

# Femur-tibia Angle and Patella-tibia Angle: New Indicators for Diagnosing Anterior Cruciate Ligament Tears in Magnetic Resonance Imaging

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## Original Research Article

**Keywords:** Anterior cruciate ligament, magnetic resonance imaging, ligament tears, rotation

**Posted Date:** August 3rd, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-751415/v1>

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**Version of Record:** A version of this preprint was published at BMC Sports Science, Medicine and Rehabilitation on April 13th, 2022. See the published version at <https://doi.org/10.1186/s13102-022-00462-w>.

# Abstract

**Background:** Torn anterior cruciate ligament (ACL) contributes to internal rotation of tibia. However, there is no indicator in MRI to reflect the rotation of knee joint. So the purpose of this study is to introduce two new measurements in MRI, femur-tibia angle (FTA) and patella-tibia angle (PTA), which reflect the rotation of knee joint and assess their role in diagnosing ACL tears.

**Methods:** Present study retrospectively reviewed the cases of primary arthroscopic knee surgery from January 2018 to December 2019 from the Arthroscopy Database at Guangdong Provincial People's Hospital. Firstly, comparisons of different measurements were conducted between the ACL tears group and isolated meniscus injury group. Then, the measurements were tested in diagnosing complete or partial ACL tears. Diagnostic performance of different measurements was assessed by area under the curve (AUC) of receiver operating characteristic (ROC) curve and cutoff values were determined by Youden index.

**Results:** FTA and PTA in ACL tears group had 4.79 and 7.36 degrees more than that of control group ( $p = 0.022$  and  $< 0.001$ , respectively). Besides, ACL angle and distance of anterior tibial subluxation (D) also showed significant differences ( $p < 0.05$ ). In distinguishing complete ACL tear with intact ACL, the ROC curves indicated that ACL angle had the highest AUC of 0.906 (95% CI: 0.833-0.978) while AUC of PTA was 0.849 (95% CI: 0.763-0.936) and AUC of FTA was 0.809 (95% CI: 0.710-0.908). In distinguishing partial ACL tear with intact ACL, the ROC curves showed that FTA and PTA had the highest AUCs of 0.847 and 0.813 with 95% CI of 0.737-0.957 and 0.680-0.947, respectively. In contrast, the AUCs of ACL angle and D were only 0.519 and 0.387 with 95% CI of 0.292-0.745 and 0.227-0.546.

**Conclusion:** Present study introduced two new quantitative parameters, FTA and PTA, to assess the rotation of knee joint. FTA and PTA increased when ACL tears and they might be valuable in diagnosing ACL tears, especially in distinguishing partial ACL tear with intact ACL which was poorly diagnosed in MRI.

## Background

Anterior cruciate ligament (ACL) is the most commonly injured ligament of the knee joint. Magnetic resonance imaging (MRI) of the knee has been used as a diagnostic tool for over thirty years and widely utilized in clinical evaluation of ACL [1, 2]. It has been reported that the sensitivities of MRI in diagnosing complete ACL tears are 90–95% while the specificities are 95–100% [2]. Although the accuracy in diagnosing complete ACL tears by MRI is relative high, partial ACL tears are poorly diagnosed. In clinical practice, partial ACL tears are often indistinguishable and the accuracy of MRI diagnosis was only 25–53%, which may cause misdiagnosis and affect treatment decision-making [3–4].

ACL extends from the medial aspect of the lateral femoral condyle and inserts at the anterior intercondylar region of the proximal tibia, which can be seen in the oblique sagittal imaging of MRI [5]. The frequently used methods for identifying torn ACL include direct and indirect signs [6]. The primary

direct sign is the continuity and signals of ACL. Normal ACL remains a well-defined band-like structure in MRI. When the ACL is torn, it will lose its continuity or become tortuous with abnormal signals, or even disappear in chronic tears [7]. One of the indirect signs is ACL angle, which is formed by the interaction of two lines in the sagittal plane: one is the tangential line of ACL while the other is the line perpendicular to long axis of tibia (Fig. 1A). ACL angle reflects the tension of ACL and will decrease when the ACL is torn [8]. Another important sign is anterior tibial subluxation which is measured by the distance between the posterior aspects of lateral femoral condyle and tibial plateau in mid-condylar sagittal plane (Fig. 1B). It will increase with the increased clinical laxity of the knee joint after ACL tears [9]. However, the above mentioned signs seem not available for partial ACL tears. Subtle increased signal intensity in ACL is often the only sign in partial ACL tears, which is indistinguishable from intact ACL. The ACL angle or anterior tibial subluxation can also be normal, which lead to the low accuracy of diagnosis on partial ACL tears [10]. New indicators in MRI are needed to improve the accuracy of diagnosis on partial ACL tears which will help treatment decision-making preoperatively.

When the ACL is torn, it will not only cause obvious anterior tibial subluxation, but also result in significant internal rotation of the tibia [11]. In physical examination, pivot shift test has been commonly used to assess the rotatory laxity of knee joint caused by ACL tear [12]. Quantitative pivot shift test has also been validated in clinical trials [13]. However, there is no indicator in MRI to reflect the rotation between tibia and femur or patella. In the present study, we introduced two new quantitative parameters, femur-tibia angle (FTA) and patella-tibia angle (PTA), to measure the rotation of knee joint and evaluated the diagnostic value for diagnosing ACL tears.

## Methods

### Patients

The present study retrospectively reviewed cases of primary arthroscopic knee surgery from the Arthroscopy Database at Guangdong Provincial People's Hospital from January 2018 to December 2019. This study was approved by the Research and Ethics Institutional Committee of Guangdong Provincial People's Hospital.

For the case control study, adult patients who arthroscopically confirmed complete ACL tears with meniscus injury or isolated meniscus injury were included. Patients with patellofemoral instability, patella alta or baja, other ligament injury (collateral ligament or posterior cruciate ligament), Osteoarthritis (Outerbridge > 2) were excluded [14, 15]. All patients should have MRI imaging taken in our institute one week before knee arthroscopy. Cases were reviewed by two authors independently. Discordant cases were evaluated by the third author. The patients were then assigned to two groups: ACL tears with meniscus injury group (ACL tears group) and isolated meniscus injury group as the control group. The ACL tears cases were matched to control group according to sex, age, body mass index (BMI), side and time to surgery. The sample size was 20 patients per group which based on the result of the power analysis (alpha with 0.05 and power with 0.8).

For diagnostic evaluation, 120 adult patients with MRI imaging undergoing knee arthroscopy were included consecutively from January 2018 to December 2019. All patients should have MRI imaging taken in our institute. No specific exclusion criteria were applied.

## MRI Measurements

All patients receiving imaging at our institution had undergone MRI at 3.0 T (Siemens Healthcare) with 3 imaging planes (axial, coronal, and sagittal). Slice thickness was 3 mm for each plane. Scans were performed in the supine position with relaxed quadriceps. All images were reviewed and analyzed using electronic radiology patient archiving and communication system (PACS) [16].

To measure the rotation between tibia and femur or patella, we developed two new indicators: femur-tibia angle (FTA) and patella-tibia angle (PTA). FTA indicated the rotation between tibia and femur, while PTA presented the rotation between tibia and patella. FTA or PTA were divided into three different angles based on the horizontal line: tibial angle, femoral angle and patellar angle. For tibial angle, the coronal plane of patellar tendon insertion in tibia was defined at the level of midsagittal plane (Fig. 2A). The tibial angle was the intersection between the line perpendicular to patellar tendon insertion and the horizontal line (Fig. 2B). For femoral angle, the coronal plane of femur was defined at the level of the most posterior aspects in midsagittal plane of lateral femoral condyle (Fig. 2C). The femoral angle was the intersection between the line of the posterior femoral condyles and the horizontal line (Fig. 2D). For patellar angle, the coronal plane of patella was defined in middle of the patella at the level of midsagittal plane (Fig. 2E). The patellar angle was the intersection between the long axis line of patella and the horizontal line (Fig. 2F). The angles were defined as positive when directed laterally, and as negative when directed medially. Therefore, FTA was the tibial angle minus the femoral angle and PTA was the tibial angle minus the patellar angle (Fig. 3).

ACL angle and distance of anterior tibial subluxation (D) were used to assess the ACL function. Patellar articular overlap index (PT index), Insall-Salvati ratio (IS ratio) were used to measure the height of patella. Ratio of the medial to lateral patellar facet (MP/LP), median eminence angle of patella (ME angle), ratio of the medial to lateral facets of the trochlea (MT/LT), Sulcus angle, lateral trochlear inclination (LTI), and trochlear angle were used to describe the morphometry of patellofemoral joint. Patella shift, congruence angle, and lateral patellofemoral angle (LPFA) were used to evaluate the alignment of patellofemoral joint [17–20]. Descriptions of these measurements were given in Table 1. All measurements were defined as positive when it directed laterally, and as negative when it directed medially. The measurements were performed by two authors independently. The mean value was used if the differences between the angles were less than 5 degrees or the distances were less than 2 mm. It would be repeated by a third author if the differences between the angles were more than 5 degrees or the distances were more than 2mm and mean value of the two closer values was used. The reliability of different observers was also tested.

Table 1  
Descriptions of measurements on ACL, patella and femoral trochlea

<b>Definition</b>	
ACL angle (°)	The angle between the tangential line of ACL and the line perpendicular to the long axis of the tibia in sagittal plane
D (mm)	The distance between the posterior aspects of lateral femoral condyle and tibial plateau in sagittal plane
PT index	The ratio of trochlear cartilage overlap with the patellar cartilage to the length of patellar cartilage in sagittal plane
IS ratio	The ratio of the length of the patellar tendon to the length of the patella in sagittal plane
MP/LP	The ratio of the lengths of the medial facet to lateral facet of the patella
ME angle (°)	The angle between the tangential lines of the medial facet and lateral facet of the patella in coronal plane
MT/LT	The ratio of the lengths of the medial facet to lateral facet of the femoral trochlea in coronal plane
Sulcus angle (°)	The angle between the tangential lines of the medial facet and lateral facet of the femoral trochlea in coronal plane
LTI (°)	The angle between the tangential line of lateral facet of the femoral trochlea and the line of the posterior femoral condyles in coronal plane
Trochlear angle (°)	The angle between the line of the femoral trochlea eminences and the line of the posterior femoral condyles in coronal plane
Patella shift (mm)	The distance between the eminence of patella and the bottom of femoral trochlea at the level of line of posterior femoral condyles in coronal plane
Congruence angle (°)	The angle between the bisecting line of Sulcus angle and the line connecting the eminence of patella and the bottom of femoral trochlea in coronal plane
LPFA (°)	The angle between the line of the femoral trochlea eminences and the tangential lines of the lateral facet of the patella in coronal plane
Patellar tilt (°)	The angle between the line of the posterior femoral condyles and long axis line of patella in coronal plane
<p>ACL angle: anterior cruciate ligament angle; D: distance of anterior tibial subluxation; PT index: patellar articular overlap index; IS ratio: Insall-Salvati ratio; MP/LP: Ratio of the medial to lateral patellar facet; ME angle: median eminence angle of patella; MT/LT: Ratio of the medial to lateral facets of the trochlea; LTI: lateral trochlear inclination; LPFA: lateral patellofemoral angle.</p>	

## Statistics

Quantitative variables were presented as mean and standard deviation (SD). For normally distributed continuous variables, unpaired Student's t-test was used to compare the differences between the two groups. For not normally distributed continuous variables, Mann-Whitney U-test was used to compare

the differences between two groups. Categorical variables were presented as number and percentage, and were compared using Chi-square test or Fisher's exact test when appropriate. Receiver operating characteristic (ROC) curve was used to determine the sensitivity and specificity of ACL, D, FTA and PTA. The area under the curve (AUC) and its 95% confidence interval (CI) were calculated. The AUC was tested by a two-sided binomial z test. The optimal cutoff value was determined at the maximal Youden index [21]. Interclass correlation (ICC) was tested between different observers. A p-value of less than 0.05 was considered as statistically significant. Data were analyzed using IBM SPSS version 23.0.

## Results

Forty patients were included for the matched comparisons (20 for ACL tears group and 20 for control group) (Fig. 4). Each group comprised 10 women and 10 men. After well matched, no significant differences were found between the two groups regarding age, BMI, injury side, time from injury to surgery ( $p > 0.05$ ) (Table 2).

Table 2  
Comparisons of demographic and medical conditions

	<b>Meniscus injury</b>	<b>ACL tear + meniscus injury</b>	<b>P</b>
n	20	20	-
Sex (male)	10	10	1.000
Age (year)	32.78 (8.42)	29.40 (9.16)	0.355
BMI(kg/m <sup>2</sup> )	23.44 (3.68)	22.49 (2.31)	0.430
Side (left)	10	10	1.000
Time (month)	6.88 (3.60)	7.67 (4.88)	0.883
BMI: body mass index.			

In comparisons, there were significant differences in the measurements of ACL angle, D, FTA and PTA ( $p < 0.05$ ) between the two groups. For ACL angle, the average angle was 49.55 degree in the control group, significant higher than that of the ACL tears group (39.71 degree,  $p < 0.001$ ). However, the ACL was not detected in 40% (8/20) cases of ACL tears group and in 5% (1/20) of the control group. D was also different between the two groups. The ACL tears group had a greater anterior tibial subluxation than the control group ( $p = 0.004$ ). For the two new measurements, FTA and PTA indicated the rotation of the knee. In ACL group, the FTA and PTA had 4.79 and 7.36 degrees more than that of the control group ( $p = 0.022$  and  $< 0.001$ , respectively). No significant differences were found in the measurements regarding the morphometry of patella or femoral trochlea and the alignment of patellofemoral joint, including PT index, IS ratio, MP/LP, ME angle, MT/LT, Sulcus angle, LTI, trochlear angle, patella shift, congruence angle, and LPFA between the two groups ( $p > 0.05$  for all) (Table 3).

Table 3  
Comparisons of various measurements

	Meniscus injury	ACL tear + meniscus injury	P
n	20	20	-
ACL angle (°)	49.55 (6.83)	39.71 (7.57)	< 0.001
D (mm)	2.94 (3.33)	4.90 (2.55)	0.004
PT index	0.22 (0.11)	0.25 (0.10)	0.381
IS ratio	1.00 (0.13)	0.98 (0.16)	0.711
MP/LP	0.64 (0.12)	0.69 (0.08)	0.101
ME angle (°)	133.69 (10.16)	131.22 (7.63)	0.390
MT/LT	0.61 (0.12)	0.65 (0.15)	0.320
Sulcus angle (°)	143.07 (7.76)	142.84 (6.36)	0.917
LTI (°)	20.07 (4.79)	22.36 (3.95)	0.106
Trochlear angle (°)	5.31 (3.39)	6.00 (3.13)	0.511
Patella shift (mm)	0.71 (2.60)	0.79 (3.49)	0.937
Congruence angle (°)	3.99 (23.44)	2.91 (21.86)	0.508
LPFA (°)	11.1 (5.94)	10.3 (4.93)	0.534
Patellar tilt (°)	-4.43 (5.58)	-7.00 (4.72)	0.124
FTA (°)	80.91 (6.11)	85.70 (6.60)	0.022
PTA (°)	85.34 (6.30)	92.70 (5.32)	< 0.001
ACL angle: anterior cruciate ligament angle; D: distance of anterior tibial subluxation; PT index: patellar articular overlap index; IS ratio: Insall-Salvati ratio; MP/LP: Ratio of the medial to lateral patellar facet; ME angle: median eminence angle of patella; MT/LT: Ratio of the medial to lateral facets of the trochlea; LTI: lateral trochlear inclination; LPFA: lateral patellofemoral angle; FTA: femur-tibia angle; PTA: patella-tibia angle.			

To further test the diagnostic performance of the measurements including ACL angle, D, FTA and PTA, 120 consecutive adult patients were included. There were 70 men and 50 women with an average age of 35.02 years old. Fifty-five patients were diagnosed as complete ACL tear, while 11 as partial ACL tear and 54 as intact ACL. All the cases were diagnosed by arthroscopy.

To distinguish between complete ACL tear and intact ACL, the ROC curves indicated that ACL angle had the highest AUC of 0.906 (95% CI: 0.833–0.978) followed by PTA with AUC of 0.849 (95%CI: 0.763–0.936), which was close to the AUC of D (0.840; 95% CI: 0.733–0.946). The AUC of FTA was 0.809 (95% CI: 0.710–0.908) (Fig. 5A, Table 4). However, there were no differences among these measurements ( $p >$

0.05). In this cohort, the calculated cutoff of ACL angle was 47 degrees with a sensitivity of 90% and specificity of 79%, while the cutoff of D was 4 mm with a sensitivity of 82% and specificity of 81%. For new measurements in the present study, the cutoff of FTA was 80 degrees with a sensitivity of 82% and specificity of 68%, while the cutoff of PTA was 91 degrees with a sensitivity of 82% and specificity of 74%.

Table 4  
AUCs in distinguishing complete ACL tear with intact ACL

	<b>AUC</b>	<b>SE</b>	<b>AS</b>	<b>95% CI</b>
ACL angle	0.906	0.037	0.000	0.833–0.978
0.840	0.054	0.000	0.733–0.946	
FTA	0.809	0.051	0.000	0.710–0.908
PTA	0.849	0.044	0.000	0.763–0.936

AUC: area under the curve; SE: standard error; AS: asymptotic significant; CI: confident interval; ACL angle: anterior cruciate ligament angle; D: distance of anterior tibial subluxation; FTA: femur-tibia angle; PTA: patella-tibia angle.

To distinguish partial ACL tear from intact ACL, the ROC curves showed that FTA and PTA had the highest AUCs of 0.847 (95% CI: 0.737–0.957) and 0.813 (95% CI: 0.680–0.947), respectively. In contrast, the AUCs of ACL angle and D were only 0.519 (95% CI: 0.292–0.745) and 0.387 (95% CI: 0.227–0.546) respectively, much lower than that of FTA and PTA ( $p < 0.01$ ) (Fig. 5B, Table 5). However, there was no difference between the AUCs of FTA and PTA ( $p > 0.05$ ). In this cohort, the calculated cutoff of FTA was 84 degrees with a sensitivity of 90% and specificity of 81%, while the cutoff of PTA was 92 degrees with a sensitivity of 80% and specificity of 77%.

Table 5  
AUCs in distinguishing partial ACL tear with intact ACL

	<b>AUC</b>	<b>SE</b>	<b>AS</b>	<b>95% CI</b>
ACL angle	0.519	0.116	0.851	0.292–0.745
D	0.387	0.081	0.259	0.227–0.546
FTA	0.847	0.058	0.001	0.737–0.957
PTA	0.813	0.068	0.002	0.680–0.947

AUC: area under the curve; SE: standard error; AS: asymptotic significant; CI: confident interval; ACL angle: anterior cruciate ligament angle; D: distance of anterior tibial subluxation; FTA: femur-tibia angle; PTA: patella-tibia angle.

Through the study, FTA and PTA were measured in MRI of 160 patients. In the measurements, the concordance rates between two observers were 93.75% and 91.88% for FTA and PTA respectively

(differences between the angles were less than 5 degrees). The ICC value was 0.945 (95% CI: 0.918–0.963) for FTA and 0.940 (95% CI: 0.911–0.960) for PTA.

## Discussion

Rotation is an important alteration in ACL deficiency knees [11]. Studies have reported that ACL deficiency could cause significant anterior tibial subluxation and internal tibial rotation at low flexion angles [22]. In the present study, similar results were also found in MRI imaging. In the ACL group of matched comparisons, distance of anterior tibial subluxation was about 2 mm more than that of the control group. For internal tibial rotation, FTA in ACL group was about 5 degrees more than that of isolated meniscus injury group while PTA was 7 degrees more.

Rotatory laxity of knee joint is also a sign of ACL injury [11, 22]. The unique geometry of the lateral femoral condyle and tibial plateau, combined with the compressive force of the iliotibial band, was shown to contribute to the sudden reduction movement in patients with ACL tears. The most frequently used one is pivot shift test, with a reported sensitivity of 49% and a specificity of 98% [23]. Recent study also reported a stepwise increase in quantitative pivot shift examination in terms of rotation with partial ACL tears and complete ACL tears [24]. However, there was no relative quantitative indicator in MRI imaging to assess the rotation of knee joint.

The present study introduced two new indicators, FTA and PTA, to measure the rotation of femur and patella based on the tibia in MRI imaging. In femur and patella, the reference line of the posterior femoral condyles and long axis line of patella were used as previously described [25]. In tibia, because of the heterogeneity of the proximal cortical bone, the posterior parts of tibia or fibula were not suitable as the reference line. In contrast, patellar tendon insertion in tibia appeared as a symmetrical arc or straight line in the coronal plane which was consistent with the tibia rotation and easy to define at the level of midsagittal plane. As a result, we used the patellar tendon insertion in tibia as the anatomical landmark and defined the line perpendicular to patellar tendon insertion as the reference line. In isolated meniscus injury group, the average FTA was 80.91 degrees with SD of 6.11 degrees, and average PTA was 85.34 degrees with SD of 6.31 degrees. In ACL tear with meniscus injury group, the average FTA was 85.70 degrees with SD of 6.60 degrees and average PTA was 92.70 degrees with SD of 5.32 degrees. The concordance between different observers also performed well. The results showed good consistency and reliability the two new measurements.

In terms of diagnostic performance, FTA and PTA showed diagnostic value in diagnosing ACL tears, especially in distinguishing partial ACL tear. In distinguishing complete ACL tear from intact ACL, although the ACL angle had the highest AUC in the ROC test, it had its limitations. However, in the present study, there were 22.50% (9/40) ACLs in matched comparisons and 30.00% (36/120) ACLs in diagnostic test that cannot be clearly showed in sagittal plane of MRI, which limited its application in MRI. However, FTA or PTA did not have such problem and also provide steady quantitative parameters to assess the rotatory instability which were complementary with the anterior tibial subluxation parameter.

In terms of distinguishing partial ACL tear with intact ACL, FTA and PTA showed unique advantages compared with ACL angle or D. It remains difficult to confirm partial ACL tears in MRI. It has been reported that the positive diagnostic value of MRI for the diagnosis of partial ACL tears was less than 50% [26]. Some studies even showed that there was no close correlation between MRI findings and arthroscopically confirmed partial ACL tear [27]. In the present cohort, FTA had a sensitivity of 90% and specificity of 81% while PTA had a sensitivity of 80% and specificity of 77%, which performed well in distinguishing partial ACL tear from intact ACL.

In the present study, the optimal cutoff value was determined using the maximal Youden index. In distinguishing complete ACL tear from intact ACL, the cutoffs of FTA and PTA were 80 and 91 degrees respectively while in distinguishing partial ACL tear from intact ACL, the cutoffs of FTA and PTA were 84 and 92 degrees respectively. It is interesting that the cutoff degrees in distinguishing partial ACL tear were greater than that in distinguishing complete ACL tear. Besides the sample size factor, the acute or chronic injury of ACL might play an important role. In complete ACL tears, most of the cases were acute injury with pain and swelling of the knee which would restrict the rotation of knee because of guarding. In contrast, most cases of partial ACL tears were chronic injury without complains and diagnosed by arthroscopy. As for the anterior drawer test, the sensitivity and specificity were also shown to be dependent on the type of the injury [28]. In acute injuries, the sensitivity was only 49% and specificity was 58%, whereas in chronic injuries the results were 92% and 91%, respectively. The changes of soft tissue around the knee after ACL tears may also affect the rotatory laxity. It has been reported that a significant elongated medial collateral ligament and shortened lateral collateral ligament were found after ACL injury [29]. It was more obvious in the chronic ACL tears which would increase the rotation of knee. However, a larger prospective study was needed to validate the cutoff value.

The present study introduced two new indicators which can be used not only in measuring the rotation of knee joint, but also in diagnosing ACL tear, especially partial ACL tears. There are some limitations in the present study. Because of the relative low prevalence of partial ACL tears (10–27% of all ACL injury), only 11 partial ACL tear cases were found in the cohort of 120 consecutive adult patients, which may affect the accuracy of the cutoff value [30]. Another limitation was the retrospective study design, and a larger prospective study was needed to confirm the value of FTA and PTA in ACL injury and also in functional evaluation in ACL reconstruction.

## Conclusion

The present study introduced two new quantitative parameters, FTA and PTA, to assess the rotation of knee joint. FTA and PTA increased significantly when ACL tears and performed well in diagnostic test. They might be valuable in diagnosing ACL tears, especially in distinguishing partial ACL tear with intact ACL which was poorly diagnosed in MRI, which may decrease misdiagnosis rate and help treatment decision-making preoperatively.

## Declarations

## Ethics approval and consent to participate

This study received Ethical approval by the ethical committee of Guangdong Provincial People's Hospital.

## Consent for publication

Not applicable.

## Availability of data and material

The data underlying this article will be shared on reasonable request to the corresponding author.

## Competing interests

The authors declare that they have no conflict of interest.

## Funding

The study was supported by the Natural Science Foundation of Guangdong Province (2021A1515011008) and the Medical Science and Technology Research Foundation of Guangdong (No. B2021165, A2020023)

## Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by ZL and ML. The draft of the manuscript was written by ZL and all authors commented on all versions of the manuscript. All authors read and approved the final manuscript. Editing and supervision was done by YD.

## Acknowledgements

None.

Ethical approval: This study received Ethical approval by the ethical committee of Guangdong Provincial People's Hospital.

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## Figures

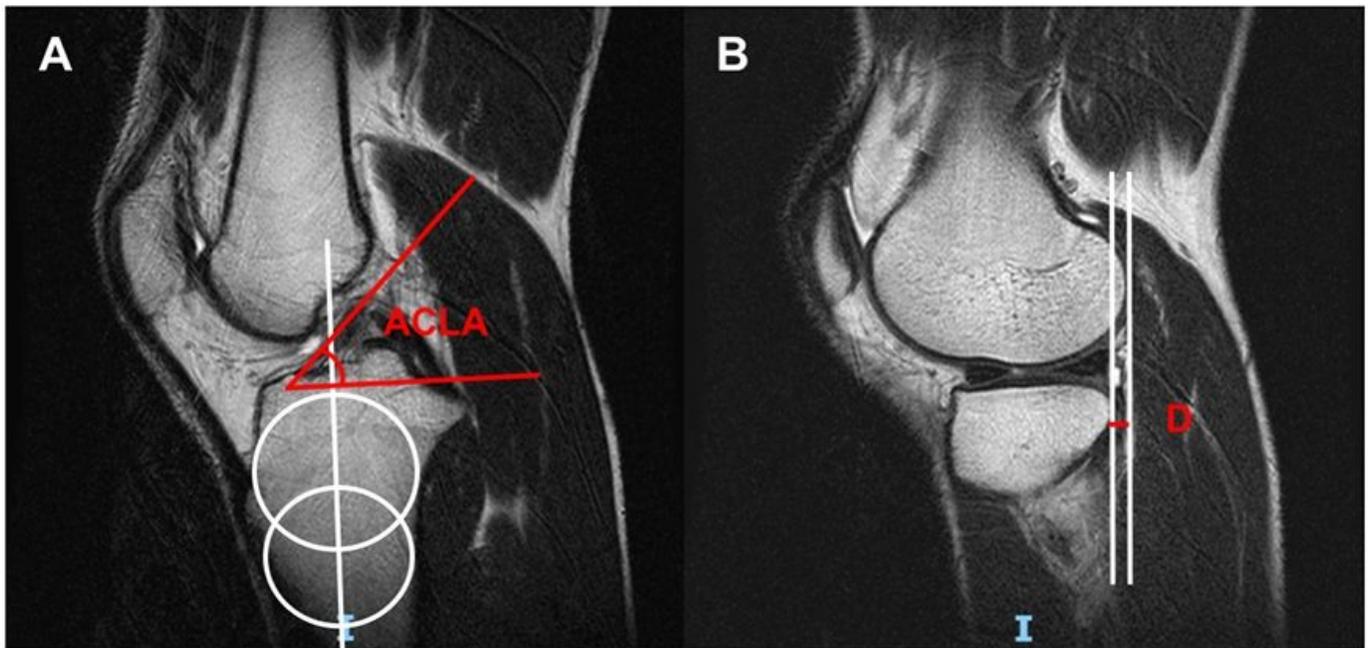
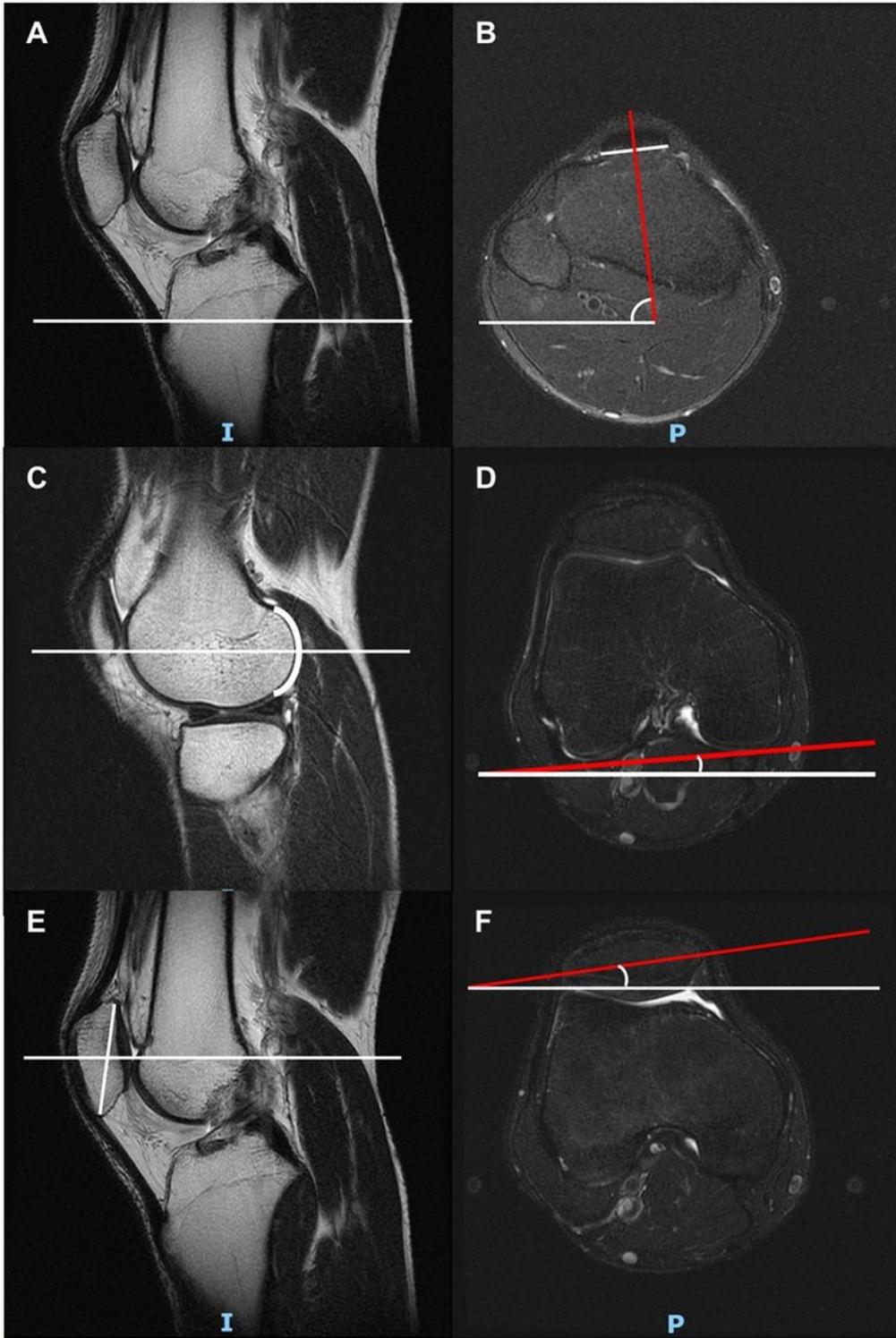


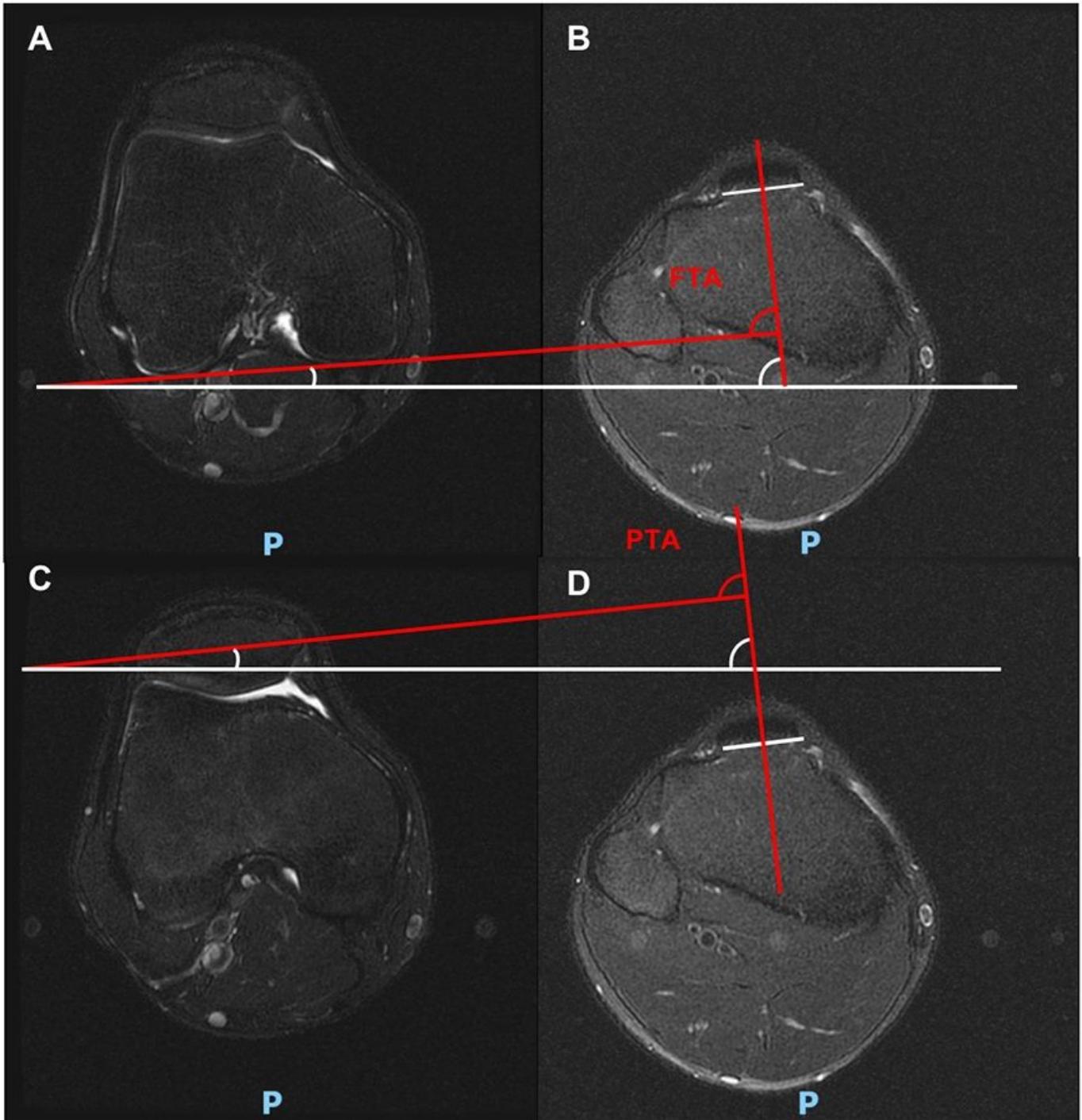
Figure 1

The measurements of ACL angle and anterior tibial subluxation. A. ACL angle; B. anterior tibial subluxation. (ACLA: ACL angle; D: distance of anterior tibial subluxation)



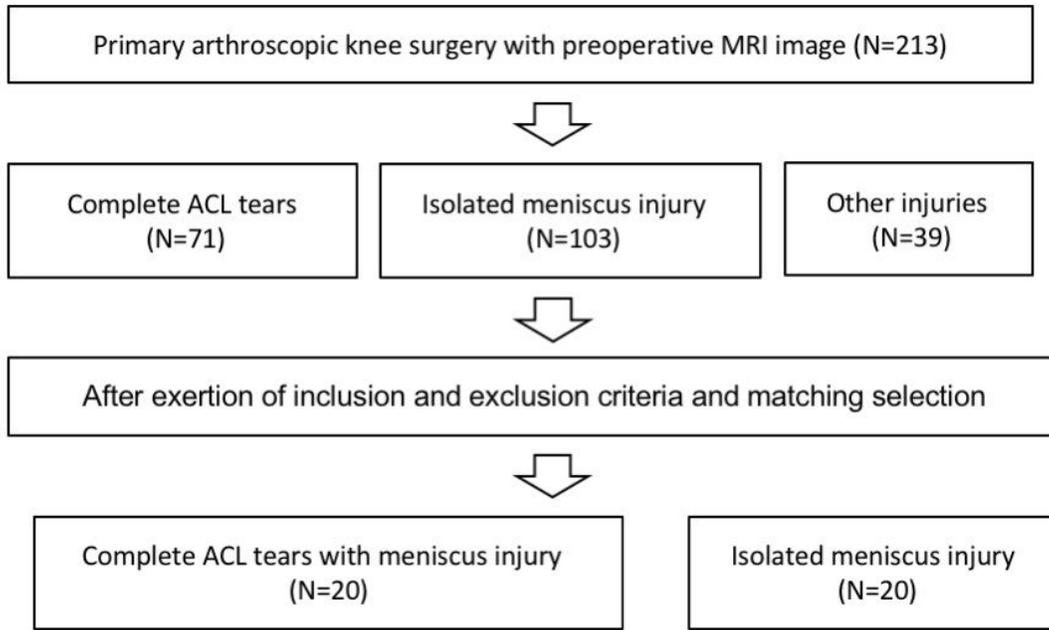
**Figure 2**

The measurement of tibial angle, femoral angle and patellar angle. A-B. the tibial angle; C-D. the femoral angle; E-F. the patellar angle. The angles were defined as positive when it directed laterally, and as negative when it directed medially.



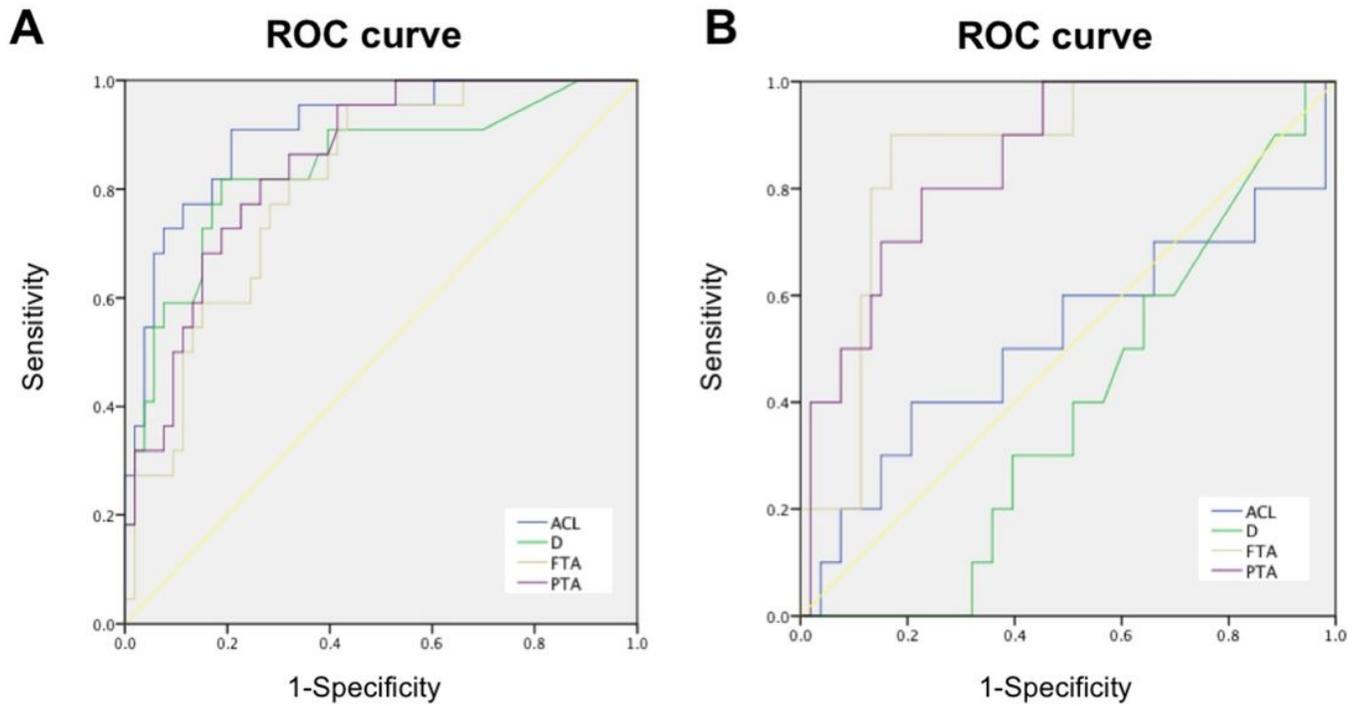
**Figure 3**

The measurement of FTA and PTA. A-B. FTA was the tibial angle minus the femoral angle. C-D. PTA was the tibial angle minus the patellar angle. (FTA: femur-tibia angle, PTA: patella-tibia angle)



**Figure 4**

Flowchart of the study participants. (ACL: anterior cruciate ligament)



**Figure 5**

ROC curves in diagnosing test. A. ROC curves in distinguishing complete ACL tear with intact ACL. B. ROC curves in distinguishing partial ACL tear with intact ACL. (ACL angle: anterior cruciate ligament angle; D: distance of anterior tibial subluxation; FTA: femur-tibia angle; PTA: patella-tibia angle)