An increased posterior slope of the medial and lateral meniscus posterior horn is associated with anterior cruciate ligament injuries

Erik Hohmann *
MBBS, FRCS, FRCS (Tr&Orth), PhD, MD
Valiant Clinic/Houston Methodist Group, Dubai, United Arab Emirates; School of Medicine, University of Pretoria, South Africa
E-Mail: dr.erik@burjeelspecialty.com

Kevin Tetsworth
MD, FRACS
Department of Orthopaedic Surgery, Royal Brisbane Hospital, Herston, Australia
Department of Surgery, School of Medicine, University of Queensland, Australia
Limb Reconstruction Center, Macquarie University Hospital, Macquarie Park, Australia
Orthopaedic Research Centre of Australia, Brisbane, Australia
Herston Biofabrication Institute, Brisbane, Australia
E-Mail: ktetsworthmd@gmail.com

Vaida Glatt
PhD
Department of Orthopaedics, University of Texas Health Science Center, San Antonio, Texas, USA
Orthopaedic Research Centre of Australia, Brisbane, Australia

Mthunzi Ngcelwane
MBChB, FCS Orth (SA)
Department of Orthopaedic Surgery, Steve Biko Academic Hospital, Pretoria, South Africa
E-Mail: mthunzi.ngcelwane@up.ac.za

Natalie Keough
PhD

Department of Anatomy, School of Medicine, Faculty of Health Sciences, University of Pretoria, South Africa
Department of Anatomy and Cellular Biology, College of Medicine and Health Sciences, Khalifa University, Abu Dhabi, United Arab Emirates
E-Mail: Natalie.VanNiekerk@ku.ac.ae>

***Corresponding Author**
Erik Hohmann, School of Medicine, Faculty of Health Sciences, University of Pretoria, Cnr Bophelo and Dr Savage Road, Gezina, Pretoria, 0001, South Africa
E-Mail: dr.erik@burjeelspecialty.com

Author contributions:
EH: Conceptualisation, protocol, design interpretation, writing, final approval of manuscript
MN: Conceptualisation, protocol, final approval of manuscript
KT: Conceptualisation, protocol, writing, final approval of manuscript
VG: Conceptualisation, protocol, writing, final approval of manuscript
NK: Conceptualisation, protocol, design interpretation, writing, final approval of manuscript

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

Abstract

Purpose:

To measure the slope of the medial and lateral posterior horn of the meniscus, and its contribution to the overall resulting posterior tibial slope (bone and meniscus combined slope) in anterior cruciate ligament-intact (ACLI) and ACL-deficient (ACLD) knees.

Methods:

Magnetic resonance images of intact menisci in patients 16 to 60 years old were included.. Posterior tibial bone slope (PTS) and meniscus slope (MS) were measured at 25%, 50%, and

75% from the medial and lateral borders of the tibial plateau. ANOVA was used to determine differences in posterior tibial slopes between ACLD and ACLI knees, and between sex for ACLD and ACLI knees.

Results:

192 ACLI patients (35.2±9.6 years) and 159 ACLD patients (34.2+10.3 years) were included. Medial and lateral PTS in ACLD was significantly ($p=0.00001$) higher at 25%, 50%, and 75%. Medial and lateral MS in ACLD was significantly ($p=0.00001$) lower at 25%, 50%, and 75%. There were no significant sex differences for both medial and lateral MS between ACLD and ACLI patients ($p=0.51$). The resultant combined medial and lateral slope in ACLD patients was significantly ($p=0.00001$) lower at 25%, 50%, and 75%. There were no significant sex differences in PTS ($p=0.68$), MS ($p=0.51$), or resultant slope ($p=0.79$)

Conclusions:

The results of this study strongly suggest that lower meniscal slopes of both the medial and lateral posterior horns are associated with ACL injuries in both males and females. Although the posterior horns reversed the bone PTS to an anterior inclined slope in both ACL deficient and ACL intact patients, both the meniscus slope and the combined resultant slope was significantly lower and more positive at all six measured locations in ACLD knees.

Key words:

Posterior tibial slope; meniscal slope; posterior horn meniscus; anterior cruciate ligament injuries; risk factors

Level of Evidence:

Level III Retrospective Cohort Study

Introduction

The anterior cruciate ligament (ACL) is the main stabilizer for anterior-posterior knee stability, and provides nearly 90% of the total restraint at 30 degrees of knee flexion. [1] However, the meniscus also plays a role and contributes to knee stability. [2] In a cadaver study that was performed over 30 years ago, application of an anterior directed load following a bucket-handle tear resection of the medial meniscus in ACL deficient knees caused the tibia to subluxate forward. [3] In the same study, complete lateral and medial meniscectomies also resulted in anterior tibial subluxations.[3] Allen et al. later demonstrated that in ACL deficient knees a medial meniscectomy resulted in significantly increased anterior tibial translation (ATT) at all knee flexion angles. [4] The lateral meniscus is a further restraint against ATT during combined anterior, valgus and rotatory loads, simulating a pivot shift test. [5] Medial meniscectomy had no effect on ATT during a pivot shift, but ATT instead increased significantly during a Lachman manoeuvre. [5] These potential changes in knee kinematics in the ACL deficient knee indicate that both medial and lateral menisci contribute to knee stability. [6]

Increased posterior tibial bone slope (PTS) has previously been identified as an independent risk factor for ACL injuries. [7-9] Dejour and Bonnin demonstrated that every 10 degree increase in PTS was associated with a 6 mm increase in ATT. [10] Similarly, Giffin et al. demonstrated that increasing PTS resulted in an anterior shift in the resting position of the tibia, and a decrease in PTS reduced ATT and was protective against ACL injury. [11] Hashemi et al. reported that a combination of an increased PTS and a shallow medial tibial plateau was associated with a greater susceptibility to ACL injury. [12]

The menisci are semi-lunar and wedge shaped structures situated between the corresponding femoral condyle and tibial plateau. [13] The posterior horn is thicker than the anterior horn, and these morphological features can be considered to contribute to the overall posterior tibial slope. [2,14] Theoretically, the posterior horns of the menisci could stabilize the knee against ATT similar to a chock block next to a tyre, impeding roll. This proposition is supported by Elmansori et al. who identified increased meniscal slope as a risk factor for ACL injury. [2] Similarly, Song et al. showed that an increased medial meniscus slope increased the risk of meniscus ramp lesions. [14]

The purpose of this study was therefore to measure the slope of both the medial and lateral posterior horn of the meniscus and its contribution to the overall resulting tibial slope (bone and meniscus combined slope) in ACL intact and ACL deficient knees. It was hypothesized that the slope of the posterior horns and combined tibial slope would be significantly lower in the ACL-deficient knees, with larger posterior horn slopes being protective against ACL-injury.

Methods

This study received prior approval from the ethics committee of the University of XX (ethics approval number: xx – blinded for review), and complied with all requirements set out in the National Health Act 63 of 2003. The IMPAX (AGFA Healthcare©, Mortsel, Belgium) picture archiving and communication system (PACS) database of the department of radiology of a subspecialty tertiary hospital for orthopaedic surgery was searched for all MRI scans of the knee performed between January 2018 to July 2020. For ACL injured patients the following inclusion criteria were applied: non-contact injury mechanism, biological age between 16-60 years, with skeletal maturity and closed growth plates on all MR images; intact menisci on all images, isolated ACL injury. Patients were excluded if there was evidence of collateral, posterior cruciate, posterolateral corner or multi-ligament injuries, chondral injuries, intra-meniscal signal changes suggestive of degenerative meniscus tears, or evidence of prior/acute fractures. The medical records of these patients were then checked to ensure that only non-contact injuries were included. The criteria of Alentorn-Geli et al. [15] were used to define non-contact injuries: no physical contact with an opponent or stationary object at the time of injury. If the mechanism of injury could not be established, the images were excluded from analysis. For the ACL intact patients, the above inclusion criteria were also applied, with the only exception that MR images with a demonstrated ACL-injury were excluded. Electronic records were further cross checked to ensure compliance with the inclusion and exclusion criteria.

Slope Measurements

The annotation tools of the PACS system were utilized to carry out all measures of the bone and meniscal slope angles. These tools allow tracing of the anatomical landmarks, connecting regions of interest, and digital measurement of different angles. Proton density images were used for all measures.

Posterior Tibial Bone Slope

On a split screen, the coronal, sagittal, and axial images were displayed, and the scout line and localizer mode were used to establish the centre of the tibial plateau on the axial image. The scout and localizer mode of the PACS software allows to precisely establish the centre of the tibial plateau [figure 1c]. The corresponding intermediate vertical line on the coronal image [figure 1a] was defined as the line dividing the tibial plateau into equal medial and lateral halves. The vertical intermediate line on the sagittal image was defined as the proximal tibial anatomic axis (PTAA), dividing the sagittal image into an anterior and posterior half [figure 1b]. On the coronal image [figure 1a] a horizontal line was drawn passing through the most inferior aspect of the medial and lateral tibial plateaus. The annotation tools were used to draw vertical lines parallel to the intermediate vertical line at 25%, 50%, and 75% from the medial and lateral borders of the tibial plateau [figure 2]. The corresponding sagittal images were identified with the scout mode on a split screen, and the previously identified PTAA (line 1b) from figure 1 was then transferred to figure 3 using the functions of the PACS software [figure 3]. The posterior tibial slope was measured as the angle between a perpendicular line to the PTAA (line 2) and a line drawn from the most anterior to the most posterior point of the tibial plateau [line 3] [figure 3]. If the slope was directed posterior it was defined as posterior or negative (-), and if the slope was directed anterior it was defined as anterior or positive (+).

Posterior Meniscus Slope

To establish the meniscus slope of the posterior horn, a line was drawn between the most posterior and proximal point of the meniscus along its superior surface [figure 4]. The angle between this meniscus line (line 4) and the tibial plateau line (line 3) (from figure 3) was measured and defined as the slope of the posterior horn of the meniscus [figure 4]. Similar to the PTS, slope was defined as posterior or negative (-) if the slope was directed posterior, and anterior or positive if the slope was directed anterior. The overall resulting slope (PTS and posterior horn meniscus slope) was calculated by adding the meniscal slope to the bone slope, defining the resultant combined posterior slope.

Statistical analysis

Descriptive statistics were used for all measures. Mean bone and meniscal slope angles, standard deviation, range, and 95% confidence intervals were calculated. Normal data distribution was assessed with the Shapiro-Wilks Test, and homogeneity of variance verified with Levene's test. One-way analysis of variance (ANOVA) was used to determine differences between posterior tibial slopes at the 25%, 50%, and 75% distances for the medial and lateral tibial plateau, between the ACL deficient and ACL intact group, and between male and female ACL injured and control groups. A level of significance of $p<0.05$ was selected for all analyses. In the event of a significant main effect or interaction, post hoc comparisons were conducted using the least significant differences. An a-priori sample size analysis was performed using G*Power 3.1.9.2 and the following variables: Cohen's effect size $q \geq 0.3$, $p=0.05$, power of 0.9, critical $t=-1.98$, ß error 0.2, two tailed. The sample size calculation based on these parameters indicated that a minimum of 119 measures were needed to provide 90% statistical power. Intra- and inter-rater reliability (ICC) were obtained by repeating the measures using ten randomly selected MR images. Any demographic details were concealed on the images, and the first author and two experienced research associates drew all lines and measured all angles independently on two consecutive days. The two research associates were board certified academic radiologists who have completed a fellowship in musculoskeletal radiology. The images were presented in random order to reduce recognition. The algorithm of Landis and Koch was used to assess the rate of agreement. [16] Values above 0.80 represented excellent agreement, values between 0.62-0.79 were considered good agreement, values between 0.41-0.61 indicated moderate agreement, and values below 0.4 suggested fair to poor agreement. [16] All analyses were conducted using STATA SE (Version 12.0; StataCorp, College Station, Texas, USA) for Windows.

Results

A total of 983 MRI studies were performed from January 2018 to July 2020. Meniscus injuries were observed on 424 image sets and were excluded, as were 95 patients under the age of 16 years and 23 patients over the age of 60 years. Chondral defects and degenerative changes were noticed on 62 image sets and 28 more had evidence of multi-ligament injuries, resulting in 632 excluded image sets. The total number of included image sets was therefore 351. There were 192 ACL-intact image sets with a mean age of 35.2±9.6 years. In the ACL-intact group, there were 118 males with a mean age of 35.7±10.2 years, and 74 females with a mean age of 34.6±11.9 years. In 114 cases the MR images did not demonstrate any pathology. The remainder of the images showed the following pathology: 45 cases with signal changes in the patellar cartilage, consistent with grade 1 and 2 chondromalacia; 21 cases with grade 2 MCL sprains; 9 cases with patella tendinitis; and 3 cases with bone bruising in the medial tibial plateau in long-distance runners, consistent with impending stress fractures. In the ACL-deficient group, there were 159 image sets with a mean age of 34.2+10.3 years. There were 93 males with a mean age of 35.3±11.1 years, and 66 females with a mean age of 33.6±9.3 years. The demographics of both groups are summarized in Table 1.

Intra- and inter-rater reliability (ICC) between the three raters for the vertical intermediate line and 25%, 50%, and 75% lines ranged from 0.95-0.98 for inter-rater reliability and 0.94-0.99 for intra-rater reliability. Intra- and inter-rater reliability (ICC) between the three raters for proximal tibial anatomic axis and tibial plateau slope lines ranged from 0.89-0.93 for inter-rater reliability and 0.92-0.96 for intra-rater reliability. Intra- and inter-rater reliability (ICC) between the three raters for the PTS ranged from 0.91-0.94 for inter-rater reliability and 0.94-0.97 for intra-rater reliability. Given the consistent higher ICC for intra-rater reliability, all measures were therefore performed by the first author [xx] only.

Posterior Tibial Slope

The results for the posterior tibial bone slope are summarized in Tables 2-4. For the medial posterior bone slope, ACLD patients had a significantly (p=0.00001) higher slope at 25%, 50%, and 75% Similarly, the lateral posterior bone slope was significantly (p=0.00001) higher in the ACLD patients. .

Males

In males, the medial posterior bone slope in ACLD patients had a significantly (p=0.00001) higher slope at 25%, 50%, and 75%. , (table 3). Similarly, the lateral posterior bone slope was significantly higher in the ACLD patients (table 3).

Females

In females, the medial posterior bone slope in ACLD patients had a significantly (p=0.00001) higher slope at 25%, 50%, and 75% (table 4). Similarly, the lateral posterior bone slope was significantly higher in the ACLD patients(table 4).

There were no significant differences in PTS between males and females, comparing between either the lateral or medial compartment bone slope in both ACLD and ACLI patients (p=0.68).

Meniscus Slope

The results for the meniscus slope of the posterior horn are summarized in Table 2-4. For the medial meniscus slope, ACLD patients had a significantly (p=0.00001) lower slope at 25%, 50%, and 75 Similarly, the lateral meniscus slope was significantly (p=0.00001) lower in the ACLD patients.

Males

In males, the medial meniscus slope in ACLD patients had a significantly (p=0.00001) lower slope (table 3). Similarly, the lateral meniscus slope was significantly lower in the ACLD patients (table 3).

Females

In females, the medial meniscus slope in ACLD patients had a significantly (p=0.00001) lower slope at 25%, 50%, and 75% (table 4). Similarly, the lateral meniscus slope was significantly lower in the ACLD patients (table 4).

ANOVA revealed no significant differences in PTS between males and females for comparisons between either the lateral or medial compartment meniscus slope in both ACLD and ACLI patients (p=0.51).

Resultant Posterior Tibial Slope

The findings for the resultant combined slope for both the medial and lateral compartment are summarized in Tables 2-4. For the medial resultant combined slope, ACLD patients had a significantly (p=0.00001) lower slope at 25%, 50%, and 75. Similarly, the lateral resultant combined slope was significantly (p=0.00001) lower in the ACLD patients.

Males

In males, the medial resultant combined slope in ACLD patients had a significantly (p=0.00001) lower slope at 25%, 50%, and 75 (table 3). Similarly, the lateral resultant combined slope was significantly lower in the ACLD patients (table 3).

Females

In females, the medial resultant combined slope in ACLD patients had a significantly (p=0.00001) lower slope at 25%, 50%, and 75 (table 4). Similarly, the lateral resultant combined slope was significantly lower in the ACLD patients (table 4).

ANOVA revealed that there were no significant differences in PTS between males and females for comparisons between either the lateral or medial compartment resultant combined slope measures in both ACLD and ACLI patients (p=0.79).

Discussion

The results of this study strongly suggest that lower meniscal slopes of both the medial and lateral posterior horns are associated with ACL injuries in both males and females. Although the posterior horns reversed the PTS to an anterior inclined slope in both ACL deficient (ACLD) and ACL intact (ACLI) patients, the resultant slope was still significantly lower and less positive by a minimum of 8 degrees at all six measured locations. The 95% confidence intervals did not overlap for any of the measures employed, suggesting these findings are likely to be clinically relevant.

This study confirms earlier findings by Elmansori et al. [2] However, Elmansori et al. utilized the highest points of the anterior and posterior horns of both menisci to calculate meniscal slopes but also demonstrated that both bony and soft tissue meniscus slopes were lower and directed more posterior in ACLD patients. [2] In direct contrast to the results of this study, they also reported that the medial tibial bone slope was greater, but the medial soft tissue slope compensated as it was larger than the lateral soft tissue slope. [2] Although the medial bone slope was also higher, the meniscus slope of the posterior horn was consistently higher in the lateral compartment. These differences in findings are most likely related to the specific measurement techniques employed. Elmansori et al. [2] included the anterior horn of the meniscus and measured overall meniscus slope, while this study focussed only on the posterior horn.

The combination of a lower PTS together with a larger lateral posterior horn meniscus slope was consistent in both the ACLD and ACLI groups, suggesting that the lateral meniscus may be more important in restraining anterior tibial translation. Musahl et al. have shown that the lateral meniscus is a more important restraint to anterior tibial translation during combined valgus and rotatory loads. [5] These findings are supported by Hudek et al., [17] who demonstrated the medial meniscus slope had no relationship with ACL injury, whereas a higher lateral meniscus slope reduced the risk of ACL injury. Again, the findings of Hudek et al. were in contrast to the results of the current study. [17] Differences between the lateral and medial compartment were not observed, and both the medial and lateral meniscus posterior horn slope were significant predictors of ACL injury. Hudek et al. also utilized the highest points of the anterior and posterior horns of both menisci to calculate meniscal slopes. [17] However, the anterior horn of both menisci almost certainly does not stabilize the knee against anterior tibial translation at all, due to its anterior location. From the biomechanical perspective, ATT would more likely increase if the posterior secondary stabilizers are dysfunctional. Guess and Razu used a finite element analysis to investigate hoop forces in an ACLI and an ACLD model, and observed increased contact forces and hoop tension in the posterior horn of the medial meniscus, with no change in the anterior horn. [20] They concluded that the posterior horn of the medial meniscus provides a physical barrier that limits anterior tibial translation. [20] In a similar study, Bendjaballah et al. demonstrated that medial meniscectomy resulted in increased coupled tibial external rotation, increased forces on the lateral tibial plateau, and larger compressive joint forces. [21] Including the anterior horn of the meniscus when measuring soft tissue slope may therefore be deceptive, and based on the above evidence one could argue that the anterior meniscal horns are not relevant with respect to anterior tibial translation and knee stability.

If the posterior meniscus horns do in fact act as a wedge between the posterior femoral condyle and tibial plateau to potentially reduce ATT, a smaller wedge should allow increased anterior excursion of the femoral condyle. [17] In the ACLD knee this would cause increased load and contribute to a higher prevalence of posterior horn injuries. Hollis et al. demonstrated that ACL tears increased strain in both the medial and lateral posterior meniscus horns by 50%, while ACL reconstruction returned the strain to its native state. [22] Song et al. reported that an increased medial meniscus slope increased the risk of meniscus ramp lesions. [14] Markl et al. showed that a higher medial compartment posterior tibial slope, defined as a PTS of >10 degrees, increased the risk of a meniscus lesion by a factor of 2.1, and a higher lateral compartment posterior slope increased the risk by a factor of 3.4 in ACLD knees [23] Okoroha et al. demonstrated that an increased posterior tibial bone slope increased the risk of a lateral meniscus posterior root tear. [24] Zaffagnini et al. demonstrated a 25% decrease in antero-posterior laxity and a 50% decrease in internal rotation following both medial and lateral meniscus transplantations. [25] Obviously, restoration of meniscus slope by MAT resulted in restoration of normal meniscus height and biomechanics, and possibly underlines the importance of the posterior meniscus horns for knee stability. Lorbach et al. reported that an additional meniscus tear in ACLD knees resulted in a 17% increase in ATT, which returned to its intact state when the meniscus was repaired. [26] Ahn et al. showed that medial meniscus posterior horn longitudinal tears resulted in a significant increase in anterior-posterior tibial translation at all flexion angles and meniscal repair improved tibial translation. [27] In a cadaveric study, resection of one-third, two-thirds, or the entire posterior horn of the medial meniscus increased ATT by 0.1 mm with minor resection, 0.5 mm with major resection, and 1.1 mm with total resection. [28] Removing the mechanical block of the posterior horn of the medial meniscus by resection of two-thirds or more changed the kinematics of the knee and caused an increase in ATT. [28] With regard to the lateral meniscus posterior horn, root tears increased anterior knee instability, while repair again restored knee stability to close to its native state. [29,30] It appears that the current available evidence supports the important role of the both the lateral and medial posterior meniscus horns in providing resistance against ATT.

The findings of this study further support an association between both MTPS and LTPS with ACL injury, consistent with the results of a recent meta-analysis. [31] However, despite the inclusion of 29 studies into the meta-analysis resulting in substantial heterogeneity, the lack of uniform imaging techniques and references for measuring tibial plateau slopes further weakened the conclusions of that particular study. Subgroup analysis suggested that PTS would only be considered a risk factor for males but not for females. [31] Wang et al. believed that other risk factors may be associated with the higher incidence of ACL injury in females, and offered no explanation as to how to interpret slopes in females. [31] Regardless, the forest plots from Wang et al. clearly demonstrate both males (SMD 0.41, p=0.0001) and females (SMD 0.31, p=0.06) have a higher risk of ACL injury with a larger PTS. The current study could not establish any meaningful differences between sexes, and also demonstrated that both males and females have very similar values, with the only differences observed being higher slopes for both PTS and MS in ACLD patients. These findings suggest that ACL injury related to posterior slope, of either bone or meniscus, is independent of sex.

The clinical relevance of this basic radiographic study is not quite clear. The highly significant between group differences clearly suggest an association between reduced posterior horn meniscal slope and ACL injury. The findings of the study also confirm the earlier findings by Hudek et al., who demonstrated that the meniscus soft tissue slopes were significantly lower in patients with an ACL injury. [17] One could argue that the increased risk of posterior meniscus injuries in ACL-deficient knees, [14] an increase of strain in both the medial and lateral posterior meniscus horns by 50%, an increase of anterior tibial translation with posterior horn meniscus tears, [27] and a significant decrease in antero-posterior laxity following meniscus transplantations are all indirect signs of the potential clinical importance of higher meniscal slopes. It is also not known whether the posterior meniscus horns compensate for increased posterior tibial slopes, and further studies are required to investigate this potential confounding variable.

Limitations

This study has some important limitations. Height and weight of the included subjects were not measured, and there might be a correlation between the posterior slope and these demographic variables. The MR images were performed in the supine position with all knees in slight flexion. The measures obtained in this study do not address dynamic aspects, and weight-bearing and loading the knee during deceleration/acceleration movements may alter the meniscal height and have a flattening effect. Slope measurements also depend on the population groups and the Asian population tends to have a higher posterior slope. [32] The images included in this study were obtained mainly in European and Arabic patients, and morphometric differences between other population groups may potentially limit the generalizability of the findings. The PTAA was established using the centralization technique described, and did not consider other deformities of the tibial shaft such as varus/valgus or other sagittal plane deformities. This could have theoretically introduced measurement error, but this approach was used consistently in both groups, and systematic error for between group differences is unlikely. Although the highly significant between group differences suggest a clear relationship between meniscus slope and ACL injury, the results of this study do not demonstrate a causal relationship.

Conclusions

The results of this study strongly suggest that lower meniscal slopes of both the medial and lateral posterior horns are associated with ACL injuries in both males and females. Although the posterior horns reversed the bone PTS to an anterior inclined slope in both ACL deficient and ACL intact patients, both the meniscus slope and the combined resultant slope was significantly lower and more positive at all six measured locations in ACLD knees.

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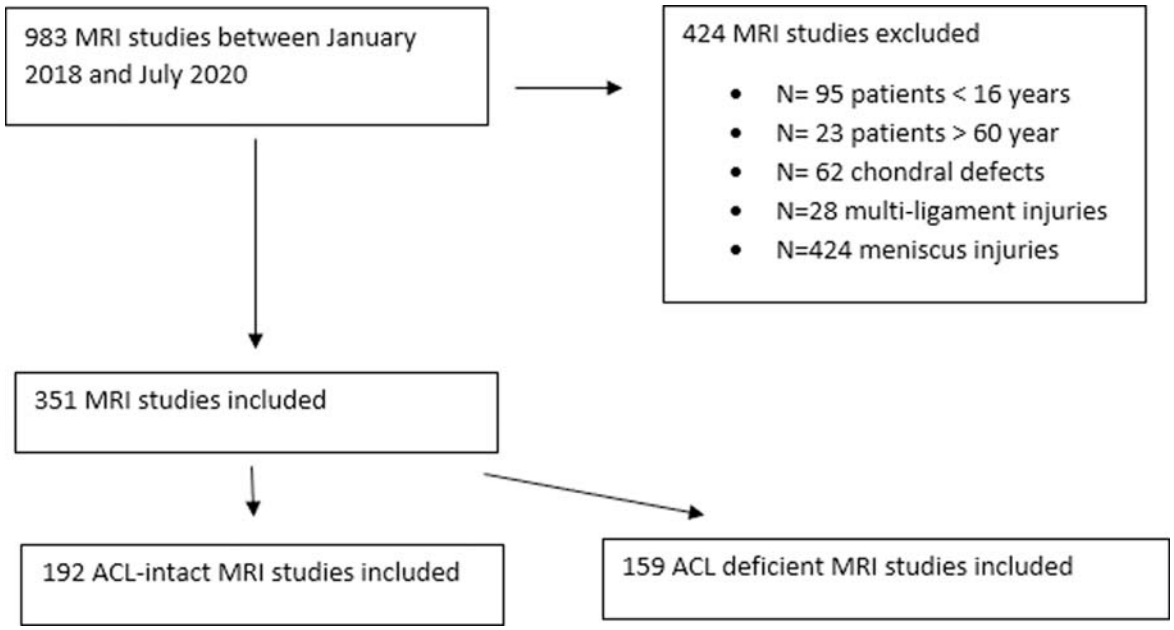

Figure 1:

Flow diagram outlining the MRI images included.

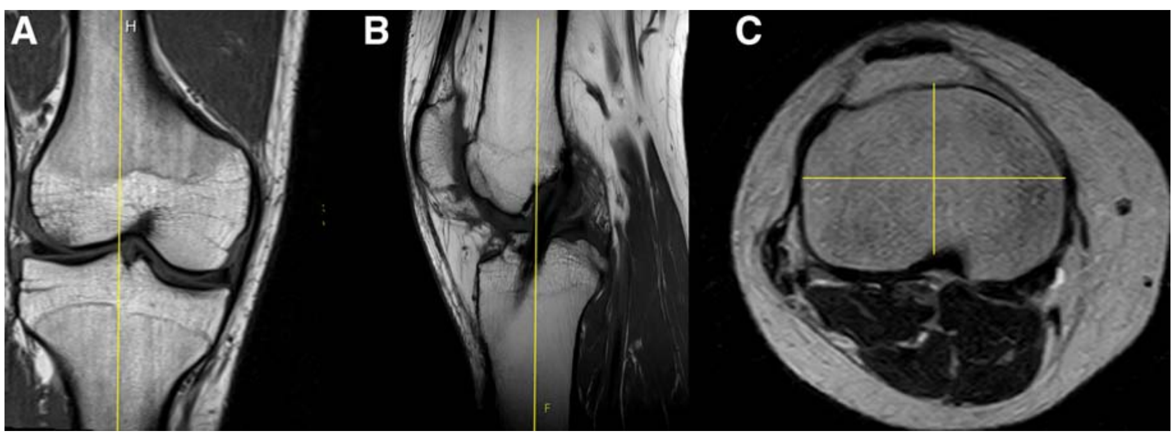

Figure 2:

The annotation tools including scout and localiser modes of the PACS Impax were used to establish the centre of the tibial plateau. The tools allow simultaneous shifting of reference lines in corresponding axial [1c], sagittal [1b] and coronal [1a] images. The vertical intermediate line on the sagittal image was defined as the proximal tibial anatomic axis and divided the plateau into an anterior and posterior half. Similar, the vertical intermediate line on the coronal image divided the tibial plateau into a medial and lateral half.

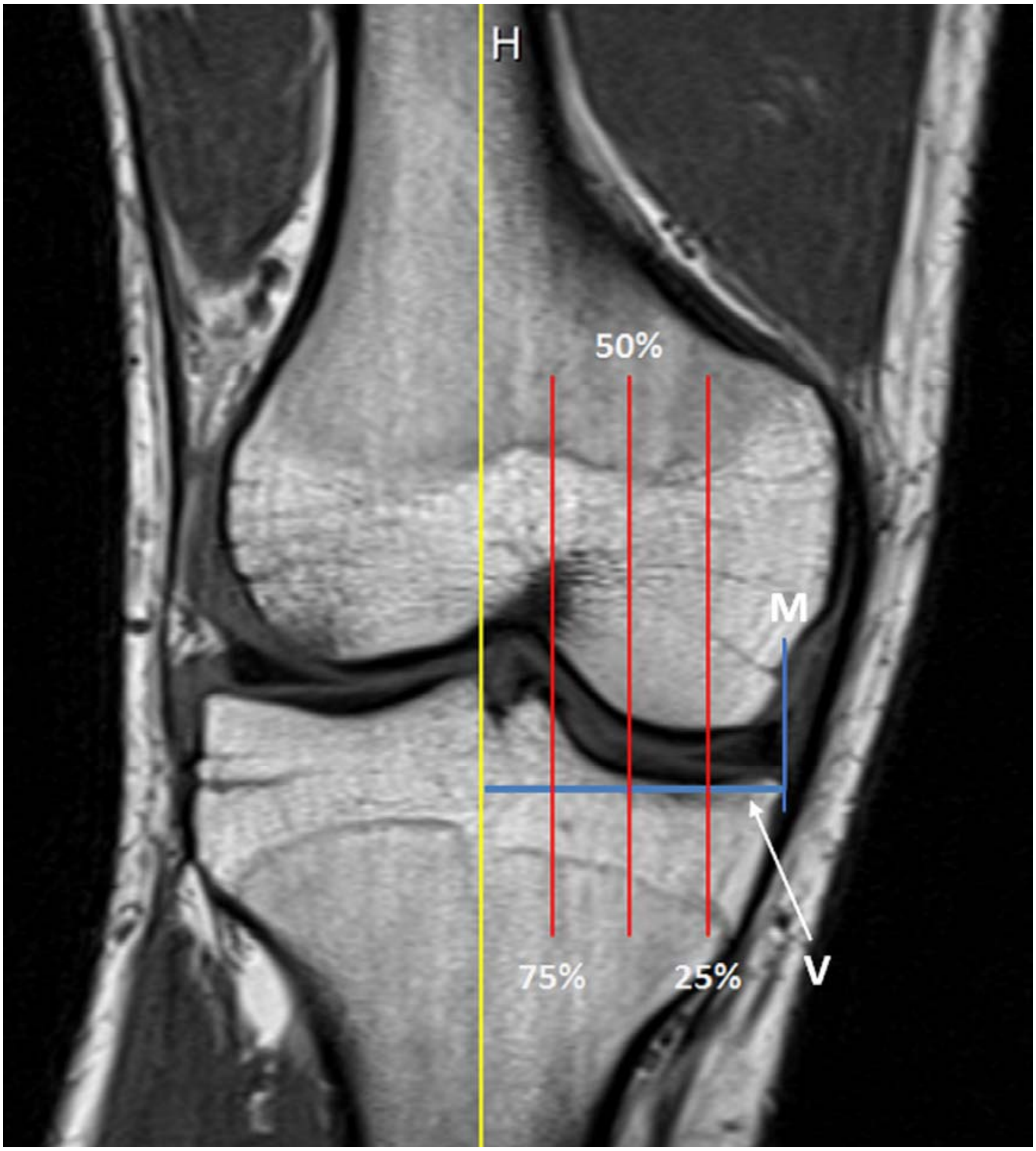

Figure 3:

The coronal image [figure 1a] including the corresponding intermediate vertical line [H] was used and the most medial respectively lateral aspect of the joint line was marked with a vertical line [M]. A line was then drawn from the joint line [V] to the centre of plateau passing through the most inferior aspect of the plateau. The annotation tool was used to draw three parallel lines 25%, 50% and 75% from the joint line.

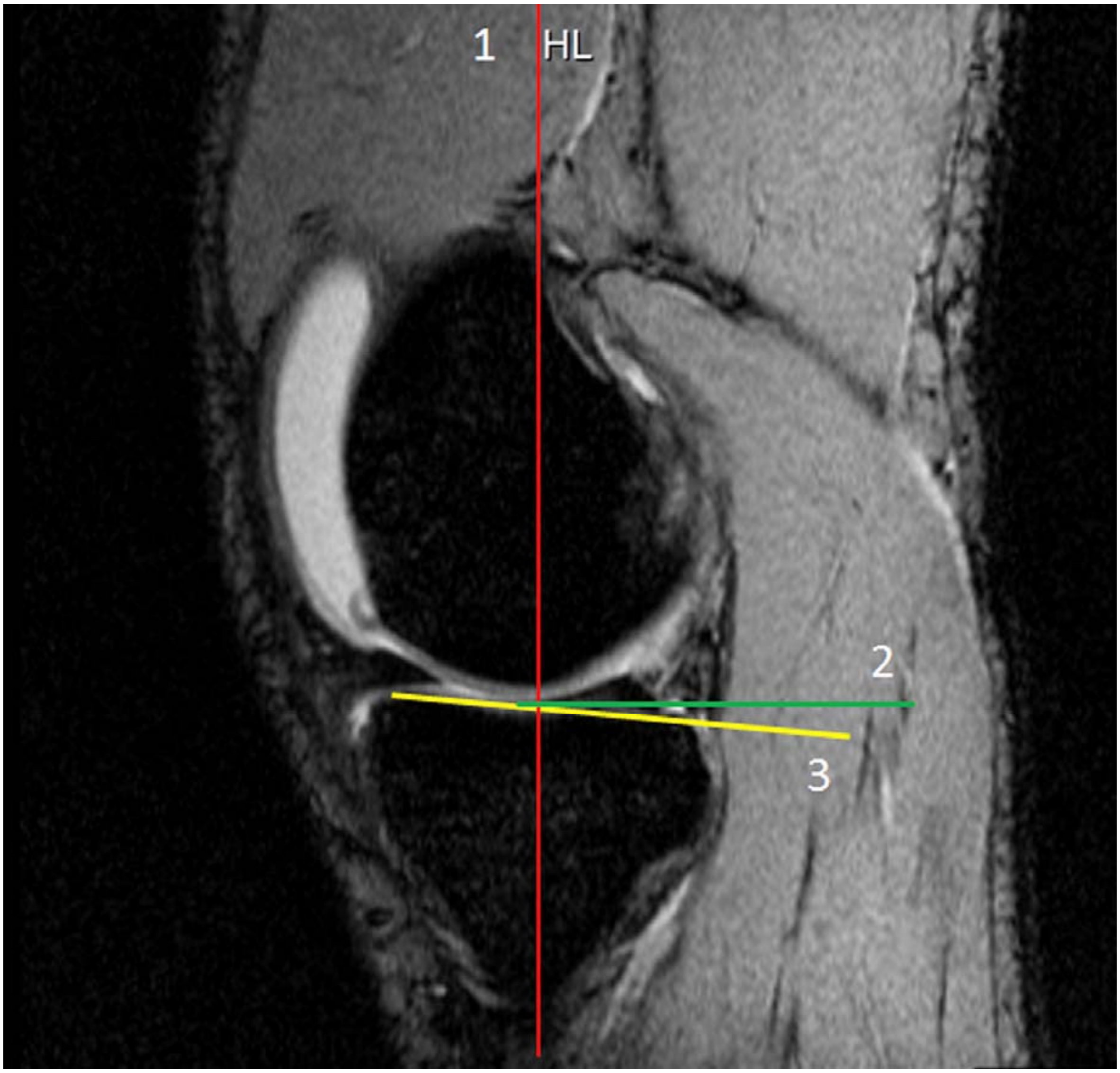

Figure 4

The previously established vertical intermediate line (line 1) from the sagittal image [figure 1b] was transferred to figure 3 and defined as the proximal tibial anatomic axis (PTAA). The tibial plateau was defined as a line drawn from the most anterior to the most posterior point (line 3). An additional perpendicular line (line 2) to the PTAA was drawn from the point where the tibial plateau line meets the PTAA. The angle between this line (line 2) and the tibial plateau line (line 3) was defined as the posterior tibial slope. The slope was defined as posterior (-) if the plateau line is inferior to the perpendicular line and anterior (+) if the plateau line is proximal to the perpendicular line.

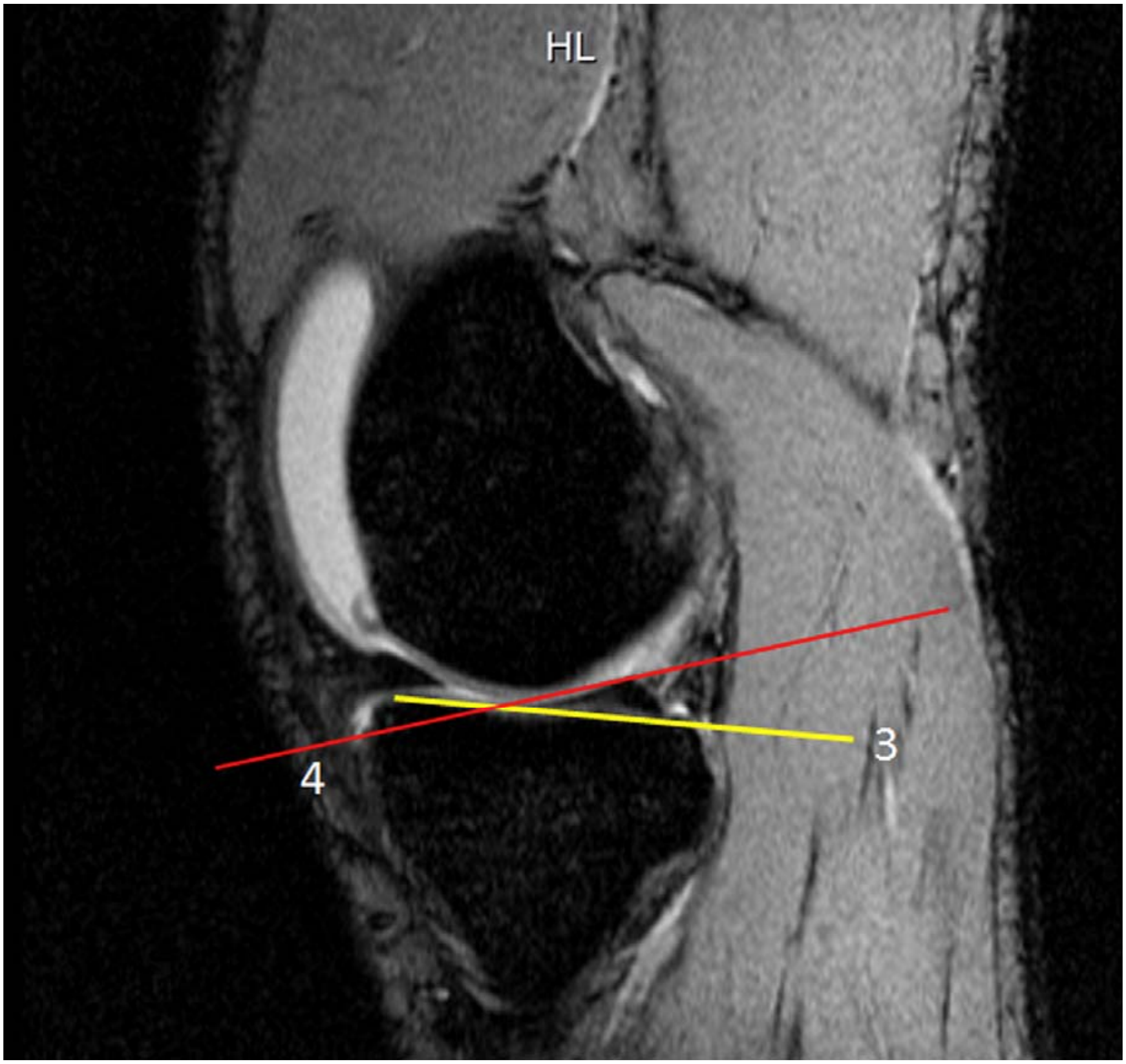

Figure 5

A line was drawn from the most posterior and proximal point of the meniscus and carried anterior along the superior surface of the meniscus (line 4). The angle between the tibial plateau (line 3) and the meniscus line (line 4) was defined as the meniscus slope.

Table 1 Demographics of the ACL-intact and ACL-deficient group

		ACL-Intact	ACL-Deficient
	Total	N=192	N=159
	Mean Age	35.2+9.6	34.2+10.3
	Range	16-60	16-60
Males	Total	N=118	N=93
	Mean Age	35.7+10.2	35.3+11.1
	Range	16-60	16-60
Females	Total	N=74	N=66
	Mean Age	34.6+11.9	33.6+9.3
	Range	16-60	16-60

Table 2: Posterior tibial slopes (in degrees) of the ACL-intact and ACL-deficient group

		ACL-Deficient (n=159)		**ACL-Intact (n=192)**		
		Mean/STD	95% CI	Mean/STD	95% CI	*P*-levels
All						
25%	Medial Meniscus Slope	24.2+5.7	23.3-25.2	30.7+6.4	29.8-31.7	0.00001
	Medial Bone Slope	-4.6+3.4	4.0-5.1	-1.5+2.2	1.2-1.8	0.00001
	Resultant Medial Slope	**19.5+5.9**	**18.5-20.5**	**29.1+6.7**	**28.1-30.0**	**0.00001**
50%	Medial Meniscus Slope	24.7+4.9	23. 9-25.5	30.9+5.9	30.0-31.6	0.00001
	Medial Bone Slope	-4.5+3.1	3.9-4.9	-1.5+2.3	1.2-1.8	0.00001
	Resultant Medial Slope	**20.4+5.7**	**19.4-21.3**	**29.3+6.5**	**28.4-30.3**	**0.00001**
75%	Medial Meniscus Slope	24.6+4.9	23.8-25.4	29.5+5.9	28.7-30.4	0.00001
	Medial Bone Slope	-5.7+3.6	5.1-6.2	-2.1+2.6	1.7-2.5	0.00001
	Resultant Medial Slope	**18.8+6.2**	**17.8-19.5**	**26.8+6.4**	**25.9-27.8**	**0.00001**
25%	Lateral Meniscus Slope	24.4+4.6	23.7-25.2	30.5+5.0	29.8-31.2	0.00001
	Lateral Bone Slope	-3.6+3.0	3.1-4.1	-0.2+2.5	(-)0.6-0.1	0.00001
	Resultant Lateral Slope	**20.7+5.5**	**19.8-21.6**	**30.2+5.7**	**29.4-31.0**	**0.00001**
50%	Lateral Meniscus Slope	25.4+3.7	24.8-26.0	31.0+4.4	30.4-31.6	0.00001
	Lateral Bone Slope	-2.7+2.3	2.3-3.0	-0.3+2.7	(-)0.67-0.1	0.00001
	Resultant Lateral Slope	**22.6+4.3**	**21.9-23.3**	**30.6+5.2**	**29.9-31.4**	**0.00001**
75%	Lateral Meniscus Slope	25.2+4.4	24.5-7.0	31.3+4.5	30.7-33.0	0.00001
	Lateral Bone Slope	-4.0+3.1	3.4-4.5	-0.4+2.5	0.1-0.7	0.00001
	Resultant Lateral Slope	**21.3+5.4**	**20.4-22.2**	**31.0+5.2**	**30.2-31.7**	**0.00001**

Table 3: Males: Posterior tibial bone slope (in degrees) of the ACL-intact and ACL-deficient group

		ACL-Deficient (n=82)		**ACL-Intact (n=114)**		
		Mean/STD	95% CI	Mean/STD	95% CI	*P*-levels
All						
25%	Medial Meniscus Slope	24.5+5.7	23.2-25.7	31.1+6.7	29.8-32.3	0.00001
	Medial Bone Slope	-4.8+3.0	4.1-5.4	-1.7+2.5	1.2-2.2	0.00001
	Resultant Medial Slope	**19.7+6.1**	**18.3-21.0**	**29.2+7.0**	**27.9-30.5**	**0.00001**
50%	Medial Meniscus Slope	26.2-5.4	25.2-27.2	31.3+6.2	30.2-32.4	0.00001
	Medial Bone Slope	-3.7+2.8	3.2-4.2	-1.5+2.0	1.1-1.9	0.00001
	Resultant Medial Slope	**22.6+6.4**	**21.4-23.8**	**29.7+6.5**	**28.5-30.9**	**0.00001**
75%	Medial Meniscus Slope	24.9+4.5	23.9-25.9	29.3+5.3	28.4-30.3	0.00001
	Medial Bone Slope	-5.5+3.6	4.7-6.3	-2.0+2.8	1.5-2.5	0.00001
	Resultant Medial Slope	**19.2+6.1**	**17.9-20.6**	**27.1+5.6**	**26.1-28.2**	**0.00001**
25%	Lateral Meniscus Slope	24.6+4.5	23.6-25.6	30.5+4.8	29.6-31.4	0.00001
	Lateral Bone Slope	-4.1+2.8	3.5-4.7	-0.3+3.3	(-)0.7-0.2	0.00001
	Resultant Lateral Slope	**20.3+5.6**	**19.0-21.5**	**30.2+5.8**	**29.1-31.2**	**0.00001**
50%	Lateral Meniscus Slope	25.4+3.9	24.5-26.2	30.8+5.0	30.0-31.7	0.00001
	Lateral Bone Slope	-2.9+2.2	2.4-3.4	-0.4+2.9	(-)0.9-0.1	0.00001
	Resultant Lateral Slope	**22.3+4.4**	**21.3-23.3**	**30.4+5.3**	**29.4-31.3**	**0.00001**
75%	Lateral Meniscus Slope	25.4+3.8	24.6-26.3	31.2+5.2	30.3-32.1	0.00001
	Lateral Bone Slope	-3.5+3.0	2.9-4.2	-1.8+3.2	(-)1.0-0.1	0.00001
	Resultant Lateral Slope	**22.0+5.2**	**20.8-23.1**	**27.1+6.8**	**29.8-31.7**	**0.00001**

Table 4: Females: Posterior tibial bone slope (in degrees) of the ACL-intact and ACL-deficient group

		ACL-Deficient (n=60)		**ACL-Intact (n=70)**		
		Mean/STD	95% CI	Mean/STD	95% CI	*P*-levels
Males						
25%	Medial Meniscus Slope	24.0+5.8	22.5-25.5	30.2+5.7	28.8-31.5	0.00001
	Medial Bone Slope	-4.3+4.0	3.3-5.4	-1.2+1.7	0.7-1.6	0.00001
	Resultant Medial Slope	**19.3+5.8**	**17.8-20.8**	**28.8+6.0**	**27.7-30.3**	**0.00001**
50%	Medial Meniscus Slope	24.3+5.3	22.9-25.7	30.3+5.6	28.9-31.6	0.00001
	Medial Bone Slope	-4.4+3.5	3.5-5.4	-1.4+2.1	0.9-1.9	0.00001
	Resultant Medial Slope	**20.0+6.4**	**18.4-21.7**	**28.8+6.4**	**27.3-30.3**	**0.00001**
75%	Medial Meniscus Slope	24.1+5.5	22.7-25.5	29.8+6.6	28.2-31.4	0.00001
	Medial Bone Slope	-5.8+3.6	4.9-6.8	-2.3+2.2	1.7-2.9	0.00001
	Resultant Medial Slope	**18.2+6.5**	**16.6-19.3**	**26.3+7.6**	**24.5-28.1**	**0.00001**
25%	Lateral Meniscus Slope	24.2+4.8	23.0-25.5	30.6+5.9	29.3-31.8	0.00001
	Lateral Bone Slope	-3.0+3.2	2.1-3.8	-0.2+2.3	(-)0.7-0.4	0.00001
	Resultant Lateral Slope	**21.2+5.4**	**19.8-22.6**	**30.2+5.6**	**28.9-31.6**	**0.00001**
50%	Lateral Meniscus Slope	25.4+3.4	24.5-26.3	30.6+5.2	29.3-31.8	0.00001
	Lateral Bone Slope	-2.4+2.3	1.9-3.0	-0.9+2.1	(-)0.6-0.4	0.00001
	Resultant Lateral Slope	**23.0+4.2**	**22.0-24.1**	**31.1+5.2**	**29.9-32.3**	**0.0001**
75%	Lateral Meniscus Slope	24.9+5.2	23.6-26.3	31.5+4.1	30.5-32.4	0.00001
	Lateral Bone Slope	-4.5+3.2	3.7-5.4	-0.2+2.1	(-)0.7-0.3	0.00001
	Resultant Lateral Slope	**20.4+5.6**	**18.9-21.8**	**31.2+5.0**	**30.1-32.5**	**0.00001**