Transverse drill lead angle and positioning during tibial tunnel creation in the anatomical single-bundle reconstruction of the anterior cruciate ligament

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Abstract

Objective

To determine the optimal tibial insertion orientation for guiding the transverse drill lead angle and tibial positioner during reconstruction of a single-bundle anterior cruciate ligament (ACL).

Methods

A total of 48 patients (26 males; 22 females) with normal knee magnetic resonance imaging (MRI) were screened. Ultimately, 46 patients underwent bilateral knee MRI examination.

Results

For right vs the left knees, the tibial ACL insertion area was $120.10 \pm 5.40 \text{ mm}^2$ and $119.46 \pm 6.59 \text{ mm}^2$, respectively in males, and $114.76 \pm 7.01 \text{ mm}^2$ and $113.68 \pm 8.30 \text{ mm}^2$, respectively, in females. The angle between the long axis of the tibial ALC insertion area and the anteroposterior line of the tibial plateau was $20.47 \pm 3.91^\circ$ and $20.95 \pm 4.15^\circ$, respectively, in males, and $19.96 \pm 4.00^\circ$ and $20.60 \pm 4.54^\circ$, respectively, in females. Additionally, the angle formed by the ACL and the tibial plateau in the sagittal plane was $43.82 \pm 4.56^\circ$ and $44.76 \pm 3.58^\circ$ respectively, in males, and $45.20 \pm 3.43^\circ$ and $44.46 \pm 2.17^\circ$, respectively, in females. The distance between the midpoint of the tibial ACL insertion and the anterior edge of the tibial plateau in the sagittal plane was $21.59 \pm 2.32 \text{ mm}$ and $21.79 \pm 2.02 \text{ mm}$, respectively, in males, and $18.93 \pm 1.12 \text{ mm}$ and $20.13 \pm 1.84 \text{ mm}$, respectively, in females. Similarly, the length of this point from the posterior edge of the tibial plateau was $34.56 \pm 3.36 \text{ mm}$ and $34.54 \pm 3.04 \text{ mm}$, respectively, in males, and $28.85 \pm 2.18 \text{ mm}$ and $29.03 \pm 2.18 \text{ mm}$, respectively, in females. The coronal angle between the ACL and the tibial plateau was $66.37 \pm 4.44^\circ$ and $66.49 \pm 4.96^\circ$, respectively, in males, and $66.70 \pm 4.84^\circ$ and $66.39 \pm 2.79^\circ$, respectively, in females, and the length from the midpoint of the tibial ACL insertion in the coronal plane to the inner edge of the tibial plateau was $34.28 \pm 1.70 \text{ mm}$ and $35.90 \pm 1.62 \text{ mm}$, respectively in males, and was $30.21 \pm 1.59 \text{ mm}$ and $31.84 \pm 1.71 \text{ mm}$ respectively, in females. The length of this point from the outer edge of the tibial plateau was also $43.82 \pm 2.09 \text{ mm}$ and $41.70 \pm 1.85 \text{ mm}$, respectively, in males, and $37.50 \pm 1.72 \text{ mm}$ and $35.64 \pm 2.29 \text{ mm}$, respectively, in females. Finally, the width of the tibial ACL insertion in the coronal plane was $9.90 \pm 1.66 \text{ mm}$ and $9.54 \pm 1.64 \text{ mm}$, respectively in males, and $8.50 \pm 1.03 \text{ mm}$ and $8.53 \pm 1.18 \text{ mm}$, respectively, in females.

Conclusion

This study determined the optimal drill lead angle for tibia positioning during ACL reconstruction in Chinese patients.

Introduction

The anterior cruciate ligament (ACL) is a band of dense connective tissue running from the femur to the tibia, maintains the stability and controls the motion of the knee in all directions¹. ACL injury is one of the most common knee injuries², which can further cause a meniscus tear and articular cartilage damage that eventually lead to knee osteoarthritis^{3,4}. Treatments for ACL injury include non-surgical therapeutics and surgical reconstruction with autologous, allogeneic, or artificial ligament, with the goal of restoring the anatomical ACL structure and function^{5,6}. The two most popular surgical ACL reconstruction procedures are the anatomical double-bundle (DB) and single-bundle (SB) ACL reconstructions. In recent years, the Ribbon theory has pointed out that the ACL originated as a single-bundle flat ribbon⁷, and that the double-bundle-like separation in the middle structure is only a result of the rotation of the flat ribbon ACL⁸. Thus, although the anatomic DB and SB ACL reconstructions after ACL rupture do not differ in quality-of-life at 2 years⁹, the medium and long-term effects of the DB technique are not superior to those of the SB technique in autologous ACL reconstruction in terms of knee joint stability, clinical function, graft failure rate, and OA changes¹⁰. This has prompted increasing attention toward the SB technique and the anatomical structure of the ACL.

Knee magnetic resonance imaging (MRI) can reflect the basic physiological information of the ACL well¹¹, and thus contralateral knee joint MRI examinations have become an important part of personalized ACL reconstructions. MRI analysis of normal knee joints has shown its capability to provide an anatomical basis for the ACL reconstruction procedure, including ACL size and insertion area, the positional relationship with the surrounding anatomical landmarks with different motions, and the size requirement of the autograft. These results play critical roles in guiding the choice of grafts, bone tunnel positioning and direction, and personalized treatment^{12–17}.

Race variance also plays a role in ACL anatomy. Studies have found that the size distribution of the tibial footprint of Chinese patients is different from that of Western patients¹⁸. Furthermore, current anatomical ACL reconstruction techniques still cause significant positioning errors in the placement of the tibial tunnel¹⁹. Previous studies have found that the area of the ellipse formed on the tibial platform is determined by the drill lead angle on the tibial locator under the same diameter drill bit, and that the major axis of the ellipse is determined by the transverse drill lead angle¹⁴. The choice of these two angles should therefore be determined based on the tibial footprint of the original ACL; however, there are no specific data on these two angles in Chinese patients.

Therefore, the objective of this study was to investigate the normal knee joint using MRI to clarify the ACL size, the area of the inserted tibia, the direction of the long axis of the inserted tibia, and the relationship with the surrounding structures. The obtained data can guide the selection of grafts, the positioning of the tibial endpoint, the drill lead angle of the tibial locator, and the transverse drill lead angle during ACL reconstruction in patients in Northeast China.

Methods

Enrollment Eligibility

Thin-sliced MRI scans of the knee from a single MRI scanner were obtained from all patients regardless of diagnosis. Eligible patients exhibited normal knee MRI in the extension position. Patients with conditions that affect the normal MRI measurement, such as ACL injury, posterior cruciate ligament injury, medial collateral ligament injury, lateral collateral ligament injury, disc meniscus, knee flexion deformity, knee joint Osteoarthritis, knee rheumatoid arthritis, were excluded.

MRI Analysis

The MRI scans were performed using standard knee joint protocols. Each MRI scan was reviewed by two independent and blinded observers to ensure the reliability between observers. A professional medical image segmentation software (Mimics Research 17.0) was used to analyze the knee MRI images. Briefly, the knee MRI images were combined for the sagittal, coronal, and axial positions, which was followed by the 3D model reconstruction of the tibial ACL insertion. The knee angle in the images was about 10°, with slight variation depending on the size of the patient. The alignment of the sagittal image was consistent with the widely used lateral femoral condyle as a substitute for ACL positioning, and thus the measured angle was not affected by the rotation of the knee joint.

As shown in Fig. 1, the angle in the middle of the ACL was measured based on the drill position during the ligament reconstruction. The tibial joint line was also measured on the same image with clear ACL appearance for the location of the tibial drill guide during reconstruction. Subsequently, the tibial insertion area of the ACL was measured and the long axis of the tibial insertion of the ACL was determined. The line of intersection formed by the mid-point of the tibial plateau at the sagittal and axial positions was defined as the anteroposterior line of the tibial plateau. The angle between the long axis of the inserted ACL in the axial image and the anteroposterior line was also measured.

The clearest level of the ACL in the sagittal position was identified and a line of the ACL and a line parallel to the tibial plateau were drawn. The angle between these two lines was then measured. The largest layer between the anterior and posterior edges of the ACL in the sagittal position was identified and the distance between the anterior and posterior edges of the ACL was measured. At the midpoint of the tibial stop of the ACL, the distance to the anterior and posterior edges of the tibial plateau was measured (Fig. 1).

Using the same method to locate the clearest level of the ACL in the coronal position, the line of the ACL and a straight-line parallel to the tibial plateau were drawn, and was followed by the measurement of the angle between these two lines. The largest layer between the inner and outer edges of the ACL in the coronal position was identified, and the distance between the inner and outer edges of the ACL was measured. At the midpoint of the tibial stop of the ACL, the distance to the inner and outer edges of the tibial plateau was measured (Fig. 1).

Statistical Analysis

The intra-group correlation coefficient (ICC) was used to analyze the reliability between observers. Pearson correlation coefficient was also used to analyze the data from the left and right knee joints. The results of

men and women were compared using an independent *t* test. The IBM SPSS Statistics 26 software was used to perform all statistical analyses. Statistical significance was considered at $p < 0.05$.

Results

Patient Characteristics

A total number of 48 patients aged 20-50 years old were enrolled from October 2013 to January 2014. Of these patients, 26 were males with a median age of 26 (24.75-27) years and 22 were females with a median age of 26 (23.75-28) years. The baseline characteristics of all patients are summarized in Table 1.

Table 1
Patient characteristics.

	Range	Median/Mean $\pm$ SD
Male (n=26)		
Age (years)	23 - 33	26(24.75-27)
Height (m)	1.68 - 1.87	1.76 $\pm$ 0.05
Weight (kg)	60 - 100	74.96 $\pm$ 11.17
BMI (kg/m ²)	19.59 - 30.67	24.16 $\pm$ 2.96
Female (n=22)		
Age (years)	21 - 49	26(23.75-28)
Height (m)	1.54 - 1.70	1.62 $\pm$ 0.03
Weight (kg)	45 - 70	55.32 $\pm$ 7.27
BMI (kg/m ²)	16.73 - 27.67	21.06 $\pm$ 2.76

Tibial ACL insertion area

A total of 94 MRI images of the knee joints were acquired. In the right knee, the ACL tibial insertion area ranged from 108.58 mm² to 133.48 mm² in male patients, with an average of 120.10 $\pm$ 5.40 mm²; and ranged from 103.19 mm² to 127.71 mm² in female patients, with an average of 114.76 $\pm$ 7.01 mm² (Table 2). In the left knee, the ACL tibial insertion area ranged from 103.76 mm² to 134.17 mm² in male patients, with an average of 119.46 $\pm$ 6.59 mm²; and ranged from 100.69 mm² to 128.88 mm² in female patients, with an average of 113.68 $\pm$ 8.30 mm² (Table 3). There was a positive correlation between the left and right knee joints, with a Pearson correlation coefficient of $r = 0.89$ ($P = 0.01$; Table 4).

Table 2
Characteristics of the right knee.

Right knee							
Male			Female		T test	P value	
Variables	Range	Mean± SD	Range	Mean± SD			
A (mm ²)	108.58~133.48	120.10±5.40	103.19~127.71	114.76±7.01	t=2.827		P=.008
B	11.47°~28.42°	20.47±3.91°	12.34°~28.16°	19.96±4.00°	t=0.433		P=.668
C	34.64°~51.79°	43.82±4.56°	38.82°~51.11°	45.20±3.43°	t=-1.124		P=.267
D	D1 (mm)	15.26~ 25.82	21.59±2.32	17.00~20.99	18.93±1.12	t=5.113	p<.001
	D2 (mm)	28.24~41.54	34.56±3.36	24.27~32.45	28.85±2.18	t=6.598	P<.001
E (mm)	14.41~25.28	18.32±2.69	9.24~22.20	15.74±3.14	t= 2.947		P=.005
F	57.41°~76.19°	66.37±4.44°	53.21°~73.10°	66.70±4.84°	t=-.238		P=.813
G	G1 (mm)	29.37~37.12	34.28±1.70	27.58~33.84	30.21±1.59	t= 8.332	P<.001
	G2 (mm)	40.38~48.64	43.82±2.09	35.08~41.45	37.50±1.72	t=11.213	P<.001
H (mm)	7.01~13.55	9.90±1.66	6.45~10.87	8.50±1.03	t=3.305		P=.002

Table 3
Characteristics of the left knee.

Left knee							
		Male		Female		T test	P value
Variables		Range	Mean± SD	Range	Mean± SD		
A (mm ²)		103.76~134.17	119.46±6.59	100.69~128.88	113.68±8.30	t=2.635	P=.012
B		10.82°~29.27°	20.95±4.15°	11.53°~28.93°	20.60±4.54°	t=.283	P=.778
C		38.22°~54.02°	44.76±3.58°	40.81°~48.88°	44.46±2.17°	t=.354	P=.725
D	D1 (mm)	18.24~ 26.06	21.79±2.02	16.62~ 23.24	20.13±1.84	t=2.962	P=.005
	D2 (mm)	27.25~ 40.28	34.54±3.04	24.77~32.22	29.03±2.18	t=7.086	P<.001
E (mm)		13.61~21.86	17.81±2.15	8.48~ 19.94	15.56 ± 3.11	t=2.865	P=.007
F		57.53°~76.48°	66.49±4.96°	60.68°~71.32°	66.39±2.79°	t=-.087	P=.931
G	G1 (mm)	32.82~ 39.32	35.90±1.62	29.56~35.10	31.84±1.71	t=8.386	P<.001
	G2 (mm)	38.82~46.55	41.70±1.85	30.88~ 40.17	35.64±2.29	t=9.967	P<.001
H (mm)		6.53~12.51	9.54±1.64	6.36~11.30	8.53 ±1.18	t=2.483	P=.017

Table 4
Comparison of metrics between the left and right knees.

Right knee			Left knee				
Variables	Range	Mean± SD	Range	Mean± SD	r value	P value	
A (mm ²)	103.19~133.48	117.78±6.64	100.69~134.17	116.81±7.89	r=0.89	P=.01	
B	11.47°~28.42°	20.24±3.91°	10.82°~29.27°	20.78±4.29°	r=0.93	P=.01	
C	34.64°~51.79°	44.42±4.12°	38.22°~54.02°	44.62±2.99°	r=0.44	P=.01	
D	D1 (mm)	15.26~ 25.81	20.43±2.30	16.62~ 26.06	20.03±2.09	r=0.77	P=.01
	D2 (mm)	24.27~41.54	32.08±4.06	24.77~40.28	32.01±3.84	r=0.96	P=.01
E (mm)	9.24~25.27	17.20 ±3.14	8.48~ 21.86	16.78 ±2.84	r=0.61	P=.01	
F	53.21°~76.19°	66.52±4.57°	57.53°~76.48°	66.44±4.07°	r=0.86	P=.01	
G	G1 (mm)	27.58~37.12	32.51±2.61	29.56~39.32	34.04±2.62	r=0.82	P=.01
	G2 (mm)	35.08~48.64	41.70±3.70	30.88~ 46.55	38.92±3.67	r=0.90	P=.01
H (mm)	6.45~13.55	9.29±1.58	6.36~12.51	9.08 ±1.52	r=0.87	P=.01	

The angle between the long axis of the tibial ACL insertion area and the anteroposterior line of the tibial plateau

In the right knee, the angle between the long axis of the tibial ALC insertion area and the anteroposterior line of the tibial plateau ranged from 11.47° to 28.42° in male patients, with an average angle of 20.47±3.91°; and ranged from 12.34° to 28.16° in female patients, with an average angle of 19.96±4.00° (Table 2). In the left knee, this angle ranged from 10.82° to 29.27° in male patients, with an average of 20.95 ± 4.15°; and ranged from 11.53° to 28.93° in female patients, with an average of 20.60±4.54° (Table 3). There was a positive correlation between the left and right knee joints, with a Pearson correlation coefficient of $r = 0.93$ ($P = 0.01$; Table 4).

Inclination of the ACL and the tibial plateau in the sagittal plane

In the right knee, the angle formed by the ACL and the tibial plateau in the sagittal plane ranged from 34.64° to 51.79° in male patients, with an average of 43.82±4.56°; and ranged from 38.82° to 51.11° in female patients, with an average of 45.20±3.43° (Table 2). In the left knee, this angle ranged from 38.22° to 54.02° in male patients, with an average of 44.76±3.58°; and ranged from 40.81° to 48.88° in female

patients, with an average of $44.46 \pm 2.17^\circ$ (Table 3). There was a positive correlation between the left and right knee joints, with a Pearson correlation coefficient of $r=0.44$ ($P = 0.01$, Table 4).

Length between the mid-point of the tibial ACL insertion in the sagittal plane to the leading edges of the tibial plateau

In the right knee of male patients, the length between the midpoint of the tibial ACL insertion and the anterior edge of the tibial plateau in the sagittal plane ranged from 15.26 mm to 25.82 mm, with an average of 21.59 ± 2.32 mm, and the length of this point from the posterior edge of the tibial plateau ranged from 28.24 mm to 41.54 mm, with an average of 34.56 ± 3.36 mm. In female patients, the length of this point from the front edge of the tibial plateau ranged from 17.00 mm to 20.99 mm, with an average of 18.93 ± 1.12 mm, and the length of this point from the posterior edge of the tibial plateau ranged from 24.27 mm to 32.45 mm, with an average of 28.85 ± 2.18 mm (Table 2). In the left knee of male patients, the length of this point from the front edge of the tibial plateau ranged from 18.24 mm to 26.06 mm, with an average of 21.79 ± 2.02 mm, and the length from this point to the posterior edge of the tibial plateau ranged from 27.25 mm to 40.28 mm, with an average of 34.54 ± 3.04 mm. In female patients, the length of this point from the front edge of the tibial plateau ranged from 16.62 mm to 23.24 mm, with an average of 20.13 ± 1.84 mm, and the length of this point to the posterior edge of the tibial plateau ranged from 24.77 mm to 32.22 mm, with an average of 29.03 ± 2.18 mm (Table 3). There was a positive correlation between the left and right knee joints, with Pearson correlation coefficients of $r = 0.77$ ($P = 0.01$) and $r = 0.96$ ($P = 0.01$), respectively (Table 4).

Length of the tibial ACL insertion on the sagittal plane

In the right knee, the length of the tibial ACL insertion ranged from 14.41 mm to 25.28 mm in male patients, with an average of 18.32 ± 2.69 mm, and ranged from 9.24 mm to 22.20 mm in female patients, with an average of 15.74 ± 3.14 mm (Table 2). In the left knee, this length ranged from 13.61 mm to 21.86 mm in male patients, with an average of 17.81 ± 2.15 mm; and ranged from 8.48 mm to 19.94 mm in female patients, with an average of 15.56 ± 3.11 mm (Table 3). There was a positive correlation between the left and the right knee joints, with a Pearson correlation coefficient of $r = 0.61$ ($P = 0.01$; Table 4).

Angle between the ACL and the tibial plateau in the coronal plane

In the right knee, the coronal angle between the ACL and the tibial plateau ranged from 57.41° to 76.19° in male patients, with an average of $66.37 \pm 4.44^\circ$, and ranged from 53.21° to 73.10° in female patients, with an average of $66.70 \pm 4.84^\circ$ (Table 2). In the left knee, this angle ranged from 57.53° to 76.48° in male patients, with an average of $66.49 \pm 4.96^\circ$, and ranged from 60.68° to 71.31° in female patients, with an average of $66.39 \pm 2.79^\circ$ (Table 3). There was a strong correlation between the left and the right knee joints, with a Pearson correlation coefficient of $r = 0.86$ ($P = 0.01$; Table 4).

Length between the midpoint of the tibial ACL insertion in the coronal plane to the left and right edges of the tibial plateau

In the right knee, the length from the midpoint of the tibial ACL insertion in the coronal plane to the inner edge of the tibial plateau ranged from 29.37 mm to 37.12 mm in male patients, with an average of 34.28 ± 1.70 mm. The length between this point and the outer edge of the tibial plateau ranged from 40.38 mm to 48.64 mm in male patients, with an average of 43.82 ± 2.09 mm. In female patients, the length between this point and the inner edge of the tibial plateau ranged from 27.58 to 33.84 mm, with an average of 30.21 ± 1.59 mm. In female patients, the length between this point and the outer edge of the tibial plateau ranged from 35.08 mm to 41.45 mm, with an average of 37.50 ± 1.72 mm (Table 2). In the left knee, the length between this point and the inner edge of the tibial plateau ranged from 32.82 mm to 39.32 mm in male patients, with an average of 35.90 ± 1.62 mm. In male patients, the length between this point and the outer edge of the tibial plateau ranged from 38.82 mm to 46.55 mm, with an average of 41.70 ± 1.85 mm. The length between this point and the inner edge of the tibial plateau ranges from 29.56 mm to 35.10 mm in female patients, with an average of 31.84 ± 1.71 mm. The length between this point and the outer edge of the tibial plateau ranged from 30.88 mm to 40.17 mm in female patients, with an average of 35.64 ± 2.29 mm (Table 3). There was a positive correlation between the left and right knee joints, with Pearson correlation coefficients of $r = 0.82$ ($P = 0.01$) and $r = 0.90$ ($P = 0.01$), respectively (Table 4).

Width of the tibial ACL insertion in the coronal plane.

In the right knee, the width of the tibial ACL insertion in the coronal plane ranged from 7.01 mm to 13.55 mm in male patients, with an average of 9.90 ± 1.66 mm, and ranged from 6.45 mm to 10.87 mm in female patients, with an average of 8.50 ± 1.03 mm (Table 2). In the left knee, this width ranged from 6.53 mm to 12.51 mm in male patients, with an average of 9.54 ± 1.64 mm, and ranged from 6.36 mm to 11.30 mm, with an average of 8.53 ± 1.18 mm (Table 3). There was a positive correlation between the left and the right knee joints, with a Pearson correlation coefficient of $r = 0.87$ ($P = 0.01$; Table 4).

Inter-observer reliability

The reliability between the observers showed that the degree of agreement between the observers for the different measurements was highly similar (Table 5).

Table 5
Inter-observer reliability.

Measurement content	Inter-observer ICC
A	0.929
B	0.914
C	0.960
D	0.986
E	0.913
F	0.974
G	0.997
H	0.939

Discussion

This study clarified information regarding the natural tibial ACL stop point of people from Northeast China and may help guide the choices of tibial tunnel size, tibial positioner placement, drilling lead angle, and lateral drilling lead angle during the anatomical SB reconstruction of the ACL. At the same time, a positive correlation between the left and right knee MRI images of each patient was determined. Therefore, the MRI of the unaffected knee joint can be used to predict the ACL orientation before surgery, which can better guide the individualized ACL reconstruction on the affected knee joint.

Although there was no significant difference between male and female patients in the measured indicator angles, apparent differences in the area size and distance were observed between these two groups. In general, female patient metrics were smaller compared to those of the male patients in terms of the area and distance indicators. This led to the consideration of gender differences before surgery to prevent damage or failure to the normal ACL during operation.

A study done by Li et al.¹⁸ revealed ethnic differences in the area and length of the tibial stop of the ACL. Chinese people generally have a smaller tibial stop area than westerners. During the ACL reconstruction procedure, larger drill lead angle and drill bit diameter can cause iatrogenic damage to the adjacent structures such as the meniscus and articular cartilage. This study clarified the area of the tibial stop of the ACL and the length of the tibial stop of the ACL in the sagittal and coronal planes, which may help guide the choice of tibial tunnel in ACL reconstruction in Chinese patients.

Another study done by Kopf et al.¹⁴ discovered that the drill lead angle and the drill bit diameter of the tibial positioner could define the size of the tibial tunnel and the area of the stop point of the posterior ACL reconstruction. The transverse borehole angle mainly affected the long axis direction of the reconstructed ACL at the tibial stop point. A large number of studies have shown that the drilling lead angle could be represented by the angle formed between the vertical line perpendicular to the long axis of the tibia and the

ACL in the sagittal position^{20–25}. Another study done by Alastair et al.²⁶ showed that this angle could also be represented by the angle formed by the tibial plateau joint line and the ACL in the sagittal position. The obtained angle was smaller, which was more in line with the design concept of the tibial positioner. Therefore, we guided the choice of drilling lead angle by measuring the angle between the joint line of the ACL and the tibial plateau in the sagittal position. The results indicate that the angle between the tibial plateau and the tibial tunnel was 44.5°, which may promote a good fit between the graft and the tunnel. Importantly, this could prevent the joint fluid from penetrating into the tibial tunnel and affect the tendon-bone healing during early straightening and fixation.

There are no studies yet showing how to guide the selection of the lateral drill guide angle of the tibial positioner. For the first time, we have clarified the direction of the long axis of the tibial stop of the original ACL in the coronal plane to theoretically derive the transverse drilling lead angle of the tibial positioner. The recommended lateral drill lead angle was 20.0°, creating a cross section of the tibial tunnel more in line with the ACL end point at the level of the tibial plateau. Earlier cadaver studies found that the long-axis direction of the tibial stop of the ACL can vary²⁷, which is not in line with what we found in this study. An accurate identity of the long axis of the tibial stop in the axial position was shown in the knee joint MRI images from all the patients after reconstruction. This may be related to the sample size, ethnic differences, or the non-flat surface of the ACL tibial stop itself; however, the specific reason for this is unknown. Therefore, this study is only a theoretical derivation of the transverse drilling lead angle of the tibial positioner where the postoperative advantages and disadvantages need further investigation.

After ACL reconstruction, the inclination angle formed by the new ligament in the sagittal and coronal planes has been shown to be related to the selection of the center points of the tibial and femoral ends as well as the angle of the bone tunnel during the operation²⁸. Thus, the restoration of the three-dimensional direction of the ACL depends on the positioning of the tibial center point and the femoral center point during the operation. However, this study was only limited to investigation of the tibial anchor point, and the femoral end was not studied. The measurement of the center point of the tibia in the sagittal plane of the original ACL, the center point of the tibial end point in the coronal plane, and the inclination angle in the coronal plane were found to be similar to the results of previous studies²⁶. This congruency may be related to race specificity, while the current results are mainly for people in Northeast China.

Conclusion

For the first time, the angle between the long axis of the tibial ACL insertion site and the anteroposterior line of the tibial plateau was measured to derive the transverse borehole angle required for anatomical SB reconstruction. The angle between the ACL and the tibial plateau was measured in the sagittal plane to clarify the required drill lead angle. The tibial ACL insertion area, the length in the sagittal plane, and the width in the coronal plane were measured to determine the size of the tibial ACL insertion in Chinese patients. The angle between the ACL and the tibial plateau joint line in the coronal plane, the position of the midpoint in the coronal plane, and the position of the midpoint in the sagittal plane were measured to guide the positioning of the tibial tunnel of the ACL. At the same time, we clarified that the left and right

knee joints exhibits positive correlations in the aforementioned metrics, and that the personalized ACL treatment can be guided through MRI examination of the uninjured knee joint.

Declarations

Ethical Approval

The institutional Review Board of China-Japan Union Hospital of Jilin University waive the need ethical approval. OR.

Consent to Participate

The need of informed consent was waived by “China-Japan Union Hospital of Jilin University Ethics Committee”.

Statement

All methods in this study were carried out in accordance with relevant guidelines and regulations.

Consent to Publish

All participating authors have reviewed the final draft of this article in detail and agreed to publish it.

Authors Contributions

Jiayin Lv conceived and designed this research. Modi Yang collected and screened MRI images of the knee joint according to the inclusion criteria. Jingtong Yan and Yu Gao measured and collected data on MRI images of the knee joint. Zheyuan Fan analyzed the data. Gaojian Hu and Yuhuan Li made the figure. Jinshuo Tang and Xingxing Wang created the table. Jingtong Yan prepared the manuscript, and all authors reviewed and redrafted it. The final manuscript was reviewed by all authors.

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Competing Interests

The authors have no relevant conflicts of interest to declare.

Availability of data and materials

The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

Figure 1

Measurement content. A) ACL insertion area in the tibia. B) The angle between the long axis of the tibial insertion area of the ACL and the anteroposterior line of the tibial plateau. C) The inclination of the ACL and the tibial plateau in the sagittal plane angle. D) The length between the midpoint of the tibial insertion of the ACL in the sagittal plane to the leading edges of the tibial plateau. E) The length of the tibial insertion of the ACL in the sagittal plane. F) The angle between the ACL and tibial plateau in the coronal plane. G) The length between the midpoint of the tibial insertion of the ACL in the coronal plane to the left and right edges of the tibial plateau. H) The width of the tibial insertion of the ACL in the coronal plane.