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ORIGINAL STUDY

Evaluation of the Posterior Tibial Slope in Noncontact ACL Injuries Using Magnetic Resonance Imaging

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This study investigated whether an increased posterior tibial slope (PTS) was a risk factor for noncontact anterior cruciate ligament (ACL) injuries. We retrospectively evaluated the Magnetic Resonance (MR) images of 60 patients with noncontact complete ruptures of the ACL and 60 age-matched, healthy individuals with normal knee MR images. We measured the medial and lateral PTS on the sagittal T1W images separately in both the patients with complete ACL ruptures and the control group, as described by Hudek et al. Medial and lateral PTS were investigated between two groups .The patients with complete ACL ruptures had a statistically significantly (p<0.01) larger PTS on the lateral tibial condyle than the control group (4.5° and 3.8°, respectively). However, there was no statistically significant differences between the two groups' medial PTS. Also, the lateral PTS was greater in the complete ACL group than the control group in both females and males (p<0.01).

Keywords : anterior cruciate ligament ; Magnetic Resonance Imaging, Posterior Tibial Slope

INTRODUCTION

Stability at the knee joint is provided by the ligaments and bony structures. Posterior inclination of the tibial plateau or posterior tibial slope (PTS) is a bony structure in anteroposterior stabilization (*12*). Previous studies show that an increased PTS was associated with an increased risk of anterior cruciate ligament (ACL) rupture (*2, 5, 10, 21*) Also, ACL injuries can also be the result of excessive valgus stress, forced external rotation of the femur on a fixed tibia, or forced hyperextension (*17*). Individual biomechanical, anatomical, hormonal, and environmental factors also increase the risk of injury (*6, 8*).

Tibial slope is defined as the angle between the line tangent to the respective tibial plateau and a line perpendicular to the longitudinal axis of the tibial bone. Tibial slope plays a role in the static stability of the knee and a greater tibial slope is claimed to be one of the causes of ACL injuries (*6, 8, 21*). An increased tibial slope causes extensive tibial translation via stess to the knee joint and may consequently induce stretching and rupture the ACL. Tibial shear force and anterior

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tibial translation force increased as tibial slope was increased (*19*). Shao et al. state that increases in the tibial slope will increase the resulting anterior tibial translation and ligament force in both healthy and ACL-deficient knees (*18*). This study investigated whether an increased PTS was a risk factor for noncontact complete ACL ruptures.

MATERIALS AND METHODS

We retrospectively reviewed the MR images of 60 patients with noncontact complete ACL ruptures from January 2014 through February 2015. The data of 60 age-matched, healthy individuals with normal knee MR images were evaluated as the control group. Patients with acute fractures, partial ACL ruptures, implants, previous knee surgeries, or bone tumors were excluded from this study.

This study was approved by the institutional review board of Samsun Education and Research Hospital. MR imaging was performed on 120 patients' knees using a 1.5-T system (Signa HDX 1.5 T ; GE Medical Systems, Milwaukee, WI, USA). The fields of view varied from 7.5 to 20 cm. The slice thickness varied from 2 to 4 mm, and the slice gap varied from 0 to 2.7 cm. Matrices of 256 x 256 were used. Axial, sagittal, and coronal images were obtained for all the examined knee MR images. For each patient, either T1-weighted spin-echo images (pulse sequences : 300/9 (TR/TE)), T2-weighted spin echo images (puls sequences : 4020/113.8 (TR/TE)), T2-weighted gradient-echo images (puls sequences : 325/13 (TR/TE)), or fast spin-echo proton density images (puls sequences : 1400/38 (TR/TE)) were obtained.

MR imaging measurements were performed using the method described by Hudek et al. (*12*). Firstly, a central sagittal slice consisting of the intercondylar eminence, the anterior and posterior tibial cortices appearing as a concave shape, and the tibial attachment of the posterior cruciate ligament was used. Later, a circle tangent to the proximal, anterior, and posterior tibial borders was drawn and followed by a second circle centered on the perimeter of the first circle. The line that connects the two centers of the circles was defined as the tibial longitudinal axis. The angle between the line perpendicular to the tibial longitudinal axis and tangent to the medial and lateral tibial plateau can then be measured. The line tangent to the medial and lateral tibial plateau was defined as the line connecting the topmost of the site on the superior-anterior and posterior cortices on the middle slice, between the most lateral/medial slice, and

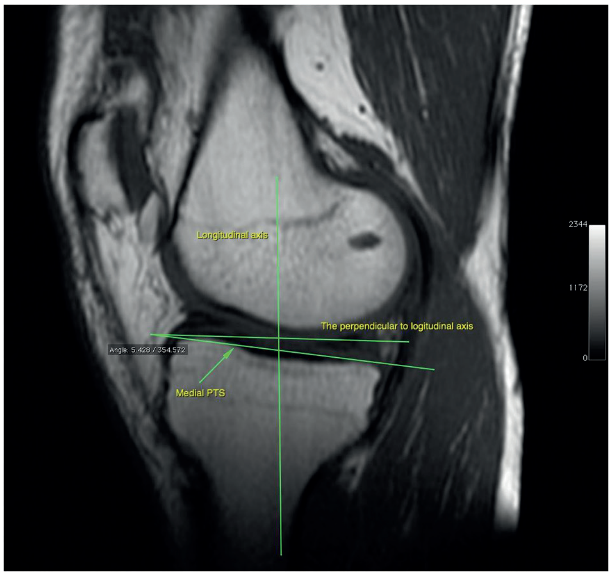

Fig. 1. — Medial posterior tibial slope measurement

the central sagittal slice. We measured the medial (Fig. 1) and lateral PTS (Fig. 2) separately using the sagittal T1W images of patients with complete ACL ruptures and of the control group. The median values of the medial and lateral PTS were evaluate to determine if there were statistically significant differences between the patients with ACL ruptures and the control group.

Also, the complete ACL rupture group was divided into 4 subgroups based on age : subgroup 1 included individuals from 20 to 29 years of age (17 patients), subgroup 2 included individuals from 30 to 39 years of age (14 patients), subgroup 3 included individuals from 40 to 49 years of age (14 patients), and subgroup 4 included individuals from 50 to 59 years of age (15 patients). The control group was divided into 4 subgroups based on age : subgroup 1 included individuals from 20 to 29 years of age (18 patients), subgroup 2 included individuals from 30 to 39 years of age (15 patients), subgroup 3 included

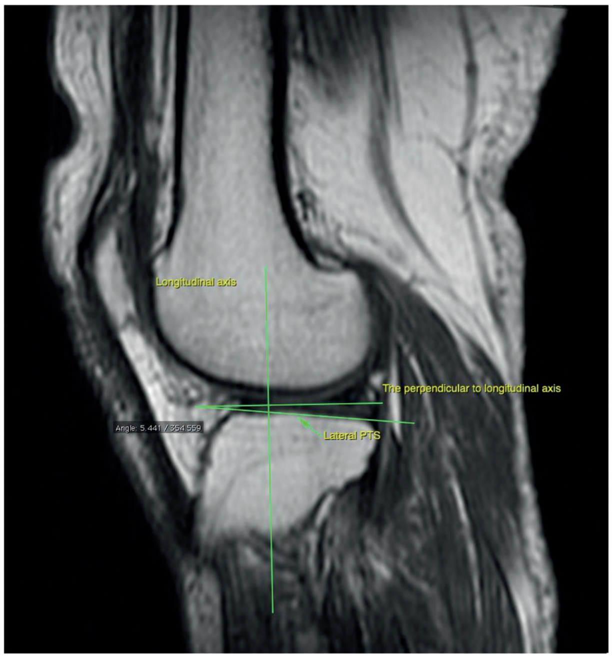

Fig. 2. — Lateral posterior tibial slope measurement

individuals from 40 to 49 years of age (14 patients), and subgroup 4 included individuals from 50 to 59 years of age (13 patients). All of the measurements were performed by the same radiologist (ATS).

Statistical analysis

The SPSS statistical software package (SPSS, version 20 for Windows ; SPSS Inc., Chicago, Illinois, USA) was used to perform all the statistical calculations. Two independent t-tests were used for the statistical comparison of the data that matches a normal distribution, and the Mann-Whitney U test was used for the statistical comparison of the groups when data were not distributed normally. The values that were not normally distributed were expressed as medians (interquartile range (Q3-Q1)). The normally distributed data were expressed as mean±SD. $P < 0.05$ was considered statistically significant.

RESULTS

The ACL rupture group consisted of 60 patients (25 female, 35 male) with a median age of 39 (*22*). The control group consisted of 60 patients (27 female, 33 male) with a median age of 37 (*21*). There were no statistically significant differences between the complete ACL rupture and control groups' median age and gender. The median angle of the PTS on the medial tibial condyle in the ACL rupture and control groups were 3.2° (1.7) and 3.1° (1.4), respectively. There was no statistically significant difference between the measurements of the complete ACL rupture and control groups' medial PTS ($p = 0.467$).

The median angle of the PTS on the lateral tibial condyle in the ACL rupture group and control group were 4.5° (1.3) and 3.8° (1.2), respectively. A statistically significant difference was found in the lateral PTS measurements of the complete ACL rupture group and those of control group ($p<0.01$).

The median angle of the PTS on the medial tibial condyle in females in the complete ACL rupture group and control group were 3.1° (1.2) and 3.1° (1.4), respectively. The median angle of the PTS on the lateral tibial condyle in females in the complete ACL rupture group and control group were 4.5° (1.3) and 4° (1.3), respectively. The median angle of the PTS on the medial tibial condyle in males in the complete ACL rupture group and control group were 3.3° (2.1) and 3.1° (1.4), respectively. The median angle of the PTS on the lateral tibial condyle in males in the complete ACL rupture group and control group were 4.7° (1.2) and 3.7° (1.1), respectively. There was no statistically significant difference in the medial PTS in males in the control and ACL rupture groups and in the females in the control and ACL rupture groups ($p = 0.847$ and $p = 0.443$, respectively). However, there was statistically significant differences in the lateral PTS in males in the control and ACL rupture groups and in the females in the control and ACL rupture groups ($p<0.01$).

Complete ACL ruptures were found on the right side in 26 patients, and 34 were found on the left side. The control group consisted of 33 right knee and 27 left knee MR images. The left median medial PTS was 3.5° (1.7) in the ACL rupture group and 2.9° (1.7) in the control group. The right median medial PTS was 2.9° (1.5) in the complete ACL rupture group and 3.1° (1.3) in the control group. There was no statistically significant difference in the right and left median medial PTS of the complete ACL rupture group and the control group. The left median lateral PTS was 4.5° (1.0) in the complete ACL rupture group and 3.7° (1.6) in the control group. The right median lateral PTS was 4.6° (1.7) in the complete ACL rupture group and 3.9° (1.1) in the control group. There was a statistically significant difference in the right lateral PTS in the ACL rupture and control groups, as well as left ($p = 0.001$ and $p = 0.004$, respectively).

There was no significant difference in the medial and lateral PTS of subgroups 2 and 3 in the ACL rupture and control groups ($p = 0.467$). There was also no statistically significant difference found in the medial PTS in subgroups 1 and 4 of both the ACL rupture and control groups. However, statistically significant differences were found in the lateral PTS of subgroups 1 and 4 of both the ACL rupture and control groups ($p = 0.001$ and 0.017, respectively) (Table I).

Table I. — Mean values of the medial and lateral PTS of patients with ACL injury and the control group were shown to according to the age.

Age		Patients	N	Mean	Std deviation	p
<30	Medial PTS	Control	18	3,2	0,94	0,488
		ACL rupture	17	3,5	1,20	
	Lateral PTS	Control	18	3,77	0,63	0,001
		ACL rupture	17	5,08	1,23	
30-39	Medial PTS	Control	15	3,61	1,16	0,893
		ACL rupture	14	3,55	1,07	
	Lateral PTS	Control	15	4,25	0,92	0,187
		ACL rupture	14	4,86	1,45	
40-49	Medial PTS	Control	14	3,34	0,65	0,432
		ACL rupture	14	3,64	1,23	
	Lateral PTS	Control	14	4,06	0,76	0,150
		ACL rupture	14	4,52	0,86	
≥50	Medial PTS	Control	13	2,99	0,82	0,564
		ACL rupture	15	3,20	1,00	
	Lateral PTS	Control	13	3,72	0,84	0,017
		ACL rupture	15	4,65	0,89	

DISCUSSION

Due to the recent increase in ACL rupture incidents (*24*), it is necessity to investigate the risk factors and causes of ACL injuries and to develop preventive measures for these injuries (*16*). Several intrinsic and extrinsic risk factors of the ACL injuries have been identified (*15*). Preventive measures are often intended to address the risk factors that can be changed. Extrinsic factors are generally environmental factors, such as playing surfaces, shoe type, weather condition, and sport type (*16*). Intrinsic factors include : anatomical, hormonal, neuromuscular, and family history factors (*6*). Intercondylar notch width, increased body mass index, landing kinematics, female sex, and anatomic alignment are anatomical variables (*1, 15*). The anatomical differences between the sexes include : age, pelvic width, hormones, ligament strength, neuromuscular and biomechanical factors, and old knee injuries (*6*). The aggressive contraction of the quadriceps during moderate knee flexion can also cause noncontact ACL injuries, due to increased anterior translation of the tibia (*16*).

In recent studies, anatomic variations, such as proximal tibial geometry and PTS, have been identified as risk factors for primary ACL injuries (*21-24*). A greater PTS with axial loading, which leads to an increase in the internal tibial rotation and greater force on the ACL, can cause greater anterior tibial translation (*16*). Dejour and Bonin (*4*) show that a 10° increase in the tibial slope results in a 3 mm increase in the radiological Lacchman test, and Shelburne et al. (*19*) show that a 5° increase in the PTS causes a 2-mm increase in the anterior tibial translation when an individual is standing.

Studies that have examined the relationship between the PTS and ACL insufficiency were present in the literature (*21-24*). These studies were performed using lateral radiographs (*4, 22, 23*), CT (*13*) scans, and MR images (*9, 11, 21*). Hashemi et al. (*8*) and Sonnery-Cottet et al. (*20*) use MR image slices and later radiographs, respectively, to determine whether a steep PTS is a significant risk factor for ACL ruptures. However, the authors do not reach a consensus about the angle responsible for ACL injuries.

Our study used MR imaging to measure the medial and tibial PTS because both of the medial and tibial plateaus can be easily distinguished using MR images. In addition, the articular surface is better represented in the MR images than other imaging modalities. A rotation of the tibia during a direct radiography examination may lead to an incorrect measurement (*16*). Also, a lateral tibial plateau cannot be viewed clearly using direct radiography due to superimposition (*12*).

Hashemi et al. (*8*) evaluate the medial and lateral PTS and their role in the ACL. The authors show that medial PTS is 6° in the ACL injury group and 5° in the control group, and the p-value between the two groups is 0.01 A lateral PTS is 9° in the ACL injury group, and 6° in the control group, and the statistical analysis shows significant differences in the lateral PTS of the ACL injury group and control group ($p = 0.005$).

Hudek et al. evaluated the association between the PTS and ACL injuries in 2011. The authors (11) report that the medial PTS is 4.7°±2.7 in the ACL injury group and 4.1°±2.8 in the control group. The authors also report that there is no statistically significant differences between these groups ($p = 0.257$). The lateral PTS is 5.6°±2.9 in the ACL injury group and 4.9°±3.2 in the control group. The authors report that there is no statistically significant differences between these groups ($p = 0.292$).

Ristic et al. (*16*) evaluate the relationship between PTS and ACL using MR imaging. The authors show that the lateral PTS is 6.68°±2.23 in the ACL injury group and 5.64°±1.90 in the control group. However, the authors report that there is no statistically significant difference between these groups. The medial PTS is 5.49°±2.77 in the ACL injury group and 4.67°±2.36 in the control group. However, the authors report that there is no statistically significant difference between these groups.

Our study evaluated the relationship between the medial and lateral PTS in an ACL injury group and a control group using MR imaging. A medial PTS was found to be 3.2° (1.7) and 3.1° (1.4) in the ACL rupture and control groups, respectively. No statistically significant difference was found in the medial PTS of the complete ACL rupture group and control group. The lateral PTS was 4.5° (1.3) and 3.8° (1.2) in the complete ACL rupture and control groups, respectively. The lateral PTS in the group with ACL ruptures was statistically significantly larger ($p < 0.01$) than the control group, which is consistent with the literature.

Haddad et al. (*7*) report that the mean medial (6.3°, SD 3.9 vs. 5.1°, SD 3.7) and lateral PTS (6.3°, SD 4.0 vs 4.8°, SD 4.2) are higher in females than in males. In addition, the authors show significant differences in the medial tibial slope and lateral tibial slope measurements in both females (t-test, $p = 0.92$) and males (t-test, $p = 0.67$). In our study, median medial (3.3° (2.1) vs. 3.1° (1.4), respectively) and lateral PTS (4.7° (1.2) vs. 4.5° (1.3), respectively) were greater in males than in females in the complete ACL rupture group. We did not find a significant difference in the medial tibial slope and lateral tibial slope measurements in females or males. In addition, a statistically significant difference was found in the lateral PTS of between males in the control and ACL groups and in the females in the control and ACL groups the males and females in the complete ACL rupture group and control group ($p < 0.01$).

Li et al. (*14*) reveal that both the medial and lateral PTS are significantly steeper in ACL reconstruction failures than in the control group. The authors also identify that a medial or lateral PTS ≥ 5° is a new risk factor of ACL reconstruction failure. According to our study, an increase in the lateral PTS (≥ 4.5°) may be an anatomical risk factor for ACL ruptures. However, preventive measures are still controversial. For example, in athletes with increased PTS, the risk of an anterior tibial translation may be reduced by strengthening the posterior thigh muscles. Corrective osteotomy may also reduce the risk of ACL ruptures and reruptures. Dejour showed that revision ACL reconstruction combined with tibial deflexion osteotomy had satisfactory results because the posterior tibia slope correction protects reconstructed ACL from fatigue failure (*3*). Although the ACL integrity is at a higher risk in patients with higher PTS, we have not done any additional corrective osteotomy during ACL reconstruction in our cases.

CONCLUSION

We found a statistically significant difference in the lateral PTS of the noncontact complete ACL rupture group and the control group, which is consistent with the literature. Increases in the lateral PTS (≥ 4.5°) is an anatomic risk factor for ACL injuries. The risk factors and causes of ACL injuries should be determined and preventive measures should be taken to reduce the incidence of these injuries because these preventative measures may be alternatives to surgery in patients with a high risk of injury. In addition, in vivo tests and further longitudinal studies with larger sample sizes may be beneficial in the evaluation of the ACL injury risk factors.

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