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The influence of the tibial slope and the size of the intercondylar notch on rupture of the anterior cruciate ligament

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It has been suggested that an increased posterior tibial slope (PTS) and a narrow notch width index (NWI) increase the risk of anterior cruciate ligament (ACL) injury. The aim of this study was to establish why there are conflicting reports on their significance. A total of fifty patients with a ruptured ACL and 50 patients with an intact ACL were included in the study. The group with ACL rupture had a statistically significantly increased PTS (p < 0.001) and a smaller NWI (p < 0.001) than the control group. When a high PTS and/or a narrow NWI were defined as risk factors for an ACL rupture, 80% of patients had at least one risk factor present; only 24% had both factors present. In both groups the PTS was negatively correlated to the NWI (correlation coefficient = -0.28, p = 0.0052). Using a univariate model, PTS and NWI appear to be correlated to rupture of the ACL. Using a logistic regression model, the PTS (p = 0.006) and the NWI (p < 0.0001) remain significant risk factors. From these results, either a steep PTS or a narrow NWI predisposes an individual to ACL injury. Future studies should consider these factors in combination rather than in isolation.

Anterior cruciate ligament (ACL) injury occurs typically when an athlete lands or pivots on the leg.1,2 The risk of injury may be increased by extrinsic or intrinsic factors.3 The former can be modified by targeted intervention according to the sport, such as improving hamstring and quadriceps strength,4,5 proprioception6 and neuromuscular control,7,8 whereas intrinsic factors such as ligamentous structures9,10 and anatomical variations cannot be modified.11,12 Preventative strategies aimed at optimising extrinsic factors have, however, had little effect on the overall rates of ACL injury,13 and further research is needed to determine the risk from specific anatomical variations.14 These include an increased posterior tibial slope (PTS),11,23-27 a narrow intercondylar notch,15-22 a smaller ACL volume28 and a shallow medial tibial plateau with a steep lateral slope.29-31 Their clinical usefulness such as ligamentous structures9,10 and anatomical variations cannot be modified.11,12

The purpose of this case-control study was to determine whether there is a difference in the PTS and notch width index (NWI) between patients with an isolated ACL injury and a control group, and to examine the relationship between the anatomical variations.

Patients and Methods

The study group comprised 50 patients who had sustained an isolated, complete rupture of the ACL, as confirmed by clinical examination, MRI and arthroscopy by the senior author (PC) within the previous year (group 1). A control group of 50 patients (group 2; matched for age and gender with group 1) was taken from 100 consecutive, skeletally mature patients who had consulted for other reasons. All those in group 2 had undergone MRI of the knee and had no previous ligamentous knee injury, knee surgery or radiological evidence of osteoarthritis of the knee. Patient demographics, i.e. gender, size, weight and age, were consistent between the groups. There were 70 men (35 in each group) and 30 women (15 in each group) with mean ages of 35 years (14 to 48) in group 1 and 37 years (21 to 50) in group 2.

Radiological assessment. All patients had anteroposterior, lateral weight-bearing Schuss views (posteroanterior (PA) weight-bearing in 20° to 30° of flexion) and MRI of the knee. The assessment was completed with a true lateral of the knee under fluoroscopic control to ensure that the femoral condyles were superimposed. This confirmation was necessary since for measurement of the tibial slope, the distance between the posterior edges of the condyles on the lateral view should be < 5 mm.32 The functional tibial slope as described by Julliard et al32 was used to determine the PTS, which is the angle between the tangent to the medial tibial plateau and the lateral mechanical axis of the

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leg (Fig. 1). We felt this method was the most suitable, as other techniques do not use the full length of the tibia, nor relate to its mechanical axis.

**Magnetic resonance imaging.** The NWI, as described by Souryal et al.\(^{20,21}\) is the width of the intercondylar notch at the level of the popliteal groove divided by the bicondylar width at the same level (Fig. 2). The scans were performed supine with the knee extended and rebuilt in T1 and T2, with frontal and horizontal sections orthogonal to the intercondylar notch.

**Statistical analysis.** Statistical analysis was performed using R statistical software (R Foundation for Statistical Computing, Vienna, Austria). Pearson’s product-moment correlation test was used to investigate the correlation between the PTS and the NWI in the overall population. A multivariate logistic regression was performed to evaluate the influence of the PTS and the NWI on ACL rupture. A p-value of < 0.05 was considered significant.

**Results**

The mean PTS was significantly higher in group 1 than in group 2 (10.1° (SD 3.3) *versus* 7.52° (SD 2.13), respectively; *p* < 0.001) and the mean NWI was significantly less in group 1 than in group 2 (0.22 (SD 0.02) *versus* 0.27 (SD 0.02), respectively; *p* < 0.01).

In all patients in both groups, the PTS was negatively correlated with the NWI (correlation coefficient = -0.28, *p* = 0.0052). There was no significant correlation between these variations in group 1 (correlation coefficient = 0.05, *p* = 0.707) or group 2 (correlation coefficient = 0.14, *p* = 0.312).

Using a univariate model for all patients, both PTS and NWI appear to be correlated with ACL rupture. Using a logistic regression model, both PTS and NWI remain significant risk factors for ACL rupture (*p* = 0.006 and *p* < 0.01, respectively).

When a high tibial slope (> 10.5°) and/or a tighter notch (NWI < 0.21) were introduced as risk factors for ACL injury, 80% of patients in the ruptured ACL group had one (56%) or two (24%) risk factors present, with PTS occurring in 56% and NWI occurring in 48% (Fig. 3). We did not perform an analysis using odds ratio to determine which of the two factors was more influential.
Discussion
To our knowledge, only one study has previously evaluated both the PTS and the NWI in the same patients.30
We found a statistically significantly steeper PTS in the patients with a ruptured ACL than in the uninjured group. However, others report differently. Meister et al25 found no correlation between the PTS and risk of ACL rupture, and although Todd et al27 found that an increased PTS was a possible risk factor in women, they found no association in men. Also, although an increased PTS leads to an anterior shift in the resting position of the tibia,26 two studies have shown that this does not increase strain in the ACL.23,33 Whereas these two studies offered useful insights into changes in PTS, their observations were made under several methodological constraints. The effect of changing the PTS was evaluated following an opening wedge osteotomy. This may not represent the effect of an increased PTS in the natural knee, and it is felt that the alterations in anatomy may have led to increased loading of secondary restraints, thereby reducing the contribution of the ACL. Also, it was suggested that the tibial plate is morphologically too complex to be defined by a single PTS angle,29,30 and a correlation between ACL rupture and a combination of an increased PTS and a shallow medial tibial plateau was shown. It was proposed that the risk of ACL rupture was increased because an axially applied force causes greater external rotation of the femur, which produces excessive strain in the ACL.

The role of a narrow intercondylar notch in ACL injury is less controversial. We found that the NWI was significantly narrower in those with a ruptured ACL. Various mechanisms whereby a narrow notch increases the risk of ACL injury have been suggested. Most authors feel that it presents a risk of impingement, particularly when the knee is extended.16,19,20,34,35 Others consider that the width of the notch reflects the size and hence the strength of the ACL.15,28,31 and Simon et al10 suggested that those with a narrower notch have a more vertical coronal orientation of the ACL, which potentially influences the loads it experiences. Others, however, found no association between the width of the intercondylar notch and risk of ACL injury, and concluded that the width of the notch alone cannot explain ACL tears.18,36

Our data indicate that both factors play a significant role in increasing the risk of ACL injury. When a high PTS (> 10.5°) and/or a tight notch (NWI < 0.21), were defined as risk factors, 80% of the patients with a ruptured ACL had at least one these factors (PTS in 28 patients, NWI in 24) but only 24% of patients had both. So the question remains why there are conflicting conclusions on the risk associated with these factors? Perhaps in our study the PTS was negatively correlated to the NWI. Failure to take both these factors into account when evaluating the risk of injury to the ACL leaves a study susceptible to bias. For example, in a study evaluating the PTS alone in which most of the patients with an ACL injury had a small PTS, the authors would conclude that PTS is not a risk factor. However, these patients may have a narrow notch, and the results must be interpreted with caution. Future studies should therefore consider these anatomical variations together rather than independently.

There are several weaknesses to our study. We did not compare the size or orientation of the ACL with the NWI on MRI slices, or take into account the shape of the notch. In order to study the correlation between PTS and NWI we measured the PTS from plain radiographs. As discussed, some authors have highlighted the morphological variation between the medial and lateral tibial plateaux and its effect on knee kinematics and risk of ACL injury.29,30 Although MRI would have allowed us to measure both slopes, we felt that this, in combination with the NWI, would have been difficult to interpret. The mean age of our patients was relatively old because most ACL tears that we treat are the result of skiing injuries. This could mean that our patients are not entirely representative of young athletes, in whom strategies to prevent ACL rupture would be of most benefit. Our statistical analysis indicates that the negative correlation between the PTS and NWI was small. This was due to a lack of power as a result of the financial limitations.

We offer new insight into the possible reason for the contradictory conclusions on the association of the PTS and the NWI with the risk of rupture of the ACL. In our study, patients with a ruptured ACL had a significantly increased PTS or a narrow NWI. As there is a correlation between these anatomical variations, future studies should consider them in combination rather than in isolation.

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