The natural orientation of the Anterior Cruciate Ligament compared to the tibial plateau on magnetic resonance imaging scans

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ABSTRACT

Purpose: Remnant preserving Anterior Cruciate Ligament (ACL) reconstruction requires the graft to be passed through the remnant ACL stump. This requires knowledge of the native alignment of the ACL. We investigated the alignment and orientation compared directly to the tibial plateau on Magnetic Resonance Imaging. We assessed if current equipment is adequate for anatomical reconstruction.

Methods: 50 MRI scans with intact ACL and PCL were reviewed. Measurements were taken of; a) angle of ACL and tibial plateau in the sagittal plane, b) angle of ACL and tibial plateau in the coronal plane, c) position of ACL insertion into tibia as percentage of anterior-posterior width, d) position of ACL insertion into tibia as percentage of medio-lateral width. Statistical analysis included intra and interobserver agreement. Commonly used tibial guides were assessed for range of angles possible in use.

Results: The mean results for each measurement (+/- standard deviation) were; a) 45°(4.4°), b) 69°(5.5°), c) 37.2%(5.5%) d) 47.4%(1.5%). Intra-observer and inter-observer reliability were measured with satisfactory values. Not all tibial guides were able to produce an angle <45°.

Conclusion: Our study is the first comparing the angle of inclination of the ACL directly with the tibial plateau. We demonstrate the angle in the sagittal plane is lower than reported previously. This data can be used in planning the tibial tunnel using remnant preserving techniques, to orientate in the natural alignment of the ACL. Not all reconstruction systems include options to align at the lower than previously thought natural angle of the ACL.

Evidence level: III.

1. Introduction

Anterior Cruciate Ligament rupture is a common sporting injury, and around 400,000 reconstructions are performed around the world each year.¹ Tibial tunnel positioning in reconstruction has evolved over time, and recent focus has been on establishing anatomical positioning, as higher rates of graft failure have been found in non-anatomical placement of the ACL.

There are numerous techniques for ACL reconstructions, including a trend lately to develop techniques which emphasise remnant preservation. The Single AnteroMedial Bundle Biological Augmentation (SAMBBA) Technique was first published in 2014.^{2–4} It was developed on the basis of research over the last decade which has suggested that ACL remnant preservation techniques have improved intrinsic potential for healing, graft vascularisation, and preservation of proprioceptive nerve fibres, resulting in improved proprioceptive function and reduced risk of graft rupture.⁵

This technique is performed using a minimally invasive approach, and a tibial guide is used to position the guidewire in the centre of the ACL tibial stump, over which sequential diameters of drills are used to the desired size of the tibial tunnel. The femoral tunnel is created using an outside-in technique, independent of the tibial tunnel position.

We believe that if attempting to perform such an anatomical, ligament preserving ACL reconstruction, the natural inclination of the ACL should be considered. It is known that a 'windshield wiper' effect caused by the change in angle of the ACL through knee flexion can lead to widening of the tibial tunnel.⁶ Our hypothesis is that if the tibial tunnel is oriented along the natural alignment of the ACL, this would give easier passage of the graft through the stump, preserving more of the remnant, reduce the amount of force on the graft and tunnel interface, and may lead to less tunnel expansion.

We reviewed the literature to determine the natural alignment of the ACL seen on MRI scans and found a small number of studies investigating this.^{3,4,7–13} The mean angle found in these studies ranged from

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47.4°–58.8°. ^{11,12} We found this to be a wide range and generally higher angles than we were seeing intra-operatively when performing the SAMBBA technique. Most of the papers compared the angle of the ACL to a line perpendicular to the long axis of the tibia, and none compared the angle directly to the tibial plateau.

It has been shown that the tibial slope is quite varied, with a mean of 6.8° posterior slope, but a large range of –9.6°–16.8° found on a large study using CT scans. ¹⁴ As we reference the tibial tunnel using a jig based on the tibial surface, we wanted to know what the inclination was in reference to the tibial plateau at the ACL insertion, however, we were unable to find this in the literature. We therefore performed an analysis of normal knee MRI scans to determine this measurement.

We also wanted to assess the devices available to align the tibial tunnel, to determine the range of angles that they would give guidance for.

2. Methods

We reviewed 50 consecutive MRI scans of the adult knee which were reported as showing no injury to the ligaments of the knee. The MRIs were performed according to the standard knee sequence performed in the trust, using a 1.5 T MRI scanner (GE or SIEMENS), with the sagittal images oriented according to the lateral femoral condyle, using 3 mm slices with a gap of 0.5 mm between slices. The images were stored and analysed on PACS (Picture Archiving and Communications System; General Electric, Chicago, IL, USA). During the scan, the knee was positioned in a transmit-receive coil and so in a position of slight flexion. The images where the ACL was most visible in the sagittal and coronal planes were identified. Our primary outcome measure was the angle of the ACL compared with the tibial plateau in the sagittal plane. Measurements were then taken of the angle formed between the middle of the ACL and the tibial joint line on that sagittal image (Fig. 1) using the ‘cobb angle’ function in the PACS software. This was also measured in the coronal image (Fig. 2). We also measured the position of the middle of the ACL insertion onto the tibia as a percentage of the anteroposterior distance on the sagittal image (Fig. 3), and mediolateral distance on the coronal image (Fig. 4).

Fig. 1. The angle of inclination of the ACL in the Sagittal Plane.

Fig. 2. The angle of inclination of the ACL in the Coronal Plane.

Fig. 3. The position of ACL insertion as a percentage of Antero-posterior distance.

Measurements were recorded and repeated at a minimum of 6 weeks later to assess intraobserver reliability. A second investigator also performed the measurements according to the same methods to assess interobserver reliability.

Intra and interobserver reliability was measured using the intra-class correlation coefficient in Microsoft Excel and reported according to the Landis and Koch recommendations. ¹⁵

To assess the tibial drill guides we reviewed those in our trust to

Fig. 4. The position of ACL insertion as a percentage of Medio-lateral distance.

assess what the minimum angle on the device was for guiding the tibial tunnel.

3. Results

The mean age of patients in this study was 47 years old (23–72) and 30 subjects (60%) were male. The mean inclination of the ACL compared with the tibial surface in the sagittal plane was 45.4° (s.d. 4.4° , range 35.5° – 55.5°). The inclination in the coronal plane was 68.9° (s.d. 5.5° , range 53.7° – 84.0°). The position of the insertion was 37.3% of the anteroposterior distance (s.d. 5.5% , range 28–50%), and 47.4% of the mediolateral distance (s.d. 1.5% , range 44–51%).

The intraobserver and interobserver reliability are shown in Table 1. This shows fair to almost perfect strength of agreement between observers for the different measurements taken.

Table 2 shows the tibial alignment drill guides that we reviewed from our department, including the device manufacturer and the minimum angle it is possible to set the guide to.

4. Discussion

Our results show that there is variation in the natural orientation of the ACL when viewed on MRI scans. The key finding of our study is the mean angle of the ACL in the sagittal plane at its insertion into the tibial joint line is lower than reported in other studies.

While this may be due to the technique in which the MRI scan was performed, or the way in which the angle was measured, we feel that our method is the one that is most applicable to planning the tibial tunnel

Table 1
Intra and inter-observer reliability.

Measurement	Intraobserver ICC	Interobserver ICC
ACL inclination Sagittal	0.83	0.56
ACL inclination Coronal	0.66	0.45
AP position	0.44	0.36
ML position	0.44	0.30

Table 2
Minimum angles on tibial drill guides.

Device Manufacturer	Minimum Angle
Arthrex	40°
Conmed	45°
Smith and Nephew	40°
Zimmer Biomet	30°

intra-operatively using a drill guide resting on the tibial plateau at the ACL insertion.

There are a number of studies in the literature investigating the natural alignment of the ACL on MRI scans. Most of these compare the anterior line of the ACL with a line perpendicular to the long axis of the tibia. A summary of the findings of these studies findings for the inclination of the ACL at the tibial insertion in the sagittal plane is seen in Table 3.

Illingworth et al.⁹ reviewed 50 ACL intact MRI scans and found a mean angle of inclination of $49.9^\circ \pm 2.8$ with a range of 43° – 57° . These scans were performed with the knee in full extension. The angle compared the ACL with a line perpendicular to the long axis of the tibia.

Ahn et al.⁴ also reviewed 50 MRI scans of patients with meniscal tears but normal ACL, with the knee in full extension, and approximately 15 of external rotation, the slices were 4 mm. They found a mean angle of $58.7^\circ \pm 3.8$ (50.4° – 67.5°) when compared to a line perpendicular to the long axis of the tibia. They found the coronal angle to be $65.9^\circ \pm 4.4$ (range 57.7° – 75.2°). The insertion of the ACL was found to be at 37% $\pm 4.9\%$ (range 18.5–44.7) of the AP distance, and 45.7% $\pm 1.8\%$ (range 42.6–49.1) of the ML distance.

Steckel¹³ reviewed 6 cadaveric knees, and measured the angles compared to the line perpendicular to the long axis of the tibia separately for the anteromedial and posterolateral bundles of the ACL. They found the mean for the AM bundle was 48° (range 44° – 51°), while the PL bundle was 43° (range 39° – 48°).

Kim et al.¹¹ compared the angles at different ages and found that the Sagittal ACL-tibial angle increases throughout childhood, and that with a closed physis the mean angle was 58.8° . They measured the ACL against a line measured on the lateral tibial plateau. They found the angle in the coronal plane averaged 69.1° in patients with a closed physis, which was consistent with our own findings.

Reid et al.¹² reported a mean angle of $47.4^\circ \pm 4.7$ in skeletally mature patients, with a coronal angle of $75.3^\circ \pm 4.7$. Their scanning techniques were similar, but again they compared to the line perpendicular to the long axis of the tibia. They also found an increased angle in skeletally mature patients compared to skeletally immature patients, but no difference based on sex, height and BMI. The angle in the coronal plane was measured against the medial edge of the ACL and tracked through more than one slice.

Gentili et al.¹⁶ reviewed 35 scans of patients who later had a normal ACL on arthroscopy, and found the mean angle to be 55.6° when compared to a reference line through the lateral tibial plateau. He knees were positioned in full extension, and with the knee at 15° of external rotation.

Ayerza et al.³ found a mean of 51° on 30 normal knees, again

Table 3
Summary of literature.

Study	Number of Normal Skeletally Mature Knees	Mean angle in sagittal plane	Range
Current study	50	45.4°	35.5° – 55.5°
Illingworth ⁹	50	49.9°	43° – 57°
Ahn ⁴	50	58.7°	50.4° – 67.5°
Kim ¹¹	87	58.9°	43.5° – 71.2°
Reid ¹²	152	47.4°	Not reported
Gentili ¹⁶	35	55.6°	Not reported
Ayerza ³	30	51°	45° – 55°

measuring the anterior border of ACL against a line perpendicular to the long axis of the tibia.

The scans in our study were performed using a standard knee protocol, with the knee in a coil, and therefore the angle of the knee in the images is approximately 10° but would vary slightly depending on the size of the patient. The alignment of the sagittal images is in line with the lateral femoral condyle which is widely used as a surrogate for the orientation of the ACL and therefore this ensures that the angle measured is not affected by rotation of the knee. We decided to measure the angle through the middle of the ACL as this would be the position of the drill when drilling through the ACL remnant in a ligament preserving technique. The tibial joint line was measured on the same image that the ACL was most easily visible, as this would be the position that the tibial drill guide would be resting on when performing a reconstruction.

The intra and inter observer reliability was satisfactory to excellent for the different measurements suggesting that this technique for measuring the angle and position of the ACL can be reliably reproduced.

The angle of inclination in the coronal plane and the position of the footprint of the ACL on the tibial plateau have been reported in other studies with findings similar to ours, demonstrating that our MRI scans are representative of the general population and can be used reliably for taking other measurements.^{4,5,17}

The MARS study¹⁸ found that 37% of ACL reconstruction failures were felt to be due to tibial tunnel malpositioning. Whilst many studies have investigated the effect of the position of the tibial tunnel, suggesting the best outcomes are achieved when the tibial tunnel is positioned between 35 and 46% of the anteroposterior width of the tibial plateau,¹⁹ few have looked at the effect of the inclination of the tibial tunnel.

The angle of the tibial tunnel in the coronal plane has been demonstrated by Howell et al.⁸ to affect knee flexion and anterior stability, with an angle of over 75° in relation to the medial joint line having an adverse effect on both of these. The technique described was a trans-tibial technique, with the femoral tunnel drilled through the tibial tunnel. The authors acknowledge that as the tibial tunnel angle was not randomly assigned, they cannot conclusively say that the angle of the tibial tunnel was the only factor responsible for these findings. Therefore it may not be possible to translate this data to a SAMBBA technique.

Hosseini et al.⁷ reviewed failed ACL reconstructions and found that they had a much steeper graft orientation than the native ACL.

We reviewed the tibial drill guides in our department and found that not all of them could accurately measure angles of less than 45°. We only reviewed those available in our hospital, but we feel this is something important to consider if attempting to drill the tibial tunnel in line with the orientation of the native ACL.

We acknowledge that there are limitations in our study. It is known that the ACL moves during flexion and extension of the knee, and we were not able to measure this through the range of movement due to the static nature of the MRI scan. We appreciate that the angles are taken in one plane whereas the ACL is a 3-dimensional structure. We also note that there are a number of factors in successful ACL reconstruction, and the orientation of the tibial tunnel is only one of these.

We only reviewed the tibial alignment guides available in our department and acknowledge that there are other devices available.

5. Conclusion

This is the first study comparing the orientation of the ACL directly to the tibial plateau on MRI scans. We believe this method most accurately corresponds to the angles that would be measured on the alignment guide intra-operatively. Our results demonstrate a lower angle of orientation in the sagittal plane when compared to other techniques. This highlights the importance of considering the individual patient's anatomy and this data can be considered to help plan more anatomically orientated tibial tunnels when performing remnant preserving ACL reconstruction.

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Ethical approval

Not required as per NHS HRA website guidance.

Informed consent

For this type of study, formal consent is not required.

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Authors' contribution

NJ conceived and designed the study. Data was collected and analysed by AK and MS. AK prepared the manuscript and this was reviewed and redrafted by all authors. The final manuscript was reviewed by all authors.

Declaration of competing interest

The authors have no relevant conflicts of interest to declare.

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