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Original Article

Difference in sex and the effect of a dominant lower extremity in the posterior tibial slope angle in healthy Japanese subjects

Yusuke Endo [a, b], Masahiro Takemura [c], Masahiko Monma [d], Hirotaka Mutsuzaki [e], Masafumi Mizukami [f, *]

[a] *Doctoral Program in Health Sciences, Graduate School of Health Sciences, Ibaraki Prefectural University of Health Sciences, Japan*
[b] *Department of Physical Therapy, Faculty of Health Science, Health Science University, Japan*
[c] *Faculty of Health and Sport Sciences, University of Tsukuba, Japan*
[d] *Department of Radiological Sciences, Faculty of Health Sciences, Ibaraki Prefectural University of Health Sciences, Japan*
[e] *Department of Orthopedic Surgery, Center for Medical Science, Ibaraki Prefectural University of Health Sciences, Japan*
[f] *Department of Physical Therapy, Faculty of Health Sciences, Ibaraki Prefectural University of Health Sciences, Japan*

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A B S T R A C T

Background/objective: Anterior cruciate ligament injuries are prone to re-injury, and it is crucial to prevent the primary injury. One of the anatomical risk factors for anterior cruciate ligament injury is the posterior tibial slope angle. Investigating the characteristics of healthy individuals with respect to the posterior tibial slope angle is important to elucidate the risk of developing anterior cruciate ligament injuries. The purpose of this study was to determine the characteristics related to sex and of the posterior tibial slope angle in healthy Japanese subjects, and the effect of the dominant lower extremity.
Methods: Sixty-two knees of 31 healthy Japanese college students (15 males and 16 females) were included in this study. Magnetic resonance images of both knee joints of the subjects were measured using a 0.3 T scanner. The medial and lateral posterior tibial slope angles were measured from the obtained magnetic resonance images. Magnetic resonance images of the knee joint of the dominant lower extremity were used to compare differences in sexes between the medial and lateral posterior tibial slope angles. Bilateral knee joint magnetic resonance images were used to compare the dominant and non-dominant lower extremities. Independent t-tests were used to compare the differences regarding sex in the medial and lateral posterior tibial slope angles and to compare the dominant and non-dominant lower extremities.
Results: A comparison of the mean lateral posterior tibial slope angle showed that males had a $8.8 \pm 1.7^\circ$ angle, while females had a $10.3 \pm 2.2^\circ$ angle, which was significantly greater ($p = 0.047$). There was no significant difference comparing the posterior tibial slope angle between the dominant and non-dominant lower extremities ($p = 0.430$).
Conclusions: From the result of this study, the lateral posterior tibial slope angle was significantly higher in the female group than in the male group. However, both the medial and lateral posterior tibial slope angles were found to be unaffected by the dominant lower extremity.

Introduction

The knee joint has less bony stability than load-bearing joints such as the hip and ankle joints, and the peri-articular joint stability is reinforced by ligaments. The biomechanical function of the anterior cruciate ligament (ACL) is to prevent anterior tibial movement and rotational movement, and ACL injuries cause giving out and interfere with daily life.[1] ACL injury is a serious form of sports trauma and requires a long period of 9–12 months to return to competition.[2] The rate of return to competition after ACL reconstruction surgery was reported to be 65–84%,[3,4] with many cases failing to return to competition after ACL reconstruction

* Corresponding author. Department of Physical Therapy, Faculty of Health Sciences, Ibaraki Prefectural University of Helath Sciences, 4669-2 Ami, Ami-machi, Ibaraki 300-0394, Japan.
E-mail address: mizukami@ipu.ac.jp (M. Mizukami).

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surgery. It has also been reported that 52–83% returned to their pre-injury level of competition,[3,5] with many cases failing to return to their pre-injury ACL injury level of competition. ACL injuries are also characterised by a high rate of re-injury. In fact, Lai et al. reported a 5.2% re-injury after ACL reconstruction.[5] A great deal of research has been conducted on the mechanisms of injury and risk factors for ACL injuries due to the long rehabilitation period required to return to competition, the low rate of return to the original level of competition, and the high incidence of re-injury.

The incidence of ACL injury is reported to be 3.21–3.59 times higher in females than in males, and it is known that females are more likely to sustain ACL injuries.[6,7] Anatomical factors, which is a risk factor for ACL injury, are classified as internal factors, and internal factors cannot be modified (non-changeable).[8] Because anatomical factors are difficult to modify through training and other means, it is considered to be directly related to an athlete's inherent risk of ACL injury. One of the anatomical risk factors for ACL injury is the posterior tibial slope (PTS) angle, defined as the angle formed at the intersection of a line parallel to the posterior tibial inclination and a line that bisects the diaphysis of the tibia.[9] Magnetic resonance (MR) imaging of the knee joint can be classified into medial posterior tibial slope (MPTS) and lateral posterior tibial slope (LPTS), and several methods of measuring these tilt angles have been developed[10,11] The shape of the tibial plateau predicts long-term outcomes after ACL reconstruction,[12] and the posterior tibial slope angle is higher in ACL-injured patients than in healthy subjects,[13,14] both of which suggest that the shape of the tibial plateau is involved with ACL injury. It has been reported that the ACL re-injury group (ACL graft failure group) had significantly greater LPTS and MPTS angles than the control group[15] It has also been reported that patients with a third ACL injury have a significantly greater PTS angle than those with one or two ACL injuries[16] However, to the best of our knowledge, there are very few studies on the PTS angle in healthy subjects, and we do not have a consistent view on the characteristics of the PTS angle in healthy subjects. ACL injuries are prone to re-injury, and it is crucial to prevent the primary ACL injury. Investigating the characteristics of healthy individuals with respect to the PTS angle is important to elucidate the risk of developing ACL injuries.

The purpose of this study was to determine the characteristics of PTS angle between sexes in healthy Japanese subjects and the effect of the dominant lower extremity. Since females are at higher risk for ACL injury, we hypothesize that the PTS angle is greater in females than in males. We also hypothesize that the PTS angle is not affected by the dominant lower extremity in healthy subjects who do not suffer from knee joint diseases such as knee osteoarthritis or knee cartilage injury.

Materials and methods

Sixty-two knees of 31 healthy Japanese college students (15 males and 16 females) were included in this study. The demographic characteristics of the subjects are shown in Table 1.

Table 1
Demographic characteristics of the subjects.

Variables	Male		Female		Total	
	Mean	SD	Mean	SD	Mean	SD
Number of Subject	15		16		31	
Age (years)	21.4	0.5	20.9	0.5	21.1	0.6
Height (mm)	1708.3	47.0	1577.0	49.9	1640.5	82.0
Weight (kg)	61.9	6.4	52.2	4.9	56.9	7.5
BMI (kg/m^2)	21.2	2.0	21.0	2.1	21.1	2.0

BMI: body mass index; SD: standard deviation.

Exclusion criteria were those with orthopaedic diseases that prevented them from participating in the measurements, those with balance disorders due to neuromuscular diseases, and those deemed unsuitable by the principal investigator. Both subject's knee joint MR images were measured using a 0.3 T scanner AIRIS Vento (Hitachi Medical Corporation, Japan) with a knee coil. MR images were taken in the supine posture and knee joint extension positions. The scan parameters were as follows: T2-weighted, slice thickness: 3 mm, field of view: 200 mm × 200 mm, echo time: 95 ms, Repetition Time: 4000 ms, and Slice numbers: 20. The obtained MR images were analysed using the image analysis software Image J (National Institute of Health, USA). The measurements of MPTS and LPTS angles were made in accordance with the method of Hashemi et al. (Fig. 1) as follows; The two vertical lines represent the location of the sagittal plane used for determination of the medial and lateral tibial slopes (Fig. 1-A). The sagittal plane was used to determine of the orientation of the longitudinal axis in the sagittal plane (Fig. 1-B). The axis perpendicular to the longitudinal axis was reconstructed on the anterior peak of the medial tibial plateau, and the MPTS was measured with respect to perpendicular axis to the longitudinal axis (Fig. 1-C). A similar approach was used to determine the LPTS (Fig. 1-D).

MR images of the knee joint of the dominant lower extremity were used to compare differences between sexes and to examine the correlation between LPTS and MPTS angles and the frequency distribution of PTS angles. Bilateral knee joint MR images were used to compare the dominant and non-dominant lower extremities. The dominant leg is defined as 'the preferred kicking leg when kicking balls'.

Independent t-tests were used to compare differences in MPTS and LPTS angles in regard to sex and to compare dominant and non-dominant lower extremities. Pearson's correlation coefficients were used to examine the correlations between LPTS and MPTS angles in the male and female groups. Matlab R2018b (Mathworks Inc., USA) for data analysis, while SPSS for statistical analysis Statics 26 (IBM), was used. The significant p value was set at 0.05. A post-hoc power analysis was performed using G*Power (version 3.1.9.7, Franz Faul, Universität Kiel, Germany).

This study was approved by the ethics committee of the authors' affiliated institution (approval No. 842), and written informed consent was obtained from the subject. This study was conducted according to the principles of the Declaration of Helsinki.

Results

The results of the comparison of the mean PTS angle between males and females are shown in Table 2. The MPTS angle in males and females was 9.2 ± 2.4° and 10.2 ± 1.8°, respectively. The MPTS angle was greater in females, but was not statistically significant ($p = 0.204$, power = 0.080). A comparison of the mean LPTS angle revealed that it was significantly greater in females (10.3 ± 2.2°) than that in males (8.8 ± 1.7) ($p = 0.047$, power = 0.534).

The results of the comparison of the mean PTS angle between the dominant and non-dominant lower extremities are shown in Table 3. The MPTS angle of the dominant and non-dominant lower extremities was 9.7 ± 2.1° and 10.1 ± 1.8°, respectively. No statistically significant difference between the MPTS angle of the dominant and non-dominant lower extremities was observed ($p = 0.430$, power = 0.999). The LPTS angle of the dominant and non-dominant lower extremities was 9.6 ± 2.1° and 9.6 ± 1.8°, respectively, and no significant difference between these values was noted ($p = 0.888$, power = 1.000).

The results of the correlation between MPTS and LPTS angle are shown in Fig. 2. A significant moderate correlation was found between the MPTS and LPTS angles in the male group ($r = 0.777$,

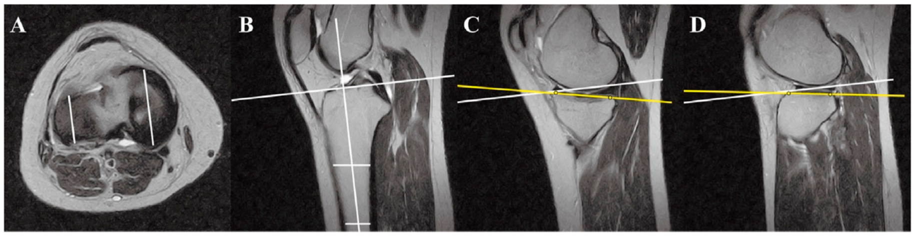

Fig. 1. The measurement methods of PTS angle. PTS: posterior tibial slope.

Table 2
PTS angle characteristics between males and females.

Variables	Male	Female	p value
MPTS angle (deg)	9.2 ± 2.4	10.2 ± 1.8	0.204
LPTS angle (deg)	8.8 ± 1.7	10.3 ± 2.2	0.047

LPTS: lateral posterior tibial slope; MPTS: medial posterior tibial slope.

Table 3
PTS angle characteristics between dominant and non-dominant extremities.

Variables	Dominant	non-Dominant	p value
MPTS angle (deg)	9.7 ± 2.1	10.1 ± 1.8	0.430
LPTS angle (deg)	9.6 ± 2.1	9.6 ± 1.8	0.888

LPTS: lateral posterior tibial slope; MPTS: medial posterior tibial slope.

$p = 0.001$, power = 0.978), but no significant correlation was found in the female group ($r = 0.456$, $p = 0.076$, power = 0.514).

In the frequency distribution of five bins of PTS angles between 4 and 14° in increments of 2°, both LPTS and MPTS angles were highest in the 8–10° bin (Fig. 3).

Discussion

An examination of differences in PTS angles between sexes revealed that LPTS angles were significantly higher in the female group than in male group. This result is similar to the paper by Hashemi et al.[10] and Dephillipo et al.[14] examining sex differences in PTS angles. It has been reported that abduction angle of the knee joint is significantly greater in ACL-injured individuals than in non-ACL-injured individuals[17] The mechanism of ACL injury involves abduction motion of the knee joint, and it is thought that the load is applied to the lateral side of the tibial plateau during knee joint abduction. In a study using cadaveric knees, it has been reported that internal rotation of the tibia and valgus rotation of the femur occurred during and after ACL injury[18] When the lateral tibia is loaded due to knee abduction, the lateral epicondyle of the femur is likely to move posteriorly, and the tibia is likely to be internally rotated relative to the femur in a subject with a large LPTS angle. The LPTS is considered more important than the MPTS in internal tibial rotation movement. Meyer et al.[18] concluded that the effective centre of rotation was located medial to the ACL, and it is assumed that internal rotation of the tibia occurs with the medial side of the tibial plateau as the centre of rotation. If the MPTS angle is large, the axis of rotation slides posteriorly with respect to the tibia. This posterior sliding of the rotation axis itself increases the amount of anterior tibial translation, and the MPTS is important in anterior tibial translation movement. The vastus medialis and vastus lateralis muscle activity is higher in female than in male during jump landing.[19] In addition to the tibial anatomical factors examined in this study, the effects of neuromuscular factors may increase the risk of ACL injury in females. Females are at a higher risk of developing ACL injuries than males.[6,7] The results of this study showed that the LPTS angle was greater in females, indicating that the LPTS angle is involved in the risk of developing ACL injury. A post-hoc power analysis for the comparison of the mean LPTS angle in males with the mean LPTS angle in females showed a moderate power (0.534). On the other hand, power was low at 0.080 when comparing the mean MPTS angle.

A study by Hashemi et al.[10] on American participants reported that the average MPTS angle in females and males was 5.9° and 3.7°, respectively; whereas, the average LPTS angle in females and males was 7.0° and 5.4°, respectively. However, a study by Zhang et al.[20] on Asian participants reported that the mean MPTS angle in females and males was 8.9° and 8.0°, respectively; whereas, the mean LPTS angle in females and males was 7.7° and 7.5°, respectively. Furthermore, multiple measurement methods were used to measure the PTS angle and the values of the PTS angle varied depending

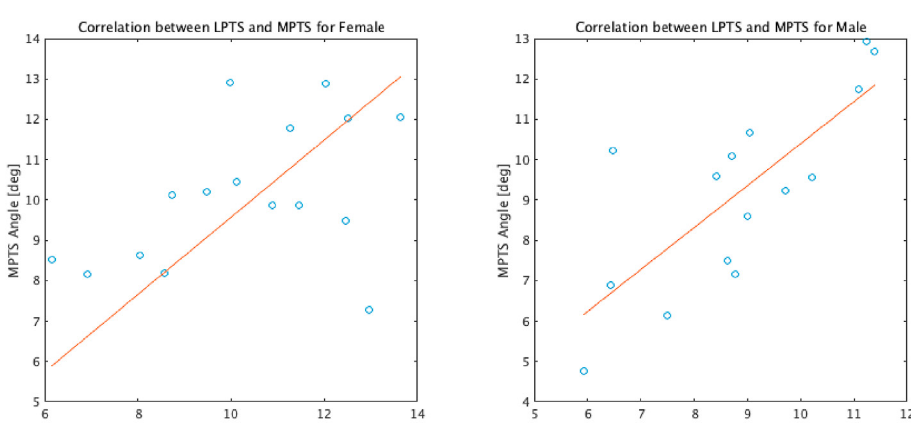

Fig. 2. The correlations between LPTS and MPTS angles for female and male groups. LPTS: lateral posterior tibial slope; MPTS: medial posterior tibial slope.

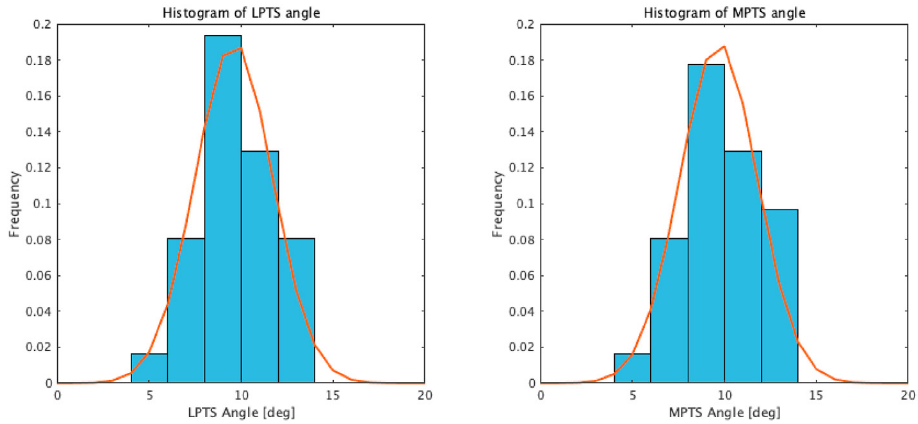

Fig. 3. The histograms of frequency distribution for LPTS and MPTS angles. LPTS: lateral posterior tibial slope; MPTS: medial posterior tibial slope.

on the measurement method. Koh et al.[21] also included Asian population in their study and reported that the mean MPTS angle in female and male individuals was 10.7° and 8.9°, respectively, and the mean LPTS angle in female and male individuals was 8.8° and 7.9°, respectively. Hence, the Asian population may have a larger PTS angle, but it is difficult to conclude on the magnitude of the PTS angle between races, as the value of the PTS angle varies depending on how the longitudinal axis of the tibia is defined and according to the measurement method.

Comparison of the differences in LPTS and MPTS angles between dominant and non-dominant lower extremities showed no significant differences. The results of this study revealed that dominant or non-dominant lower extremity had no effect on the magnitude of the PTS angle. As far as I can find, there have been no reports that examines the effect of dominant lower extremity on the PTS angle, which seems to be a new finding for PTS angle. It has been reported that there is no significant difference between dominant and non-dominant lower extremities in the patient with ACL injury,[22] while it has also been reported that non-dominant lower extremities are more likely to develop ACL injuries in females[23] The results of this study support the results of the former study by Negrete et al.[22] However, since the subject of this study was different from the studies that investigated the PTS angle in ACL-injured patients, it is difficult to compare the results.

The correlation between MPTS angle and LPTS angle was a significant positive correlation and was present in the male group. On the other hand, there was no significant correlation found in the female group, but a tendency to correlate was observed ($p = 0.076$, $r = 0.456$). The results of the histogram of the frequency distribution showed that both MPTS and LPTS angles are most frequently in the 8–10° bin. The results of this study showed that the medial and lateral tibial plateaus were similar in angular shape. The correlation between MPTS angle and LPTS angle would lead to a larger contralateral side of tibial slope angle in a subject with a larger PTS angle on either side. In subjects with a large bilateral PTS angle, it is predicted that the load on the tibia (vertical force on the tibial plateau) will be converted into an anterior tibial translation that will be more likely in causing ACL injury.

This study had a limitation. The present study did not examine the effect of PTS angle on knee biomechanics. The effect of PTS angle on biomechanics has been studied using cadaveric knees and computer simulations,[18,24,25] and there are many unknown aspects of the relationship between biomechanics and PTS angles in living subjects that need to be examined in the future.

In this study, we aimed to determine the racial differences in the PTS angle; however, this was difficult because of the differences in the measurement method of the PTS angle and paucity of studies reporting on healthy individuals. There are two methods of measuring the PTS angle using MR imaging as follows: the method developed by Hashemi et al.[10] and method developed by Hudek et al.[11] We chose the method reported by Hashemi et al., in 2008, and many previous studies have adopted this method. However, the measurement efficiency of this method is slightly lower than that of the method developed by Hashemi et al. We chose the method developed by Hashemi et al., because it required approximately 10 min to measure the PTS angle. Furthermore, this method was simple and had a high potential for clinical application. We hope that similar studies will be conducted in the future regarding the methods of measuring PTS angles.

This study investigated the characteristics of the PTS angle in Japanese healthy college students. Regarding the result of the effect of sex on the PTS angle, the LPTS angle was significantly higher in the female group than in the male group. Both MPTS and LPTS angles had the highest frequency distribution in the 8–10° bin. We also investigated the effect of dominant foot on the PTS angle and found no significant difference between the PTS angles of dominant and non-dominant lower extremities. The results of this study revealed that there was a difference in PTS angle between sexes, but these were not affected by the dominant lower extremity.

Authorship

Conception and design of study: Y. Endo, M. Takemura, H.Mutsuzaki, M. Mizukami

Acquisition of data: Y. Endo, M. Takemura, M. Monma

Analysis and/or interpretation of data: Y. Endo, M. Takemura.

Drafting the manuscript: Y. Endo

Revising the manuscript critically for important intellectual content: M. Takemura, M. Monma, H.Mutsuzaki, M. Mizukami.

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Declaration of competing interest

A conflict of interest occurs when an individual's objectivity is potentially compromised by a desire for financial gain, prominence, professional advancement or a successful outcome. *AP-SMART* Editors strive to ensure that what is published in the Journal is as balanced, objective and evidence-based as possible. Since it can be difficult to distinguish between an actual conflict of interest and a perceived conflict of interest, the Journal requires authors to disclose all and any potential conflicts of interest.

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