

Height group (m)	Mean standard \pm deviation (<i>P</i> value)					
	PMA ($^{\circ}$)	OTD (mm)	APD (mm)	PPED (mm)	PSA ($^{\circ}$)	
Total	1: ~1.65 (<i>n</i> =161)	48.0 \pm 5.8	44.4 \pm 4.3	31.7 \pm 3.0	17.2 \pm 3.9	122.7 \pm 6.0
	2: 1.66~1.75 (<i>n</i> =207)	48.2 \pm 5.3	47.5 \pm 3.7 (*0.000)	33.9 \pm 2.6 (*0.000)	18.6 \pm 2.0 (*0.000)	124.0 \pm 5.4 (*0.034)
	3: 1.76~ (<i>n</i> =40)	48.9 \pm 4.8	49.2 \pm 4.1 (*0.000; † 0.015)	35.1 \pm 2.9 (*0.000; † 0.016)	19.7 \pm 2.3 (*0.000; † 0.021)	123.6 \pm 5.4

Compared to 1, **P* < 0.05; compared to 2, † *P* < 0.05

PMA the permissible maximum angle of the tibial tunnel, *OTD* the distance from the anterior orifice of the tibial tunnel to the tibial tuberosity, *APD* the anterior–posterior diameter of the tibial plateau, *PPED* the distance from the center of PCL attachment site to posterior edge of the tibial plateau, *PSA* the angle between the tibial plateau and the posterior slope

Table 4 ICCs values of the measurements on proximal tibial parameters

Parameter	Inter-observer	Intra-observer
PMA (°)	0.840	0.889
OTD (mm)	0.703	0.751
APD (mm)	0.677	0.681
PPED (mm)	0.773	0.875
PSA (°)	0.853	0.912

ICCs intraclass correlation coefficients, *PMA* the permissible maximum angle of the tibial tunnel, *OTD* the distance from the anterior orifice of the tibial tunnel to the tibial tuberosity, *APD* the anterior–posterior diameter of the tibial plateau, *PPED* the distance from the center of PCL attachment site to posterior edge of the tibial plateau, *PSA* the angle between the tibial plateau and the posterior slope

transtibial anatomic PCL reconstruction. X-ray measurement would be accurate to decide the value of PMA. In addition, the value of OTD could be measured easily with palpation in most patients during PCL reconstruction, though it was influenced by sex, age, and height.

Results of this study showed that the mean value of APD was 33.2 ± 3.1 mm. Unlike the current study, Osti et al. [20] reported that APD was 57.43 ± 3.69 mm by measuring human cadaveric knee from anterior edge of tibia to posterior tibial cortex. Another MRI analysis conducted by Frank et al. [19] reported that APD was 50 ± 4 mm. They measured APD from the anterior articular margin of the tibia to the posterior edge of PCL attachment. The obvious differences were resulted by the measurement methods that we measured APD from the anterior tibial plateau to the beginning of the sloped area of the PCL insertion (as shown in Fig. 1). The value of APD is contribute to determine the posterior insertion depth of the tibial drill guide during PCL reconstruction when the drill guide in the same direction as the tibial plateau (34.4 mm in males and 31.7 mm in females). Moreover, the value of PPED suggested that the inferior insertion depth of tip of the tibial drill guide was 18.9 mm in males and 17.2 mm in females. Besides, the PSA provided a point of reference for the angle design of hook of the tibial drill guide which the mean value was 124.0° in males and 122.7° in females. Noteworthy, the value of APD and PPED would increase with height.

In addition, the mean values of APD, OTD, and height were lower in the elderly group (46–60 years old). Meanwhile, the average values of OTD, PPED, APD, PSA, and height of the females were lower than that of the males. The potential explanation was that the body height had a significant influence on those parameters. Therefore, PMA may be an excellent parameter to prevent the breakage of posterior tunnel wall, because it was not affected by sex, age, and height.

There are some limitations to this study. First, we could not validate the disadvantages of fracture of the posterior tunnel wall, because the suspensory fixation or expansion fixation at anterior orifice is usually performed. However, expansion fixation is possible within the posterior orifice of the proximal tibial tunnel [8, 21]. Second, the present study only used CT imaging to determine the position and other parameters of PCL without anatomic study. Therefore, small differences may exist between measurement value and actual position. Third, this is a retrospective study, the scanning direction of knee CT is difficult to achieve consistent, and small errors may emerge. Fourth, the current study described PMA according to sex, age, and height only. A biomechanical study is needed to further explore this critical angle. Finally, a sample size calculation was not specially performed; the sample size of 1.76~ was small when we performed height subgroup analysis.

Conclusions

The angle of the tibial tunnel should be limited in transtibial anatomic PCL reconstruction to prevent fracture of the posterior tunnel wall. The permissible maximum angle (PMA) of the 10-mm-diameter tibial tunnel relative to the tibial plateau was 48.2° . Besides, the determination of the value of OTD, APD, PPED, and PSA could provide a clinical reference to insertion site, depth, and angle of the tibial drill guide in PCL reconstruction.

Funding This study was financially supported by the Natural Science Foundation of China [81874017], the Cuiying Science and Technology Innovation Project of Lanzhou University Second Hospital [CY2017-ZD02; CY2017-QN12], and the Cuiying Scientific Training Program for Undergraduates of Lanzhou University Second Hospital [CYXZ-32].

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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