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Age-Related Changes of Posterior Tibial Slope and Its Roles in Anterior Cruciate Ligament Injury

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Nearly all previous studies in posterior tibial slope (PTS) and anterior cruciate ligament (ACL) injuries ignored age-related changes, and the published data are inconsistent. The objective of this study was to reveal age-related changes of PTS and its roles in ACL injury. Data for 2618 lower limbs were included initially based on the availability of lateral X-rays and a suitable femorotibial angle. The final 1431 subjects were analyzed according to age, sex, side, and injury status. Student *t*-tests, 1-way analysis of variance, and curve fitting were used to analyze data. The PTS in males was greater than that in females in the 0–9 and 30–39-year-old groups, but this pattern was reversed in the 40–49, 60–69, 70–79, and 80–89-year-old groups. The PTS was greater on the left side than on the right side in the 0–9, 10–19, 50–59, 60–69, and 80–89-year-old groups. The curve fitting for PTS demonstrated a trend of first decreasing and then increasing with aging. The PTS values differed significantly between knees with an ACL injury and those without in the 20–29, 30–39, and 40–49-year-old groups but not in the 50–59-year-old group. The PTS follows a trend of first decreasing and then increasing, and its role in ACL injury changes with advancing age. The higher PTS is only unrelated to the risk of ACL injury in age groups with a lower mean PTS value.

Key words: Age-related – Posterior tibial slope – Anterior cruciate ligament – Injury – X-ray

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The posterior inclination of the tibial plateau relative to the longitudinal axis of the bone, known as the posterior tibial slope (PTS), is important to know for the pathology of anterior cruciate ligament (ACL) injury.[1] On the basis of large X-rays of the lower limbs of adults, Genin *et al*[1] reported that the PTS ranges from 0° to 18°. Jiang *et al*[2] found that the PTS, as determined from lateral radiography of the knee, is 10° ± 4° (range, 0° to 20°). Chiu *et al*[3] studied 25 pairs of Chinese cadaveric tibias and concluded that the medial PTS is 14.8°, the lateral PTS is 11.8°, the PTS according to intramedullary radiographic measurement is 11.5°, and the PTS based on extramedullary radiographic measurement is 14.7°. Moreover, many studies have reported that an increased PTS is a risk factor for ACL injury. Brandon *et al*[4] found that an increased PTS is associated with noncontact ACL rupture in both males and females. Todd *et al*[5] and Hohmann *et al*[6] reported that an increased PTS is a possible risk factor for noncontact ACL injury only among women. Senişik *et al*[7] found that there is a higher PTS in injured male soccer players compared with uninjured male players. Webb *et al*[8] suggested that an increased PTS is associated with a greater chance for further ACL injury after ACL reconstruction. Recently, Li *et al*[9] reported that a PTS of 5° or greater is a new risk factor for ACL reconstruction failure. However, some other studies refuted the conclusions above. Meister *et al*[10] found that the PTS is not an identifiable risk factor for noncontact ACL injury on the basis of 100 knee joint lateral X-ray films. In a human cadaveric study, Fening *et al*[11] concluded that an increase in the PTS can lead to an anterior shift in the tibial resting position, but does not increase the strain in the ACL. Hohmann *et al*[12] suggested that ACL-deficient and ACL-reconstructed patients with a higher PTS have more functional knees. Kostogiannis *et al*[13] reported that ACL injury patients with a flat PTS are at higher risk for reconstruction in a 15-year follow-up study.

Indeed, nearly all previous studies of the PTS in relation to ACL injury have ignored age-related changes, and the published data are inconsistent. The present study aimed to determine whether there is: (1) a trend in the variation of the PTS with advancing age, a significant difference in the PTS between males and females of different ages, and a significant difference in the PTS between the left and right sides of individuals of different ages; and (2) variation in the role of the PTS in ACL injury with advancing age.

Patients and Methods

Our study was approved by the Institutional Review Board of Shandong University Qilu Hospital. The requirement for informed patient consent was waived because of the study's retrospective design.

Weight-bearing X-rays of lower limbs from Han Chinese patients taken between January 2011 and January 2014 were retrieved from the Shandong University Qilu Hospital archives. Data for 2618 lower limbs were included initially, with lateral views being taken with both the tibia and femoral condyles overlapping with at least 20 cm of the tibial shaft, and with the femur visible.[14] A femorotibial angle (FTA) between 170° and 175° was required.[15] A total of 1187 subjects were excluded: 329 cases for previous reparative surgery, 284 cases for femoral or tibial fracture, 228 cases for a congenital structural anomaly, 186 cases for developmental delay, and 160 cases for the presence of serious osteophytes. The final 1431 subjects were grouped into nine 10-year age intervals with ages ranging from 0–9 years to 80–89 years. Moreover, the included knees were all reviewed and grouped according to the diagnosis of ACL injury or noninjury in the case histories. Lateral views of the knees were obtained without moving the patients from a standardized position, including control of the knee flexion angle, ankle position, and limb rotation.[16] The focus-film distance was 90 cm, and the radiographic parameters were 57 kV and 21 mA. Imaging was performed using a digital radiography system (Philips Medical Systems DMC GmbH, Hamburg, Germany).

All numeric measurements were performed in duplicate, independently, and blindly by two researchers (Y.S. and L.C.). All discordant assessments were resolved by consensus measurement. The mean PTS values of the two researchers' measurements were used as the final PTS values. All measurements were made using the annotation tools on a digital picture archiving and communication system (Centricity Enterprise PACS, GE Medical Systems Co Ltd, Jiangsu, China).

PTS was calculated as the complement of angle B defined by the two lines in the lateral X-ray (Fig. 1). Line 1 (*i.e.*, the tibial proximal anatomic axis) connected the midpoints of the outer cortical diameter at 5 and 15 cm distal to the tibial tuberosity, because this line is the most parallel to the anatomic axis of the tibia.[17] Line 2 was formed by joining the highest anterior and posterior points

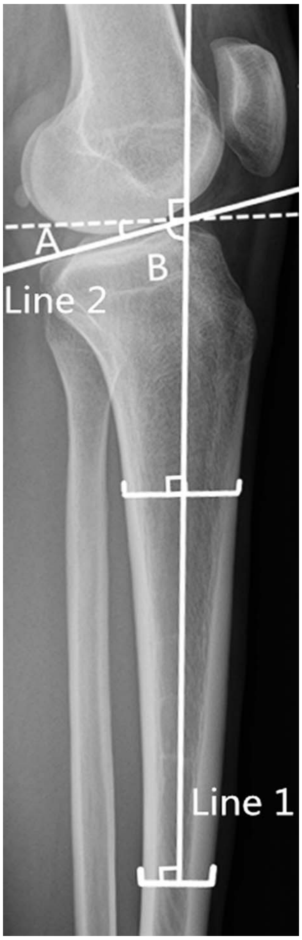

Fig. 1 The PTS is A, and A = 90° – B (*i.e.*, A is the complement of B defined by Line 1 and Line 2 in the lateral X-ray).

of the medial plateau on the lateral X-ray, avoiding osteophytes.[14]

The repeatability and reproducibility of this PTS measurement method were evaluated by an intraclass correlation analysis.[18] A significant correlation coefficient of 0.942 ($P < 0.001$) was obtained, which demonstrates an acceptable degree of intraobserver reproducibility. The repeatability also was found to be acceptable, with a correlation coefficient of 0.938 ($P < 0.001$).

Data normality was assessed using the Kolmogorov-Smirnov test or Shapiro-Wilk test, and homogeneity of variance was assessed using the Levene test. $P > 0.05$ was considered to indicate data normality and variance homogeneity. All normal quantitative data are expressed as mean ± SD, and independent Student *t*-tests were used to identify statistically significant differences between males versus females, left side versus right side, and ACL-injured versus noninjured knees in each age group. One-way analysis of variance (ANOVA) was used to identify significant differences among the 9 age groups. Line graphs, scatter diagrams, and curve fitting (regression equation: $Y = b_0 + b_1x + b_2x^2$) were used to identify the trend for PTS variation with advancing age. All analyses were conducted using SPSS version 19.0 (SPSS, Chicago, Illinois). $P < 0.05$ was considered to be statistically significant.

Results

The final 1431 subjects, ages 0 to 89 years, were distributed into nine 10-year age intervals and were analyzed according to age, sex, side, and injury status (Table 1). The trend in the mean PTS value with advancing age was evaluated using a line graph. A scatter diagram and quadratic function model with dependent (Y) for PTS and independent (X) for age were used to fit the trends in PTS with advancing age (Fig. 2).

Analysis of PTS for each sex among the 9 age groups

The PTS values differed significantly between males and females in the 0–9, 30–39, 40–49, 60–69, 70–79, and 80–89-year-old groups (Table 2). In the 0–9 and 30–39-year-old groups, the PTS in males was greater than that in females, whereas in the 40–49, 60–69, 70–79, and 80–89-year-old groups, the PTS in men was lower than that in women. There were no significant differences in the PTS between males and females in the other 3 age groups (Table 2).

Analysis of left versus right PTS among the 9 age groups

The PTS values differed significantly between the left and right sides in the 0–9, 10–19, 50–59, 60–69, and 80–89-year-old groups (Table 2). In all of these age groups, the PTS of the left side was greater than that of the right side. There were no significant differences between the left and right sides in the other 4 age groups (Table 2).

Analysis of PTS in males among the 9 age groups

In men, a significant difference in PTS was detected between the left and right sides in the 0–9, 10–19, and 70–79-year-old groups (Table 3). In these groups, the PTS value of the left side was greater than that of the right side. There were no significant differences between the left and right sides in the other 6 age groups (Table 3).

Table 1 *Sex, side, and injury data for 1431 knees of patients in 9 age groups*

	Male patients		Female patients			Injured knees			Noninjured knees	
Age group, y	Left side	Right side	Left side	Right side	Total	ACL	PCL	ACL and PCL	ACL and PCL	Total
0–9	23	19	18	20	80	0	0	0	80	80
10–19	55	52	34	25	166	4	1	0	161	166
20–29	56	36	48	43	183	19	7	1	156	183
30–39	36	38	57	41	172	22	4	1	145	172
40–49	49	34	66	48	197	31	5	3	158	197
50–59	33	28	68	55	184	15	5	4	160	184
60–69	37	29	53	54	173	2	4	0	167	173
70–79	27	29	67	52	175	0	0	0	175	175
80–89	12	18	36	35	101	0	0	0	101	101
Total	328	283	447	373	1431	93	26	9	1303	1431

Analysis of PTS in females among the 9 age groups

In females, a significant difference in the PTS was detected between the left and right sides in the 50–59 and 60–69-year-old groups (Table 3), with the PTS on the left side being greater than that on the right side. There were no significant differences between the PTS of the left and right sides in the other 7 age groups (Table 3).

Analysis of the variable trend in mean PTS values and curve fitting

For male and female data combined, male samples only, and female samples only, analysis of the variation in mean PTS with aging and curve fitting showed a trend of first decreasing and then increasing with increasing age ($P < 0.001$; Fig. 2). The lowest PTS value occurred in a patient whose

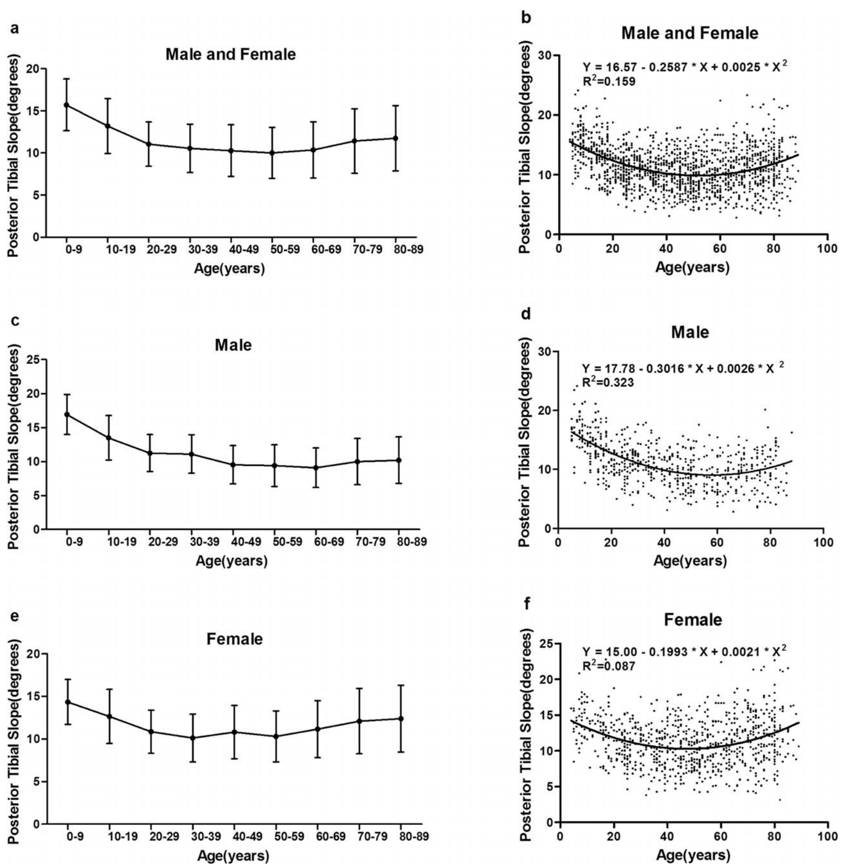

Fig. 2 The trend in the mean PTS value and curve fitting with increasing age. (a and b) A trend of first decrease and then increase for male and female samples combined; (c and d) a trend of first decrease and then increase for male samples; and (e and f) a trend of first decrease and then increase for female samples.

Table 2 Comparison of PTS data for different sexes and sides in the 9 age groups

	Sexes				Sides				Levene test		*t*-test	
	Male patients		Female patients		Left side		Right side		*P* value		*P* value	
Age group, y	n	°, Mean ± SD	n	°, Mean ± SD	n	°, Mean ± SD	n	°, Mean ± SD	Sexes	Sides	Sexes	Sides
0–9	42	16.93 ± 2.94	38	14.34 ± 2.63	41	16.63 ± 2.75	39	14.71 ± 3.11	0.873	0.353	<0.001	0.004
10–19	107	13.50 ± 3.27	59	12.63 ± 3.18	89	13.77 ± 3.25	77	12.53 ± 3.15	0.730	0.720	0.099	0.014
20–29	92	11.26 ± 2.72	91	10.84 ± 2.53	104	11.32 ± 2.60	79	10.70 ± 2.65	0.815	0.900	0.289	0.119
30–39	74	11.11 ± 2.85	98	10.11 ± 2.81	93	10.78 ± 2.86	79	10.26 ± 2.85	0.639	0.970	0.023	0.239
40–49	83	9.53 ± 2.82	114	10.81 ± 3.13	115	10.58 ± 3.02	82	9.83 ± 3.08	0.223	0.785	0.003	0.090
50–59	61	9.40 ± 3.07	123	10.30 ± 2.99	101	10.62 ± 3.06	83	9.25 ± 2.85	0.816	0.666	0.058	0.002
60–69	66	9.09 ± 2.92	107	11.14 ± 3.35	90	11.20 ± 3.34	83	9.45 ± 3.11	0.256	0.771	<0.001	<0.001
70–79	56	9.99 ± 3.39	119	12.09 ± 3.84	94	11.63 ± 3.58	81	11.18 ± 4.10	0.321	0.215	0.001	0.439
80–89	30	10.20 ± 3.42	71	12.39 ± 3.91	48	12.54 ± 4.16	53	11.01 ± 3.50	0.898	0.642	0.009	0.048
P value		<0.001[a]		<0.001[a]		<0.001[a]		<0.001[a]				

[a]One-way ANOVA *P* values indicate significant differences between male and female patients and between the left and right sides among patients in the 9 age groups.

age was approximately between 50 and 59 years, in the curve fitting model of all samples. Compared with women, men exhibited a steeper rate of decline in the PTS value in the curve fitting model (Fig. 2).

Analysis of PTS in cases of ACL injury versus noninjury among 4 age groups

The age group including more than 15 cases of ACL injury was analyzed. The PTS values differed significantly between the knees with and without ACL injury in the 20–29, 30–39, and 40–49-year-old groups (Table 4). In these groups, the PTS was greater in injured knees than in noninjured knees. There was no significant difference in the PTS between the knees with and without ACL injury in the 50–59-year-old group (Table 4).

Discussion

Many recent studies have attempted to identify potentially modifiable risk factors related to the PTS and to develop strategies to prevent ACL injuries. However, nearly all previous studies ignored age-related changes in the PTS. The present study showed that the PTS follows a trend of first decreasing and then increasing, and plays different roles in ACL injury with advancing age.

Although PTS did not differ significantly between men and women in the 50–59-year-old group, the *P* value (0.058) for this comparison was very close to

Table 3 Comparison of PTS data for male and female patients in the 9 age groups

	Males				Females				Levene test		*t*-test	
	Left side		Right side		Left side		Right side		*P* value		*P* value	
Age group, y	n	°, Mean ± SD	n	°, Mean ± SD	n	°, Mean ± SD	n	°, Mean ± SD	Males	Females	Males	Females
0–9	23	17.92 ± 2.50	19	15.73 ± 3.04	18	14.99 ± 2.14	20	13.75 ± 2.93	0.662	0.230	0.014	0.149
10–19	55	14.21 ± 3.26	52	12.75 ± 3.13	34	13.05 ± 3.13	25	12.07 ± 3.22	0.970	0.529	0.020	0.248
20–29	56	11.45 ± 2.74	36	10.96 ± 2.70	48	11.16 ± 2.44	43	10.49 ± 2.62	0.663	0.471	0.403	0.208
30–39	36	11.20 ± 3.13	38	11.03 ± 2.59	57	10.51 ± 2.67	41	9.55 ± 2.93	0.278	0.507	0.799	0.094
40–49	49	9.71 ± 2.69	34	9.26 ± 3.02	66	11.23 ± 3.11	48	10.24 ± 3.09	0.332	0.838	0.481	0.094
50–59	33	9.88 ± 3.35	28	8.83 ± 2.65	68	10.98 ± 2.86	55	9.46 ± 2.95	0.088	0.431	0.187	0.004
60–69	37	9.30 ± 2.66	29	8.81 ± 3.24	53	12.52 ± 3.13	54	9.79 ± 3.01	0.254	0.992	0.504	<0.001
70–79	27	11.06 ± 3.42	29	9.00 ± 3.11	67	11.86 ± 3.64	52	12.39 ± 4.10	0.951	0.428	0.022	0.457
80–89	12	10.68 ± 3.59	18	9.88 ± 3.36	36	13.16 ± 4.20	35	11.60 ± 3.47	0.549	0.679	0.535	0.093
P value		<0.001[a]		<0.001[a]		<0.001[a]		<0.001[a]				

[a]One-way ANOVA *P* values indicate significant differences between male and female patients and between the left and right side among patients in the 9 age groups.

Table 4 Comparison of PTS data for knees with and without anterior cruciate ligament injury in the 4 age groups

	ACL-injured knees			Noninjured knees			Levene test	*t*-test
Age group, y	n	°, Mean ± SD	*P* value	N	°, Mean ± SD	*P* value	*P* value	*P* value
20–29	19	12.57 ± 0.51	0.832[a]	156	10.89 ± 0.21	0.200[b]	0.423	0.008
30–39	22	12.67 ± 0.43	0.092[a]	145	10.22 ± 0.24	0.200[b]	0.097	<0.001
40–49	31	11.68 ± 0.48	0.273[a]	158	10.01 ± 0.25	0.200[b]	0.273	0.006
50–59	15	11.18 ± 0.73	0.142[a]	160	9.83 ± 0.24	0.065[b]	0.572	0.102

[a]Shapiro-Wilk test *P* value.
[b]Kolmogorov-Smirnov test *P* value.

0.05 (Table 2). Moreover, PTS did differ significantly between men and women in the 60–69-year-old group, and the *P* value (<0.001) for this comparison was far below 0.05. Therefore, when these adjacent age groups were merged and redistributed, PTS was found to differ significantly between men and women from ages 40 to 89 years ($P < 0.001$). Furthermore, there were significant differences in the PTS between males and females in the 0–9-year-old group ($P < 0.001$) and the 30–39-year-old group ($P = 0.023$). Therefore, these results indicated that the PTS does not differ between males and females only from the ages of 10–29 years. The difference in PTS between the younger and older groups likely is related to the regulation of skeletal growth and degeneration. Generally, males achieve skeletal maturity later than females, but women are more likely than men to develop osteoarthritis of the knees with advancing age. Zhang *et al*[19] reported prevalence values for radiographic knee osteoarthritis of 42.8% in females and 21.5% in males in a sample of persons aged >60 years in Beijing. Moreover, PTS has been shown to increase with the onset of osteoarthritis.[18,20] Thus, females, who experience earlier skeletal maturity and are more likely to be affected by degeneration and serious osteoarthritis, may have higher PTS values than males beyond the age of 40 years.

A significant difference in PTS was detected between the left and right sides in the 80–89-year-old group ($P = 0.048$), but the difference was not too great, because the *P* value was very close to 0.05 (Table 2). There was no significant difference between the left and right sides in the 70–79-year-old group, with a corresponding *P* value (0.439) far greater than 0.05. Therefore, when the 70–79 and 80–89-year-old groups were merged, the difference between the left and right sides was not significant for patients ages 70 to 89 years ($P = 0.075$). These results suggested that the PTS does not differ between the left and right sides in the 20–39 and 70–89-year-old groups, whereas it does differ in the 0–19 and 50–69-year-old groups. Moreover, the PTS on the left side is higher than that on the right side. Senişik *et al*[7] reported that a higher PTS was determined in dominant legs compared with the nondominant side for ACL-injured soccer players, and the different PTS measures in dominant and nondominant legs might be the result of different loading and/or adaptation patterns. In the present study, the PTS differences between left side and right side may be related to skeletal physiologic degeneration with patient aging and dominant leg loading.

In published studies,[1,17,18,21–23] PTS data have been based on X-ray, magnetic resonance imaging (MRI), and computed tomography (CT). Compared with MRI and CT, X-rays have been widely used because of easy access, sufficient tibia length, precise landmarks, and significant results.[1,17,21] The large number of X-ray analyses provided a large sample size, which greatly enriched this study. Moreover, the FTA is easy to evaluate in long X-ray images of lower extremities. Bruni *et al*[15] suggested that a knee with FTA greater than 175° is a varus knee, and one with FTA less than 170° is a valgus knee, on radiographic measurement. In the present study, varus and valgus knees were excluded. However, Matsuda *et al*[24] reported that the differences in the medial PTS and lateral PTS determined using MRI between 30 normal and 30 varus knees were not statistically significant. Although MRI and CT images may differentiate the medial and lateral aspects of the tibial plateau, these imaging techniques are not standard procedures for assessing PTS. Siu *et al*[16] confirmed that most angles are sensitive to contrived positional variation in radiographic procedures, especially limb rotation and knee flexion. Therefore, the key to obtaining a good lateral view of the knee is to keep the patient in a standardized position.

ACL injury is divided into contact and noncontact types according to whether the injury was caused by external violence or not. Most previous studies of the PTS focused on its roles in noncontact ACL injury.[4–6,10] Griffin *et al*[25] reported that 70% of ACL injuries occur in noncontact situations. However, Kostogiannis *et al*[13] reported that patients with contact ACL injuries have a higher PTS than those injured in noncontact sports. The causes of ACL injury in the present study were not clarified, and the result showed that the PTS in patients with an ACL injury was greater than that among patients without an ACL injury in 20–49-year-old groups. Our results also indicated that there is no significant difference in the PTS values between patients with or without ACL injury in the 50–59-year-old group. Meanwhile, the lowest PTS value was observed in the 50–59-year-old group in the curve fitting model of age-related PTS changes in this study. The high coincidence of the two age ranges listed above revealed that the conclusion that a high PTS is not a risk factor for ACL injury can only be made based on a specific age group with a lower mean PTS value.

One limitation of the present study was that the X-ray measurements of the PTS only displayed bony structures, without considering cartilage and menisci thickness. The posterior horn of the meniscus is thicker than the anterior one, and this may decrease the PTS.[26] Hudek *et al*[27] concluded that a greater lateral meniscal slope may indicate a greater risk of ACL injury. Pauli *et al*[28] reported chances in the meniscus and cartilage with aging at both macroscopic and microscopic levels. In the future, not only tibial plateau bony structures but also cartilage and menisci thickness should be considered in the study of the relationship between PTS and ACL injury. A further potential limitation was that the causes of ACL injury in the present study were not clarified. Griffin *et al*[25] concluded that violence may be the only factor causing contact ACL injury, decreasing the correlation among other risk factors and ACL injury. However, the present study still provided valuable information regarding the clinical significance of PTS in ACL injury. Future, more complex, and potentially accurate methods are expected to become available for studying ACL injury.

In conclusion, PTS follows a trend of first decreasing and then increasing with advancing age, and sex and left versus right side are both factors affecting the PTS value in patients ages 50 to 69 years but not in those ages 20 to 29 years. The role of the PTS in ACL injury differs with different patient age, and a higher PTS value is a risk factor for ACL injury in individuals ages 20 to 49 years but not those ages 50 to 59 years. A higher PTS can only be considered not a risk factor for ACL injury based on data from patients in a lower mean PTS value age group.

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