New combined method using MRI for the assessment of tibial plateau slope and depth as risk factors for anterior cruciate ligament injury in correlation with anterior cruciate ligament arthroscopic findings: does it correlate?

Tarek Mohamed Ghandour[a], Amr Ahmed Abdelrahman[a], Alaa Eldin Mahmoud Talaat[a], Ahmad Mohammad Ghandour[b], Hesham Youssef Al Gazzar[c]

Departments of [a]Orthopaedic Surgery, [b]Radiology, Faculty of Medicine, Ain Shams University, Cairo, [c]Department of Radiology, Faculty of Medicine, Benha University, Benha, Egypt

Correspondence to Ghandour Tarek Mohamed, MD, Al Salama Hospital, Abu Dhabi, PO Box 46266, United Arab Emirates
E-mail: tarekghndr@yahoo.com

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Background

Anterior cruciate ligament (ACL) injury continues to be the largest single problem in orthopaedic sports medicine. MRI has become the prime diagnostic tool for various pathological and anatomical variability conditions of the knee.

Objectives

The aim of this study was to test the integrity of the new combined method for the assessment of tibial plateau anatomic variables using conventional MRI.

Settings and design

This was a retrospective control study.

Patients and methods

Medial tibial plateau slope (MTPS), lateral tibial plateau slope (LTPS) and medial tibial plateau depth (MTPD) were evaluated in the ACL-injured group of patients ($n = 52$) and the non-ACL-injured control group ($n = 33$) using MRI scan. Inclusion criteria for the ACL-injured group, as surgically confirmed, were isolated ACL injury. However, inclusion criteria for the non-ACL-injured group were minor trauma, bruises, etc.

Statistical analysis

Statistical analysis was carried out using Student's *t*-test and intraclass correlation coefficient. A P value less than 0.05 was assigned as significant.

Results

Both male and female patients in the ACL-injured group showed increased LTPS in comparison with the control group ($P = 0.0197$), with no significant difference in MTPS and MTPD ($P = 0.73$ and 0.8, respectively). Steeper LTPS was detected in the male population of the patient group than in the control group ($P = 0.0001$). Male participants from the control group had less steep MTPS ($P = 0.002$) and LTPS ($P = 0.034$) and deeper MTPD ($P = 0.004$) compared with female participants of the control group.

Conclusion

We conclude that the combined method by Khan and colleagues using conventional MRI for the measurement of MTPS, LTPS and MTPD as risk factors for ACL injury is solid and reproducible.

Level of evidence

Diagnostic study level III.

Keywords:

anterior cruciate ligament, lateral tibial plateau slope, medial tibial plateau depth, medial tibial plateau slope, MRI knee

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Introduction

The anterior cruciate ligament (ACL) is one of the most commonly disrupted ligaments in the knee [1]. Each year in the USA there are ~300 000 ACL injuries in the general population [2,3]. It is also estimated that 38 000 ACL injuries occur each year in female athletes [4]. Apart from the obvious short-term implications, the injury also presents with substantial longer-term morbidities. Radiological signs of osteoarthritis, for example, appear in more than 50% of ACL-deficient knees as early as 5–15 years after injury [5,6].

Renstrom *et al.* [3] reported that ACL injury continues to be the largest single problem in orthopaedic sports medicine, with the incidence of noncontact ACL tears being much higher in female athletes in sports such as basketball and team handball than in male athletes.

Understanding the underlying causes or risk factors for one of the more severe sports-related knee injuries, an ACL disruption, is important for the development of intervention strategies and for identifying those at increased risk for injury. This provides a target group for intervention.

Radiographic study of the knee joint has long been used to speculate the anatomic factors of the knee joint associated with increased risk for ACL injury. Several factors and measurements have been proposed by the literature; nevertheless, they showed great variability in figures with no single satisfactory value.

Dating years back, MRI has become the prime diagnostic tool for various pathological and anatomical variability conditions of the knee, affecting either the soft tissue or the bone components; hence, it has become the imaging modality of choice for measuring various length, thickness and angles through the knee.

The aim of this work was to test the integrity and reproducibility of the new combined method for assessment of tibial plateau anatomic variables using conventional MRI as risk factors for ACL injury conducted by Khan *et al.* [7].

Patients and methods

The present work was conducted in a retrospective manner to evaluate the medial tibial plateau slope (MTPS), lateral tibial plateau slope (LTPS) and medial tibial plateau depth (MTPD) in the ACL-injured group of patients and the non-ACL-injured control group. The research was stretched over a period of 15 months (from February 2011 until May 2012) through review of patients' surgical and medical records as well as MR knee scan and included 85 participants. This study approved by the Ethical committee of Ain Shams University, Cairo, Egypt.

Inclusion criteria for the patient group was as follows:

(a) Surgically confirmed isolated ACL injury,
(b) No collateral ligament injury,
(c) No posterior cruciate ligament injury,
(d) No meniscal injury,
(e) No bone abnormality,
(f) No osteoarthritis and
(g) No patellofemoral pain.

Inclusion criteria for the control group was as follows:

(a) Minor knee trauma,
(b) Bruises,
(c) Other medical causes for knee MR scanning,
(d) No meniscal injury and,
(e) No osteoarthritis.

All patients and controls underwent MR scan of the knee in our institution. For the patient group the preoperative MR scan was assessed.

The patient (ACL-injured) group included 52 patients (42 male and 10 female) with a mean age of 31 years (age range 17–42 years), whereas the control group included 33 participants (24 male and nine female) with a mean age of 27.6 years (age range 15–41 years).

All knee (ACL) surgeries were performed and confirmed arthroscopically.

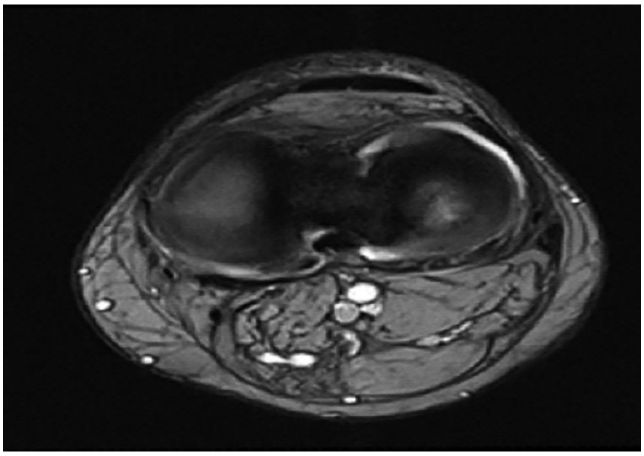
Imaging techniques

MRI of the knee was performed for all patients with 1.5-T superconducting unit (Magnetom Espree, Syngo, MR B15; Siemens, Erlangen, Germany) using a phased-array multicoil. No specific preparation was asked from the patients before examination. No contrast agents were used. Knee MR scan was performed for all patients as follows: PD-weighted and T2-weighted fat saturation imaging in the sagittal plane with a TR of 4000 ms, TE_1 of 30 ms, slice thickness of 3 mm, acquisition matrix size of 256 × 256, field of view of 170 mm and acquisition time 3 min; T1-weighted imaging in the sagittal plane with a TR of 550 ms, TE of 14 ms, slice thickness of 3 mm, acquisition matrix size of 256 × 256, field of view of 170 mm and acquisition time 2.5 min; STIR sequence in the coronal plane with a TR of 3000 ms, TE of 30 ms, slice thickness of 4 mm, acquisition matrix size of 256 × 256, field of view of 170 mm and acquisition time of 2 min; gradient echo-weighted imaging in the axial plane with a TR of 800 ms, TE of 23 ms, slice thickness of 4 mm, acquisition matrix size of 256 × 256, field of view of 170 mm and acquisition time 2 min 16 s; T1-weighted imaging in the coronal plane with a TR of 450 ms, TE of 13 ms, slice thickness of 4 mm, acquisition matrix size of 256 × 256, field of view of 170 mm and acquisition time of 1 min 39 s; and T2-weighted imaging in the sagittal plane for ACL with a TR of 3000 ms, TE of 74 ms, slice thickness of 2 mm, acquisition matrix size of 256 × 256, field of view of 170 mm and acquisition time of 1 min 31 s.

MRI measurement method for MTPS, LTPS and MTPD was the same as the combined method described by Khan *et al.* [7] using the T1-weighted images (i.e. depicting the best anatomical details for bone contour). The measurements were as follows: using the most proximal transverse image of the tibia at the tibiofemoral joint to identify the central sagittal plane (Fig. 1), two circles were drawn at the proximal tibia, with the proximal circle touching the anterior, posterior and the most proximal cortex, and the distal circle touching the anterior and posterior cortex and its centre lying on the circumference of the proximal circle. The longitudinal tibial axis (TA) was identified as the line connecting the centre of the two circles. A line perpendicular to this axis was drawn (Fig. 2). Using the transverse image, the midarticulating portion of the medial plateau was identified and the corresponding sagittal image selected. On this image, a line connecting the peak anterior and posterior points on the medial plateau was drawn, which defined the slope of the medial plateau. The perpendicular line to the TA was reproduced in this image, and the angle between the two was calculated, which gave the value of MTPS (Figs. 3 and 4). In the same way, the central articulating region of the lateral plateau was identified and the LTPS was calculated (Figs. 5 and 6). If the posterior peak point was superior to the anterior peak point, the angle was measured as a negative value (Fig. 7). The MTPD was calculated using the method described by Hashemi *et al.* [8] by drawing a line connecting the peak anterior and posterior points of the medial plateau and a line drawn tangential to the deepest point of the medial plateau with calculation of the vertical distance between the two lines (Figs. 8 and 9).

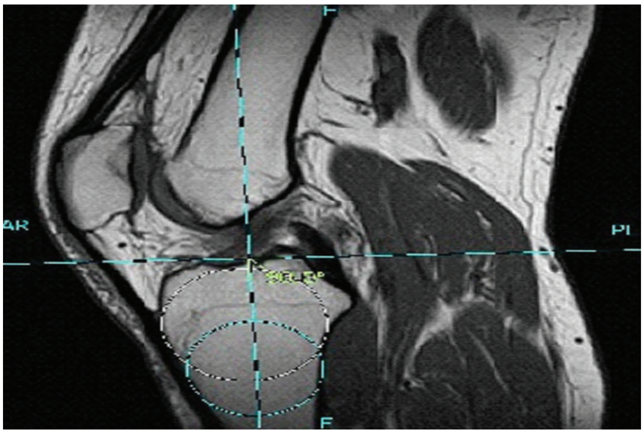
At the start, a pilot study was conducted to evaluate the intrarater and inter-rater reliability in the measurement of MTPS and LTPS using the combined method. Ten patients were randomly selected from the patient and control groups (five men and five women from each group). Measurement reliability was assessed using the intraclass correlation coefficient (ICC). Measurements were performed at two different sessions, 4 weeks apart,

Figure 1



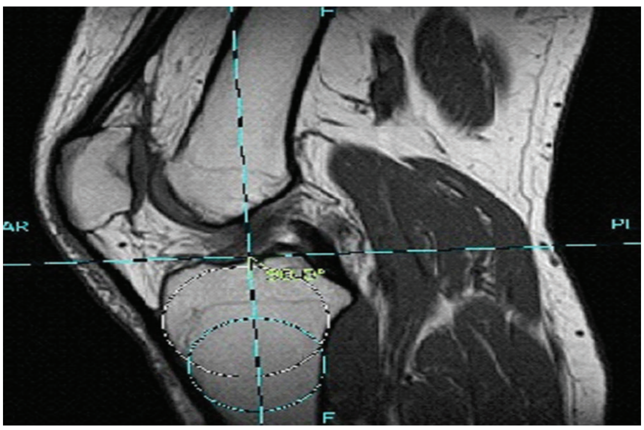
Axial GRE image of the knee joint showing the most proximal transverse image of the tibia at the tibiofemoral joint to identify the central sagittal plane.

Figure 2



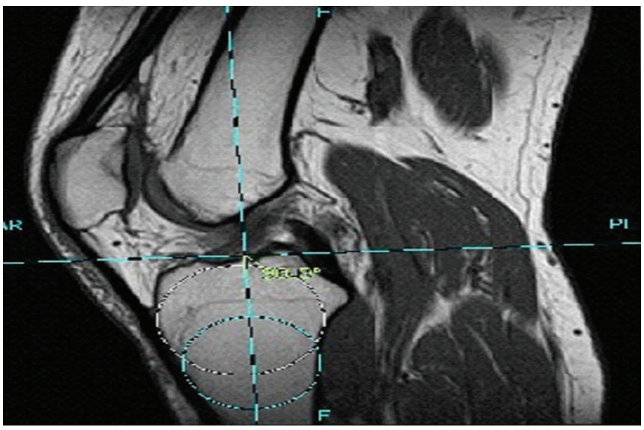
Sagittal T1WI of the knee joint showing the method of circle drawing and identification of tibial axis (TA) with the overlying perpendicular line.

Figure 3



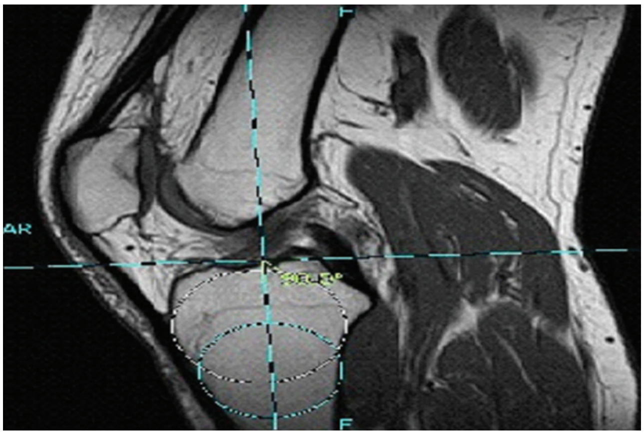
Sagittal T1WI of the knee joint showing the method of calculating the value of medial tibial plateau slope (MTPS).

Figure 4



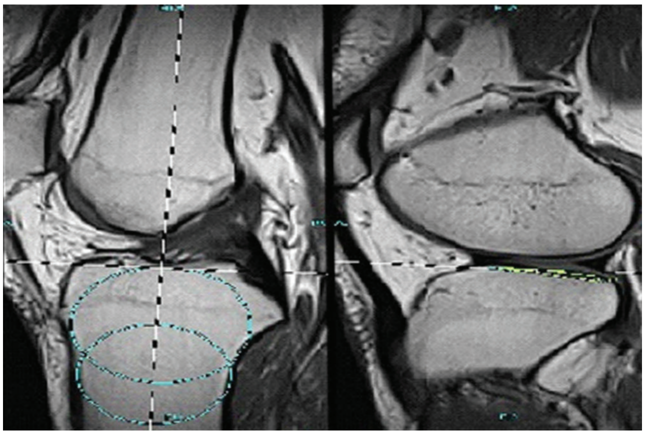
Sagittal T1WI of the knee joint showing the method of calculating the value of medial tibial plateau slope (MTPS) in another patient.

Figure 5



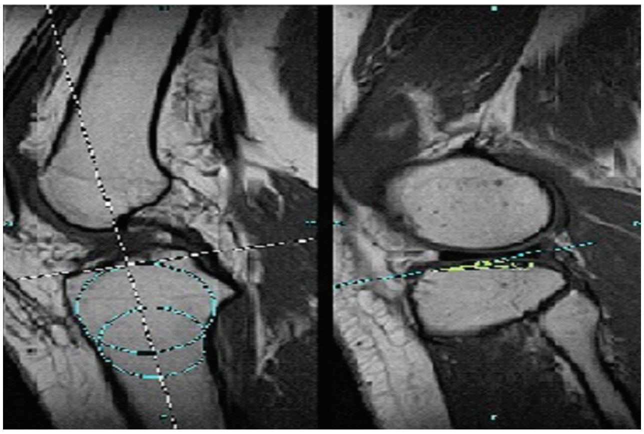
Sagittal T1WI of the knee joint showing the method of calculating the value of lateral tibial plateau slope (LTPS).

Figure 6



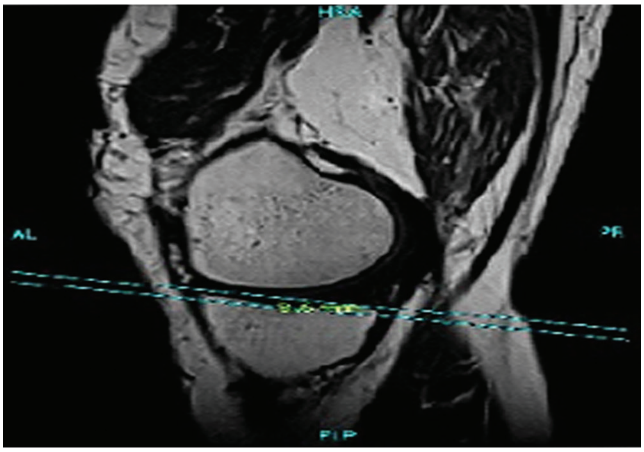
Sagittal T1WI of the knee joint showing the method of calculating the value of lateral tibial plateau slope (LTPS) in another patient.

Figure 7



Sagittal T1WI of the knee joint showing the method of calculating the value of lateral tibial plateau slope (LTPS) in another patient with higher posterior than anterior peak with resultant negative angle.

Figure 8



Sagittal T1WI of the knee joint showing the method of calculating the value of medial tibial plateau depth (MTPD).

by two different observers. Each observer was blinded to the initial results as well as the other observer's results. All final measurements were performed by a third observer. All values for ICC were significant ($P < 0.05$).

Statistical analysis

Student's *t*-test was used for statistical analysis of the relation between MTPS, LTPS and MTPD between the patient and control groups and between male and female patients.

ICC was used for the intrarater and inter-rater analysis for reliability.

A *P* value less than 0.05 was assigned as significant value for *t*-test and ICC analysis.

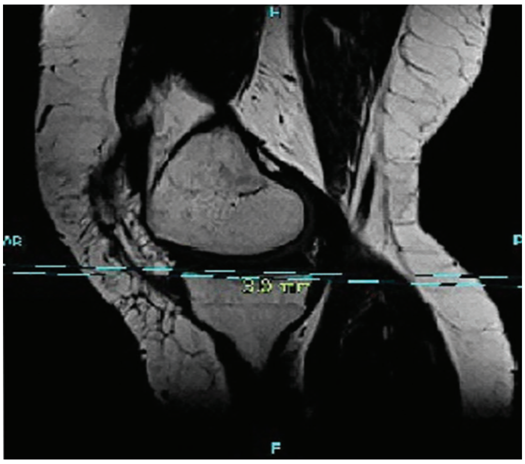
Statistical calculations were conducted using PASW Statistics 18 software (IBM SPSS, Chicago, Illinois, USA).

Results

ICC was calculated before the actual interpretation of tibial plateau slopes and depth, to measure the intrarater and inter-rater reliability of the combined method adopted by Khan *et al.* [7]; the results are shown in Table 1.

In our study population, both male and female patients in the ACL-injured group showed increased LTPS in comparison with the control group ($P = 0.0197$), whereas no significant difference in MTPS and MTPD was detected ($P = 0.73$ and 0.8, respectively). Steeper LTPS was detected in male patients of the patient group than

Figure 9



Sagittal T1WI of the knee joint showing the method of calculating the value of medial tibial plateau depth (MTPD) in another patient.

that in the control group (P = 0.0001), whereas female patients in the patient group had significantly shallower MTPD compared with female participants in the control group (P = 0.002) and male patients in the patient group (P = 0.0005). Male participants in the control group had less steep MTPS (P = 0.002) and LTPS (P = 0.034) compared with female participants in the control group, yet a deeper MTPD (P = 0.004) (Tables 2–4).

Discussion

The risk factors for ACL injury have been considered as either internal or external to an individual. External risk factors include the type of competition, footwear and surface, and environmental conditions. Internal risk factors include anatomical, hormonal and neuromuscular risk factors [3]. Among anatomical risk factors, most studies have been conducted on the size of the intercondylar notch [9–11]; however, recently, posterior tibial slope (PTS) has also been identified as an important risk factor [8,12]. Tibial plateau slopes, MTPS and LTPS independently are important determinants of knee biomechanics [7]. A highly significant correlation has been reported between the posterior inferior tibial slope and anterior tibial translation, and this is supported by the evidence that, in arthroplasty, an inappropriate cutting angle of the PTS results in polyethylene wear, component loosening and posterior cruciate ligament strain [13–15].

The posterior inclination of the tibial plateau, which is referred to as PTS, is determined routinely on lateral radiographs. However, radiographically, it is not always possible to reliably recognize the lateral plateau, making a separate assessment of the medial and lateral plateaus difficult [16].

Table 1 Intrarater and inter-rater reliability of the combined method

Method	MTPS	LTPS
Observer 1 intrarater	0.90	0.93
Observer 2 intrarater	0.92	0.91
Inter-rater	0.94	0.90

LTPS, lateral tibial plateau slope; MTPS, medial tibial plateau slope.

Table 2 Control group mean, SD and range for MTPS, LTPS and MTPD illustrating sex difference

Group	Mean	SD	Range
MTPS (°)			
Male	4.2	2.5	0.9–8.2
Female	5.6	2.8	2–12
Total	4.5	2.4	0.9–12
LTPS (°)			
Male	2	2.31	−2.4 to 6.9
Female	3.5	2.6	−0.67 to 9
Total	2.8	2.7	−2.4 to 9
MTPD (mm)			
Male	2.7	0.9	1.1–3.7
Female	1.6	0.57	0.91–3.5
Total	1.98	0.8	0.91–3.7

LTPS, lateral tibial plateau slope; MTPD, medial tibial plateau depth; MTPS, medial tibial plateau slope.

Table 3 Patient group mean, SD and range for MTPS, LTPS and MTPD illustrating sex difference

Group	Mean	SD	Range
MTPS			
Male	5	2.3	0.98–9.5
Female	4.9	2.5	−0.25 to 9.8
Total	5.1	2.5	−0.25 to 9.8
LTPS			
Male	4.5	3.05	−1.07 to 11.4
Female	5	3.1	0.5–10.5
Total	4.7	3.03	−1.07 to 11.4
MTPD			
Male	2.3	1	0.5–7.1
Female	1.52	0.63	0.35–2.78
Total	2.21	1.2	0.35–7.1

Table 4 *P* value for injured and control group male and female participants

Group	MTPS	LTPS	MTPD
I vs. C	0.73	0.0197	0.8
Male I vs. female C	0.08	0.564	0.09
Male I vs. female I	0.754	0.156	0.0005
Female I vs. female C	0.21	0.356	0.002
Male I vs. male C	0.06	0.0001	0.912
Male C vs. female C	0.002	0.034	0.004

C, control; I, injured; LTPS, lateral tibial plateau slope; MTPD, medial tibial plateau depth; MTPS, medial tibial plateau slope.

One recent case–control study suggested that individuals with ACL-deficient knees had a significantly greater slope of the lateral tibial plateau and a lower slope of the medial tibial plateau compared with the control group.

This paper suggests that the tibial slope of the medial and lateral condyle be compared separately [3,17,18]. The increased tibial anterior translation results in increased joint contact force, specifically its anterior shear component, leading to substantially increased strain on the ACL [7].

Lately, shallower MTPD has also been recognized as a risk factor [7].

Hashemi *et al.* [12] and Hudek *et al.* [16] studied the MTPS, LTPS and PTS with two different methods using conventional MRI; however, Khan *et al.* [7] have stated that the former method necessitates at least 150 mm of bone below the knee joint gap be available for assessing the longitudinal axis, which is not normally provided by conventional MRI of the knee joint, whereas the latter method describes an ambiguous selection of sagittal image for measurements. Hence, they proposed a new combined method using both methods in a modified way by choosing the central sagittal image and midarticulating sagittal images of the medial and lateral tibial plateau described in the former method and then drawing the TA using the latter method, and thus avoiding the drawbacks of each method.

ICC calculation in our study was almost perfect for both inter-rater and intrarater reliability, with values of 0.9 or greater; this is in agreement with the results of Khan *et al.* [7].

In the present study, we found that the LTPS was steeper in ACL-injured patients than in controls; this is in accordance with the findings of Khan *et al.* [7] as well as other workers [12,16]. Moreover, LTPS in injured men was steeper than that in control group men; this is supported by the work of Khan *et al.* [7] as well as other workers [12,18,19].

Using the combined method, MTPS difference was not significant between the ACL-injured patient and control group either in our study or the study by Khan *et al.* [7] and also in other studies [18,19]. However, Hashemi *et al.* [12] stated that 'male cases had increased medial tibial slope ($P = 0.02$) compared with controls'.

In contrast, we found a significantly shallower MTPD in injured female participants than in control female participants and injured male participants; this is supported by the results of Khan *et al.* [7] and Hashemi *et al.* [12].

Khan *et al.* [7] postulated that steeper LTPS combined with shallow MTPD will result in anterior translation of the tibia and external rotation of the femur under joint loading conditions, which will put the ACL under excess strain. Each one of the former parameters will explain the increased incidence of ACL injury in male and female participants having steeper LTPS and shallower MTPD, respectively.

Conclusion

From our study, testing the integrity and reproducibility of the new combined method for assessment of tibial plateau anatomic variables using conventional MRI as risk factors for ACL injury conducted by Khan *et al.* [7], we conclude that the combined method is solid and reproducible in terms of measurement of MTPS, LTPS and MTPD in different ACL-injured patients and uninjured participants and can be used as a reference to prospect the more prone individuals to injuries of the ACL for early protective measures to be undertaken. However, threshold fixed values should be attested to establish an evaluation chart for those at high risk for ACL injury. Moreover, we agree with Khan *et al.* [7] in that LTPS and MTPD in male and female participants, respectively, are the most important determinants for ACL injury.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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