Review

Posterior Tibial Slope in Patients With Torn ACL Reconstruction Grafts Compared With Primary Tear or Native ACL

A Systematic Review and Meta-analysis

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Background: Increased posterior tibial slope (PTS) is a risk factor for anterior cruciate ligament (ACL) rupture and failure of ACL reconstruction (ACLR) grafts.

Purpose: The purpose was to conduct a systematic review of literature on PTS measurements and to conduct a meta-analysis of comparable PTS measurements based on a patient’s ACL status. It was hypothesized that patients with torn ACLR grafts would have significantly larger medial and lateral PTS compared with patients with native ACLs or those who underwent primary ACLR.

Study Design: Systematic review; Level of evidence, 4.

Methods: A systematic review was performed using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Included were studies that reported medial and/or lateral PTS measurements, those that reported PTS measurements based on ACL status (ie, intact ACL, primary ACL tear, failed ipsilateral ACLR, or revision ACLR), and those that reported their specific PTS measurement technique. Average PTS measurements, measurement location (medial or lateral tibial plateau) and technique, imaging modality used, and ACL status were extracted from each study. Data were pooled using Der-Simonian and Laird random-effects models, and results were compared using the Altman interaction test.

Results: The literature search identified 1705 studies, of which 82 (N = 12,971 patients) were included. There were 4028 patients in the intact ACL group (31%), 7405 in the primary ACLR group (57%), and 1538 in the failed ACLR group (12%). Measurements were obtained from lateral radiographs in 31 studies (38%), from magnetic resonance imaging in 47 studies (57%), and from computed tomography in 4 studies (5%). The failed ACLR group had a significantly larger lateral PTS (9.55°; 95% CI, 8.47°–10.63°) than either the primary ACL tear (7.13°; 95% CI, 6.58°–7.67°) or intact ACL (5.57°; 95% CI, 5.03°–6.11°) groups (P < .001 for both). The failed ACLR group also had a significantly larger medial PTS (9.05°; 95% CI, 7.80°–10.30°) than the primary (6.24°; 95% CI, 5.71°–6.78°) or intact ACL (6.28°; 95% CI, 5.21°–7.35°) groups (P < .001 for both).

Conclusion: Both lateral and medial PTS measurements were greater in patients who had failed previous ACLR than those with a primary ACL tear or an intact native ACL. The lateral PTS of patients with primary ACL tears was greater than those with an intact native ACL.

Keywords: ACL risk factor; anterior cruciate ligament; anterior cruciate ligament revision; posterior tibial slope

Posterior tibial slope (PTS) is an important radiographic measurement that is defined by the sagittal angulation of the tibial plateau relative to the tibial shaft.68 Biomechanical data suggest that anatomic variations in PTS can significantly alter biomechanical knee stability; studies have reported a linear relationship between the PTS and the amount of tension placed on native cruciate ligaments and reconstructed cruciate grafts.7,8,49,98 Previous case series have reported that patients with primary anterior cruciate ligament (ACL) tears have steeper PTS.58,104 Others have shown that patients with graft rupture after previous ACL reconstruction (ACLR) have greater PTS than those undergoing primary ACLR.72,86 To protect reconstruction grafts from variations in PTS, some authors advocate the use of slope reducing, anterior closing-wedge high tibial osteotomy.22,24,27 Measurement strategies include a variety of imaging modalities, such as standard lateral radiographs, long-leg...
lateral radiographs, magnetic resonance imaging (MRI), and computed tomography (CT), in addition to several different techniques including utilization of the anatomic or mechanical axis or the anterior or posterior cortex. Previous reports have demonstrated that increases in PTS, by as little as 2°, places a clinically significant amount of increased strain on the ACL.

Despite numerous case series and biomechanical studies that evaluated PTS in patients with ruptured ACLs and those undergoing revision or rerevision ACLR, there are few comprehensive reviews comparing the PTS of patients with ACL pathology. As such, the purpose of the current analysis was to conduct a systematic review of literature on PTS measurements and to conduct a meta-analysis of comparable PTS measurements based on patients’ ACL status/integrity (intact ACL, primary ACL tear, failed ACLR).

It was hypothesized that patients with torn ACLR grafts would have significantly larger medial and lateral PTS compared with patients with native ACLs or those with primary ACLRs.

METHODS

Article Identification and Selection

A systematic review was completed using the PRISMA (Preferred Reporting Items for Systematic Meta-Analyses) guidelines on the PTS of patients undergoing primary and revision ACLR; the query was performed in May 2021 (Figure 1). The specific search terms were “Tibial Slope” AND “ACL” OR “PTS” AND “ACL” OR “Tibial Slope” AND “Revision” OR “Anterior Cruciate Ligament” AND “Revision.” This systematic review was registered in May 2021 using the PROSPERO international prospective register of systematic reviews (registration No. CRD42021256743).

The inclusion criteria for studies in both the systematic review and meta-analysis consisted of the following: studies written in English, studies that reported either medial or lateral PTS, studies that reported PTS measurements based on the status of a patient’s ACL (ie, intact ACL, primary ACL tear, failed ACL ipsilateral reconstruction, or revision ACLR), studies that reported their PTS measurement technique, and studies that were published during or after the year 2000. Measurements for the intact ACL group were obtained from patients who had non-ACL pathologies. These measurements were not obtained from the contralateral limb of patients with ACL tears. Exclusion criteria were ACL studies that did not include PTS measurements; studies that failed to describe the ACL status; studies that failed to differentiate measurement location (medial vs lateral PTS) or technique of PTS measurement; studies that failed to report measures of variance (eg, standard deviation or confidence interval); case studies with level V evidence; any study published before the year 2000; studies that used or compared multiple measurement techniques; studies that included posterior cruciate ligament injuries; and biomechanical, in vitro, or animal model studies. Studies that included both revision and primary ACLRs in the same cohort were not included in the meta-analysis portion of the current study. Two investigators (R.S.D., N.N.D.) independently reviewed the abstracts from all identified articles. If necessary, full-text articles were obtained for review to allow further evaluation.

Figure 1. PRISMA flowchart demonstrating the article selection process. ACL, anterior cruciate ligament; PRISMA, Preferred Reporting Items for Systematic Meta-Analyses; PTS, posterior tibial slope.
application of the established inclusion and exclusion criteria. In addition, reference lists from the included studies were reviewed and reconciled to verify that all eligible articles were considered.

Data Extraction

The variables of interest that were extracted from each study included average PTS measurements, PTS measurement location (medial or lateral PTS), imaging modality used to measure PTS, PTS measurement technique, indications for knee imaging (for intact cohort), country of origin of study, and primary versus revision ACL tear. In addition, descriptive article information and patient demographics were extracted and recorded from each study. The country of origin was defined by the corresponding authors’ listed country. Some studies separated their cohorts into subgroups that were unable to be combined; these included groupings by sex, laterality (unilateral vs bilateral), outcomes (superior vs inferior), PTS (high vs low), and laxity (high vs low). These studies were therefore included as separate entries in the meta-analysis. Patients were grouped into 1 of 3 cohorts: intact ACL, primary ACL tear, or failed ACLR. Demographic variables, country of origin, PTS measurement technique, PTS measurement modality, and article descriptive information were not evaluated in the meta-analysis portion of the current study but were reported in the systematic review. Measurement modalities were grouped into radiographs, MRI, or CT.

The measurement techniques were grouped into 1 of 4 categories, each of which has been described previously in the literature (Figure 2). The first technique used MRI and measured the vertical component of the PTS measurement using the midpoint of parallel horizontal lines at least 4 cm apart and distal in the image. The second technique utilized a sagittal MRI slice to place 2 circles: a superior circle touching the anterior, posterior, and superior cortex of the tibia, and an inferior circle touching the anterior and posterior cortex. A vertical line was then drawn between the midpoint of both circles to establish the longitudinal component of the measurement. The third technique utilized standard radiographs. Points at 5 and 15 cm distal to the joint line on both the anterior and posterior tibial cortices were identified. The midpoint between the respective anterior and posterior points were then established. These midpoints were connected with a vertical line to establish the longitudinal axis of the PTS calculation. The fourth category included all other techniques, which included an adaptation of the circle measurement technique on standard radiographs, all measurements obtained on CT images, and techniques that considered the anterior or posterior tibial cortex exclusively. Based on previous studies, the minimal clinically significant difference (MCID) for PTS was defined as ≥2°, which represents the difference in measurements between the different locations (medial vs lateral).

Risk-of-Bias Evaluation

All studies were reviewed for bias using the previously reported Methodological Index for Non-Randomized Studies (MINORS) tool. The MINORS tool includes 12 questions to assess quality, 4 of which are applicable only to those studies that are comparative. Each of the 12 items was scored 0 to 2: 0, not reported; 1, reported but described or performed poorly or inadequately; 2, reported accurately and well described. Higher scores are associated with a lower risk of bias. Scores of at least 75% were considered high quality with low risk for bias; scores between 50% and 75% were considered medium risk for bias; scores of less than or equal to 50% were considered high risk for bias. For
RESULTS

The literature search identified 1705 unique studies, of which 82 were included in the final systematic review and meta-analysis (Figure 1). There were 40 studies that reported the PTS of patients with intact ACLs (Table 1), 65 studies that reported the PTS of patients with primary ACL tears (Table 2), and 18 studies that reported the PTS of at least 1 failed ipsilateral ACLR (Table 3).

In total, there were 12,971 patients, including 4028 (31%) patients in the intact ACL group, 7405 (57%) in the primary ACLR group, and 1538 (12%) in the failed ACLR group. There were 22 studies (27%) that reported only the medial PTS, 15 studies (18%) that reported only the lateral PTS, and 45 studies (55%) that reported both medial and lateral PTS.

The mean age range of included patients was 13.1 to 51.6 years. Among the included studies, 31 (38%) reported measurements obtained from lateral radiographs, 47 (57%) reported measurements obtained from MRI, and 4 (5%) reported measurements obtained from CT. The measurement techniques reported were as follows: studies that used the midpoint lines technique on MRI (n = 26), studies that used the midpoint lines technique on standard radiographs (n = 17), and studies that used the circles technique on MRI (n = 23). There were also 2 studies that used the anterior tibial cortex19,97 and 3 studies that used the posterior tibial cortex for their measurement techniques.53,44,86

Risk of Bias

Each of the studies were evaluated for quality and risk of bias using the MINORS tool. In total, there were 76 studies that were considered a low risk for bias and 6 studies with a medium risk for bias. The full results of this portion of the study can be viewed in Supplemental Table S1.

DISCUSSION

The primary finding of this systematic review and meta-analysis was that patients with failed ACLRs had significantly greater medial and lateral PTS than those with either intact native ACLs or those that had primary ACL tears. Moreover, the difference in mean PTS between the failed ACLR group and either the intact or primary ACL tear cohorts was greater than the previously established MCID. Ultimately, our hypothesis that patients with torn ACL grafts would have significantly larger lateral PTS compared with patients with native ACLs or those with primary ACL tears was supported by the findings of the current analysis.

In the current analysis, patients in the failed ACLR cohort were found to have significantly larger medial and lateral PTS compared with patients in the intact ACL and primary ACL tear cohorts; the difference in mean PTS was greater than 2° for both medial and lateral PTS. In addition, the lateral PTS of the primary ACL tear group was significantly greater than the intact ACL cohort, whereas there was no significant difference between these subgroups with respect to medial PTS. A previous case series by Todd et al included 140 total patients and concluded that patients with noncontact ACL injury had significantly larger PTS (9.39° vs 8.50°). Previous studies reached similar conclusions with respect to intact ACLs compared with torn ACLs. Additional studies have also reported increased PTS with 1 or more patients undergoing revision ACLR compared with those undergoing primary
The authors of the aforementioned meta-analysis reported that they were skeptical of this finding because of the wide variability in their included studies. We are more confident in our findings in the current review because of the large number of studies and patients, and because of the large difference in pooled means between groups that we observed.

There was no clinical or statistical difference identified between the medial PTS of the intact ACL and primary ACL. A previous meta-analysis that included 14 studies reported greater lateral PTS in individuals with ACL injury than in those with intact ACLs. However, the authors of the aforementioned meta-analysis reported that they were skeptical of this finding because of the wide variability in their included studies. We are more confident in our findings in the current review because of the large number of studies and patients, and because of the large difference in pooled means between groups that we observed.

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### TABLE 1

Demographics and Measurement Variables for Intact ACL Cohort

| Lead Author (Year) | Total No. of Knees Included | Sex, M/F | Mean Age, y (Range or SD) | Measurement Modality | Measurement Technique | Country of Origin | PTS: Medial, Lateral, or Both |
|-------------------|-----------------------------|----------|---------------------------|----------------------|----------------------|-------------------|-------------------------------|
| Sun (2016)         | 619                         | NA       | Age range: 20-39 (n = 156); 30-39 (n = 145); 40-49 (n = 158); 50-59 (n = 160) | Radiograph           | Midpoint lines (3)  | China             | Medial                        |
| Alentorn-Geli (2015) | 53                          | 53/0     | 33.7 (16-51)              | MRI                  | Midpoint lines (1)  | Spain             | Both                          |
| Kizilgoz (2018)    | 109                         | 63/46    | 28.6 (0.6)                | MRI                  | Midpoint lines (1)  | Turkey            | Both                          |
| Shen (2018)        | 125                         | 65/60    | 32.4 (9.7)                | MRI                  | Circles (2)         | China             | Both                          |
| Bojicic (2017)     | 42                          | 21/21    | 26.5 (8.3)                | MRI                  | Midpoint lines (1)  | USA               | Lateral                       |
| Bisson (2009)      | 40                          | 20/20    | 33 (13.5)                 | MRI                  | Midpoint lines (3)  | USA               | Both                          |
| Vasta (2018)       | 200                         | 100/100  | 24.3 (4.7)                | Radiograph           | Midpoint lines (3)  | Italy             | Lateral                       |
| Suprasanna (2019)  | 33                          | 14/19    | 30.2 (8.4)                | MRI                  | Midpoint lines (1)  | India             | Both                          |
| Raja (2019)        | 55                          | 33/22    | 31.7                      | MRI                  | Midpoint lines (1)  | India             | Both                          |
| Sayit (2015)       | 60                          | 33/27    | 37 (21)                   | MRI                  | Midpoint lines (2)  | Turkey            | Both                          |
| Rahmehn-Azar (2016) | 45                         | 45/50    | 20 (2)                    | MRI                  | Midpoint lines (2)  | USA               | Both                          |
| Dare (2015)        | 76                          | 36/40    | 14.8 (1.3)                | MRI                  | Midpoint lines (1)  | USA               | Both                          |
| Vyas (2011)        | 23                          | NA       | 14.4                      | Radiograph           | Midpoint lines (3)  | USA               | Lateral                       |
| Hudek (2011)       | 55                          | 24/31    | M: 32 (9); F: 36 (12)     | MRI                  | Circles (2)         | Switzerland       | Both                          |
| Zeng (2016)        | 109                         | 44/65    | 36 (14)                   | Radiograph           | Posterior tibial cortex (4) | Australia       | Lateral                       |
| Stijak (2007)      | 33                          | 21/12    | 30.1 (11.1)               | Radiograph           | Midpoint lines (3)  | Serbia            | Both                          |
| DePhillippo (2019) | 56                          | 30/26    | 34.1 (15.3)               | MRI                  | Circles (2)         | USA               | Lateral                       |
| Chung (2011)       | 20                          | 16/4     | 28                        | Radiograph           | Anterior tibial cortex (4) | Hong Kong       | Medial                        |
| Alentorn-Geli (2015) | 53                          | 53/0     | 28.1 (8.7)                | Radiograph           | Midpoint lines (3)  | China             | Lateral                       |
| Senisik (2011)     | 54                          | 54/0     | 23.8 (2)                  | Radiograph           | Midpoint lines (3)  | Turkey            | Medial                        |
| Kililgoz (2019)    | 101                         | 59/42    | 28 (11-18)                | Radiograph           | Midpoint lines (3)  | Turkey            | Medial                        |
| El Mansori (2017)  | 100                         | 52/48    | 18.86                     | MRI                  | Midpoint lines (1)  | France            | Both                          |
| Huang (2019)       | 52                          | 32/20    | 24.5 (5.1)                | MRI                  | Midpoint lines (1)  | China             | Both                          |
| Hendrix (2016)     | 50                          | 18/32    | 25.8 (14.5)               | Radiograph           | Circles (4)         | USA               | Lateral                       |
| Terauchi (2011)    | 73                          | 33/40    | 25.5 (14-44)              | MRI                  | Anterior tibial cortex (4) | USA               | Medial                        |
| Hashemi (2009)     | 55                          | 22/33    | NA                        | MRI                  | Midpoint lines (1)  | USA               | Both                          |
| Brandon (2006)     | 100                         | 51/49    | NA                        | Radiograph           | Midpoint lines (3)  | USA               | Medial                        |
| O’Malley (2005)    | 32                          | 24/8     | 13.1 (9-16)               | Radiograph           | Midpoint lines (3)  | USA               | Medial                        |
| Kizilgoz (2019)    | 81                          | 81/0     | NA                        | MRI                  | Midpoint lines (1)  | Turkey            | Both                          |
| Sonnery Cottet (2011) | 50                        | 35/15    | NA                        | Radiograph           | Midpoint lines (3)  | France            | Medial                        |
| Todd (2011)        | 179                         | 126/53   | NA                        | Radiograph           | Midpoint lines (3)  | USA               | Medial                        |
| Ristic (2014)      | 30                          | 25/5     | 25.3 (16-56)              | MRI                  | Circles (2)         | Serbia            | Both                          |
| Sundar (2016)      | 290                         | 140/150  | 40                        | MRI                  | Midpoint lines (1)  | India             | Both                          |
| Li (2020)          | 32                          | 23/9     | 37 (10.6)                 | Radiograph           | Circles (4)         | China             | Lateral                       |
| Kwak (2021)        | 100                         | 75/5     | 14.4 (3.6)                | MRI                  | Circles (2)         | Korea             | Both                          |
| Zikria (2020)      | 48                          | 19/29    | 51.6 (13.9)               | MRI                  | Circles (2)         | USA               | Both                          |
| Freitas (2021)     | 433                         | NA       | NA                        | MRI                  | Circles (2)         | Brazil            | Both                          |
| Edwards (2021)     | 20                          | 15/5     | 14.8 (2.4)                | MRI                  | Circles (2)         | England           | Both                          |

**ACL, anterior cruciate ligament; F, female; M, male; MRI, magnetic resonance imaging; NA, not available; PTS, posterior tibial slope.**

The numbers in parentheses correspond to the various measurement techniques: (1) midpoint lines technique using MRI; (2) circles technique using MRI; (3) midpoint lines using standard radiographs; (4) other (combination of circles on radiographs, posterior tibial cortex, anterior tibial cortex).
| Lead Author (Year) | Total No. of Knees Included | Sex, M/F | Mean Age, y (Range or SD) | Measurement Modality | Measurement Technique | Country of Origin | PTS: Medial, Lateral, or Both |
|-------------------|----------------------------|----------|--------------------------|----------------------|----------------------|-------------------|------------------------------|
| Alentorn-Geli (2015)³ | 46 | 46/0 | 33 (16-49) | MRI | Midpoint lines (1) | Spain | Both |
| Kiapour (2019)⁵¹ | 43 | 15/28 | 23.7 (9.2) | MRI | Circles (2) | USA | Both |
| Grassi (2018)⁵⁶ | 42 | 36/6 | 26.3 (8.4) | MRI | Midpoint lines (1) | Italy | Both |
| Shen (2018)⁸⁷ | 125 | 65/60 | 32.4 (9.7) | MRI | Circles (2) | China | Both |
| Li (2014)¹¹¹ | 20 | NA | NA | MRI | Midpoint lines (1) | China | Both |
| Vasta (2018)¹⁰¹ | 200 | 100/100 | 24.4 (4.8) | Radiograph | Midpoint lines (3) | Portugal | Lateral |
| Kiapour (2019)⁵⁰ | 20 | NA | 24 | MRI | Midpoint lines (1) | USA | Lateral |
| Suprasanna (2019)⁵⁶ | 33 | 15/18 | NA | MRI | Midpoint lines (1) | India | Both |
| Li (2014)¹³ | 104 | 104/0 | 29.5 (6.3) | MRI | Midpoint lines (1) | China | Both |
| Lee (2018)⁶⁰ | 64 | 58/6 | 31 | Radiograph | Midpoint lines (3) | Korea | Medial |
| Hohmann (2010)⁴³ | 68 | 51/17 | 28.5 (16-49) | Radiograph | Posterior tibial cortex (4) | Australia | Medial |
| Sayit (2015)⁸³ | 60 | 35/25 | 39 (22) | MRI | Circles (2) | Turkey | Both |
| Song (2020)⁹¹ | 60 | 47/9 | 25.1 (7.3) | Radiograph | Other (4) | China | Lateral |
| Oshima (2019)⁷⁵ | 98 | 58/40 | 31.3 (10.3) | MRI | Midpoint lines (1) | Australia | Both |
| Schneider (2019)⁸⁴ | 276 | 138/138 | 32.5 (12) | CT | Midpoint lines (4) | France | Medial |
| El Mansori (2018)³⁰ | 362 | 238/124 | 32.1 (11) | CT | Midpoint lines (4) | France | Both |
| Li (2019)⁶² | 119 | 81/38 | 32.7 (11.4) | MRI | Circles (2) | China | Lateral |
| Rahenemai-Azar (2016)⁷⁸ | 45 | 45/0 | 20 (2) | MRI | Circles (2) | USA | Both |
| Rahenemai-Azar (2016)⁷⁸ | 53 | 36/17 | 26 (11) | MRI | Circles (2) | USA | Both |
| Jaecker (2018)⁴⁸ | 69 | 48/1 | 31.9 (18-68) | MRI | Midpoint lines (1) | Germany | Both |
| Song (2016)⁹⁰ | 106 | 86/20 | 26.1 (7.3) | MRI | Circles (2) | China | Medial |
| Napier (2019)⁷² | 280 | 210/70 | 27.7 (2.6) | Radiograph | Circles (4) | Australia | Both |
| Hohmann (2011)⁴⁴ | 272 | 199/73 | 26 (15-54) | Radiograph | Posterior tibial cortex (4) | Australia | Lateral |
| Wawiniole (2016)¹⁰³ | 105 | 52/53 | 36 (14) | MRI | Circles (2) | USA | Both |
| Stijak (2007)⁹³ | 33 | 21/12 | 29.9 (9.8) | Radiograph | Midpoint lines (3) | Serbia | Both |
| DePhillipo (2019)²⁸ | 112 | 60/52 | 33.5 (15.7) | MRI | Circles (2) | USA | Lateral |
| Christianson (2015)¹⁸ | 35 | 21/14 | 21.4 | MRI | Midpoint lines (1) | USA | Lateral |
| Chung (2011)¹⁹ | 28 | 25/3 | 26 | Radiograph | Anterior tibial cortex (4) | Hong Kong | Medial |
| Choi (2019)¹⁷ | 148 | 107/41 | 24.5 (4.1) | MRI | Circles (2) | Korea | Both |
| Shen (2019)⁸⁸ | 50 | 30/20 | 28.5 (6.3) | MRI | Circles (2) | China | Both |
| Webb (2013)¹⁰⁴ | 131 | NA | 26 | Radiograph | Midpoint lines (3) | Australia | Medial |
| Sensikis (2011)⁸⁵ | 27 | 10/17 | 22.7 (3.5) | Radiograph | Midpoint lines (3) | Turkey | Medial |
| Li (2014)¹¹¹ | 40 | 28/12 | 23.5 (6.5) | MRI | Circles (2) | China | Both |
| Dejour (2018)²⁵ | 151 | 173/78 | 29.8 (10.5) | Radiograph | Midpoint lines (3) | France | Medial |
| Mitchell (2018)⁶⁹ | 363 | 193/170 | 31 (23-45) | Radiograph | Circles (4) | USA | Lateral |
| El Mansori (2017)³⁰ | 100 | 67/33 | NA (18-63) | MRI | Midpoint lines (1) | France | Both |
| Huang (2019)⁴⁵ | 52 | 31/21 | 25.5 (5) | MRI | Midpoint lines (1) | China | Both |
| Hendrix (2016)⁴¹ | 100 | 48/52 | 21.9 (11.1) | Radiograph | Circles (4) | USA | Lateral |
| Dekker (2017)²⁶ | 58 | 21/37 | 14.1 (2.2) | Radiograph | NA | USA | Lateral |
| Kolbe (2018)⁵² | 59 | 37/22 | 30 (11) | MRI | Circles (2) | Germany | Both |
| Grassi (2019)³⁵ | 40 | 34/6 | 28.2 (8.6) | MRI | Circles (4) | Italy | Both |
| Nagai (2018)⁷⁰ | 25 | 19/6 | 20.5 (4.3) | MRI | Circles (4) | Japan | Both |
| O’Malley (2005)⁷⁴ | 32 | 23/9 | 13.1 (9-17) | Radiograph | Midpoint lines (1) | USA | Medial |
| Sauer (2018)⁵² | 54 | NA | NA | MRI | Circles (2) | New | Lateral |
| Todd (2011)⁹⁸ | 179 | 126/53 | 25.4 (8.7) | Radiograph | Midpoint lines (1) | USA | Medial |
| Ristic (2014)⁷⁰ | 30 | 24/6 | 30.4 (9-59) | MRI | Circles (2) | Serbia | Both |
| Ahn (2017)² | 290 | 270/20 | NA | Radiograph | Midpoint lines (3) | Korea | Medial |
| Grassi (2019)⁷⁷ | 43 | 34/9 | 23.3 (19.6-23.2) | MRI | Midpoint lines (1) | Italy | Both |
| Kililogz (2018)⁵⁵ | 109 | 63/46 | 28.6 (0.6) | MRI | Midpoint lines (1) | Turkey | Both |
| Li (2020)⁶³ | 32 | 23/9 | 37 (10.8) | Radiograph | Circles (4) | China | Lateral |
| Kim (2020)⁵² | 275 | 236/39 | NA | MRI | Midpoint lines (1) | Korea | Both |
| Batty (2021)⁹ | 618 | 299/319 | 18.9 (3.2) | Radiograph | Circles (4) | Australia | Lateral |
| Ziegler (2021)¹¹³ | 109 | 51/58 | 32 (21-45) | MRI | Midpoint lines (1) | USA | Both |
| Oshima (2020)⁷¹ | 98 | 58/41 | 32.5 (11.7) | MRI | Circles (2) | Australia | Both |

(continued)
ACL tear cohorts; these were the only groups that were not significantly different. This finding is supported in the literature by several studies that have postulated that the lateral slope is a more significant risk factor for ACL injury than the medial slope. A study by Webb et al found that ACL-deficient knees had significantly greater lateral PTS (5.7 vs 3.4, P < .001) but not medial PTS (5.4 vs 5.1, P = .42) compared with those with intact

**Table 2 (continued)**

| Lead Author (Year) | Total No. of Knees Included | Sex, M/F | Mean Age, y (Range or SD) | Measurement Modality | Measurement Technique | Country of Origin | PTS: Medial, Lateral, or Both |
|---------------------|-----------------------------|----------|---------------------------|----------------------|----------------------|---------------------|-----------------------------|
| Freitas (2021)      | 140                         | NA       | NA                        | MRI                  | Circles (2)          | Brazil              | Both                        |
| Bernholt (2021)     | 206                         | NA       | NA                        | MRI                  | Circles (2)          | USA                 | Both                        |
| Yoon (2020)         | 232                         | 183/49   | 28.2 (8.9)                | MRI                  | Circles (2)          | Korea               | Both                        |
| Tradati (2020)      | 43                          | 28/15    | 25 (8)                    | MRI                  | Circles (2)          | Luxembourg          | Both                        |
| Nakazato (2020)     | 103                         | 29/74    | NA (14-58)                | CT                   | Circles (4)          | Japan               | Both                        |
| Shellbourne (2021)  | 126                         | NA       | NA                        | Radiograph           | Posterior tibial cortex (4) | USA       | Medial                      |
| Mitchell (2021)     | 114                         | NA       | NA                        | Radiograph           | Circles (4)          | Canada              | Lateral                     |
| Beel (2021)         | 56                          | 42/14    | 26 (7)                    | MRI                  | Circles (2)          | Luxembourg          | Both                        |
| Hagiwara (2021)     | 43                          | 26/17    | 32.8 (14.8)               | MRI                  | Midpoint lines (1)   | Japan               | Both                        |
| Kim (2021)          | 226                         | 192/34   | NA                        | MRI                  | Midpoint lines (1)   | Korea               | Both                        |
| Ni (2020)           | 25                          | 18/7     | 28.9 (8.1)                | Radiograph           | Circles (4)          | China               | Medial                      |

**Table 3**

Demographics and Measurement Variables for Revision ACL Tear Cohort

| Lead Author (Year) | Total No. of Knees Included | Sex, M/F | Age, y (Range or SD) | Measurement Modality | Measurement Technique | Country of Origin | PTS: Medial, Lateral, or Both |
|---------------------|-----------------------------|----------|----------------------|----------------------|----------------------|---------------------|-----------------------------|
| Li (2014)           | 20                          | NA       | NA                   | MRI                  | Midpoint lines (1)   | China               | Both                        |
| Lee (2018)          | 64                          | 58/6     | 31                   | Radiograph           | Midpoint lines (3)   | Korea               | Medial                      |
| Jaeker (2018)       | 57                          | 37/20    | 26.6 (18-46)         | MRI                  | Midpoint lines (1)   | Germany             | Both                        |
| Christianson (2015) | 35                          | 21/14    | 21.2                 | MRI                  | Midpoint lines (1)   | USA                 | Lateral                     |
| Webb (2013)         | 35                          | NA       | 26                   | Radiograph           | Midpoint lines (3)   | Australia           | Medial                      |
| Dejour (2018)       | 124                         | 65/59    | 32.3 (12.1)          | Radiograph           | Circles (4)          | USA                 | Lateral                     |
| Yoon (2019)         | 82                          | 65/17    | NA                   | Radiograph           | Midpoint lines (3)   | Korea               | Lateral                     |
| Dekker (2017)       | 27                          | 13/14    | 13.6 (1.7)           | Radiograph           | NA                   | USA                 | Lateral                     |
| Grassi (2019)       | 51                          | 45/6     | 31.6 (10.2)          | MRI                  | Circles (4)          | Italy               | Both                        |
| Ahmed (2017)        | 29                          | 16/13    | 26.4                 | Radiograph           | Midpoint lines (3)   | Australia           | Medial                      |
| Sauer (2018)        | 54                          | 32/22    | 21.8 (18.6-26.7)     | MRI                  | Circles (2)          | New Zealand         | Lateral                     |
| Grassi (2019)       | 43                          | 34/9     | 21.8 (18.6-26.7)     | MRI                  | Midpoint lines (1)   | Italy               | Both                        |
| Winkler (2021)      | 102                         | 53/49    | NA (13-58)           | Radiograph           | Midpoint lines (3)   | USA                 | Medial                      |
| Ziegler (2021)      | 90                          | 46/44    | 31.5 [IQR: 22.3, 42] | MRI                  | Midpoint lines (1)   | USA                 | Both                        |
| Freitas (2021)      | 32                          | NA       | NA                   | MRI                  | Circles (2)          | Brazil              | Both                        |
| Alm (2021)          | 53                          | 33/20    | NA                   | Radiograph           | Midpoint lines (3)   | Germany             | Medial                      |
| Mitchell (2021)     | 39                          | NA       | NA                   | Radiograph           | Circles (4)          | USA                 | Lateral                     |
| Winkler (2021)      | 260                         | 144/116  | 26.2 (9.4)           | Radiograph           | Midpoint lines (3)   | USA                 | Both                        |
Medial and Lateral PTS Depending on ACL Status

|                | Lateral PTS, deg | Medial PTS, deg |
|----------------|-----------------|-----------------|
| Intact ACLb    | 5.57 (5.03-6.11)| 6.28 (5.21-7.35)|
| Primary ACL tear| 7.13 (6.58-7.67)| 6.24 (5.71-6.78)|
| Revision ACL tear| 9.55 (8.47-10.63)| 9.05 (7.80-10.30)|

aData are reported as mean (95% CI). ACL, anterior cruciate ligament; PTS, posterior tibial slope.

bMeasurements for the intact ACL group were obtained from patients who had non-ACL pathologies. These measurements were not obtained from the contralateral limb of patients with ACL tears.

ACLs. This conclusion is also supported by the biomechanical literature, which suggests that an increased lateral PTS is associated with greater anterior motion of the lateral compartment, which creates a net internal rotation that increases the strain on the ACL.\(^9,33\) Despite the findings from the current study and the supporting literature that lateral PTS likely has a greater effect on overall ACL strain than does medial PTS, several studies have shown that severe inclinations at either plateau can significantly affect overall ACL strain and that both the medial and lateral PTS likely affect ACL stability.\(^9,67\)

The current meta-analysis also provides accurate, updated normative values for 3 distinct cohorts based on ACL integrity: intact ACL, primary ACL tear, and failed ACLR. Specifically, for knee surgeons and sports medicine researchers, PTS is a growing area of interest and clinical importance.\(^1\) The anatomic axis, which is commonly identified using either the circle or midpoint lines technique; the mechanical axis; the posterior tibial cortex; or the anterior tibial cortex. Several studies have noted significant differences between measurement values from these measurement techniques.\(^15,23,65,108\) Specifically, one study with 140 total patients reported a significant difference in PTS measurement techniques that utilized the anatomic axis from lateral long-leg tibia radiographs (11.6°) and standard lateral radiographs (11.8°) compared with those that considered the mechanical axis obtained from lateral long-leg tibia radiographs (9.5°); 55% of measurements from this study were more than 2° different when comparing the anatomic axis and mechanical axis for an individual on the same lateral radiograph.\(^23\)

We acknowledge that this systematic review and meta-analysis has some limitations. First, many of the included studies either did not include all demographic variables or did not provide measures of variation for these variables, and we were unable to include these data in the final analysis. As such, we are unable to exclude these as possible confounding variables that may have contributed to our findings. In addition, there were a variety of measurement techniques across the included studies, including 3 different imaging modalities. While all included techniques have been validated in the literature, we recognize that this could contribute to the variability within groups of the current analysis. Finally, the failed ACLR group is relatively heterogeneous as many of these studies included patients who underwent multiple re-revisions and because the specific reason for ACLR failure was not always noted in the individual studies.

CONCLUSION

This systematic review and meta-analysis found that both lateral and medial PTS measurements are greater in patients who had failed previous ACLR than those with a primary ACL tear or with an intact native ACL. In addition, the lateral PTS of patients with primary ACL tears is greater than those with an intact native ACL. Finally, the current analysis highlights the variety of measurement techniques and modalities used in the literature and emphasizes the importance of continuity in measurement reporting and referencing.

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REFERENCES

1. Ahmed I, Salmon L, Roe J, Pinczewski L. The long-term clinical and radiological outcomes in patients who suffer recurrent injuries to the anterior cruciate ligament after reconstruction. Bone Joint J. 2017; 99(3):337-343.
2. Ahn JH, Kang HW, Choi KJ. Outcomes after double-bundle anterior cruciate ligament reconstruction. Arthroscopy. 2018;34(1):220-230.
3. Alentorn-Geli E, Pelfort X, Mingo F, et al. An evaluation of the association between radiographic intercondylar notch narrowing and anterior cruciate ligament injury in men: the notch angle is a better parameter than notch width. Arthroscopy. 2015;31(10):2004-2013.
4. Alm L, Drenck TC, Frings J, et al. Lower failure rates and improved patient outcome due to reconstruction of the MCL and revision ACL.
reconstruction in chronic medial knee instability. *Orthop J Sports Med.* 2021;9(3):23259671211989312.
5. Batty LM, Firth A, Moatshe G, et al. Association of ligamentous laxity, male sex, chronicity, meniscal injury, and posterior tibial slope with a high-grade preoperative pivot shift: a post hoc analysis of the STAT-BILITY study. *Orthop J Sports Med.* 2021;9(4):2325967121110000.
6. Beel W, Mouton C, Tradati D, Nührenbörger C, Seil R. Ramp lesions are six times more likely to be observed in the presence of a posterior medial tibial bone bruise in ACL-injured patients. *Knee Surg Sports Traumatol Arthrosoc.* 2022;30(1):184-191.
7. Bernhardson AS, Aman ZS, DePhillipono NN, et al. Tibial slope and its effect on graft force in posterior cruciate ligament reconstructions. *Am J Sports Med.* 2019;47(5):1168-1174.
8. Bernhardson AS, Aman ZS, Dornan GJ, et al. Tibial slope and its effect on force in anterior cruciate ligament grafts: anterior cruciate ligament force increases linearly as posterior tibial slope increases. *Am J Sports Med.* 2019;47(2):296-302.
9. Bernhardsson AS, DePhillipono NN, Aman ZS, Kennedy Mi, Dornan GJ, LaPrade RF. Decreased posterior tibial slope does not affect postoperative posterior knee laxity after double-bundle posterior cruciate ligament reconstruction. *Am J Sports Med.* 2019;47(2):318-323.
10. Bernholdt D, DePhillipono NN, Aman ZS, Samuelson BT, Kennedy Mi, LaPrade RF. Increased posterior tibial slope results in increased incidence of posterior lateral meniscal root tears in ACL reconstruction patients. *Knee Surg Sports Traumatol Arthrosoc.* 2021;29(11):3883-3891.
11. Bisson LJ, Gurske-DePerio J. Axial and sagittal knee geometry as a risk factor for noncontact anterior cruciate ligament tear: a case-control study. *Arthroscropy.* 2010;26(7):901-906.
12. Bojicic KM, Beaulieu ML, Imaizumi Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
13. Bojicik KM, Beaulieu ML, Imaizumi Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
14. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
15. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
16. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
17. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
18. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
19. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
20. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
21. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
22. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
23. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
24. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
25. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
26. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
27. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
28. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
29. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
30. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
31. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
32. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
33. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
34. Bocker JS, Micallef EM, Imai K, Krieger DY, Ashton-Miller JA, French RM, Hyman MD. Anatomical features of tibia and fibula in ACL deficient knees. *Arthroscopy.* 1996;82(3):195-200.
42. Herbst E, Imhoff A, Imsgang J, Anderst W, Fu F. The difference between the medial and lateral posterior tibial slope is associated with greater internal tibial rotation. *Orthop J Sports Med*. 2018;6(4 suppl 2):232596711880003.

43. Hohmann E, Bryant A, Reaburn P, Tetsworth K. Does posterior tibial slope influence knee functionality in the anterior cruciate ligament-deficient and anterior cruciate ligament-reconstructed knee? *Arthroscopy*. 2010;26(11):1496-1502.

44. Hohmann E, Bryant A, Reaburn P, Tetsworth K. Is there a correlation between posterior tibial slope and non-contact anterior cruciate ligament injuries? *Knee Surg Sports Traumatol Arthrosc*. 2011;19(suppl 1):S109-S114.

45. Huang M, Li Y, Guo N, Liao C, Yu B. Relationship between intercondylar notch angle and anterior cruciate ligament injury: a magnetic resonance imaging analysis. *J Int Med Res*. 2019;47(4):1602-1609.

46. Hudek R, Fuchs B, Regenfelder F, Koch PP. Is noncontact ACL injury associated with the posterior tibial and meniscal slope? *Clin Orthop Relat Res*. 2011;469(8):2377.

47. Hudek R, Schmutz S, Regenfelder F, Fuchs B, Koch PP. Novel measurement technique of the tibial slope on conventional MRI. *Clin Orthop Relat Res*. 2009;467(8):2066-2072.

48. Jaecker V, Drouven S, Naendrup JH, Kanakamedala AC, Pfeffer T, Shafizadeh S. Increased medial and lateral posterior tibial slopes are independent risk factors for graft failure following ACL reconstruction. *Arch Orthopa Trauma Surg*. 2018;138(10):1429-1431.

49. Kang K-T, Kwon SK, Son J, Kwon O-R, Lee J-S, Koh Y-G. The increase in posterior tibial slope provides a positive biomechanical effect in posterior-stabilized total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(10):3188-3195.

50. Kiapour AM, Ecklund K, Murray MM, et al. Changes in cross-sectional area and signal intensity of healing anterior cruciate ligaments and grafts in the first 2 years after surgery. *Am J Sports Med*. 2019;47(8):1831-1843.

51. Kiapour AM, Yang DS, Badger GJ, et al. Anatomic features of the tibial plateau predict outcomes of ACL reconstruction within 7 years after surgery. *Am J Sports Med*. 2019;47(2):303-311.

52. Kim SH, Seo HJ, Seo DW, K-Il Kim, Lee SH. Analysis of risk factors for ramp lesions associated with anterior cruciate ligament injury. *Am J Sports Med*. 2020;48(7):1673-1681.

53. Kim SH, Seo JH, Kim DA, Lee JW, K-II Kim, Lee SH. Steep posterior tibial slope, bone contusion on lateral compartments and combined medial collateral ligament injury are associated with the increased risk of lateral meniscal tear. *Knee Surg Sports Traumatol Arthrosc*. 2022;30(1):298-308.

54. Kizilozg V, Sivrioglu AK, Aydin H, Ulusoy GR, Cetin T, Tuncer K. The combined effect of body mass index and tibial slope angles on anterior cruciate ligament injury risk in male knees: a case-control study. *Clin Med Insights Arthritis Musculoskelet Disord*. 2019;12:117954411987922.

55. Kizilozg V, Sivrioglu AK, Ulusoy GR, Aydin H, Karayol SS, Menderes T. The anterior tibial slopes? A case control study. *Clin Med J (Engl)*. 2014;12(14):2649-2653.

56. Li K, Li J, Zheng X, et al. Increased lateral meniscal slope is associated with greater incidence of lateral bone contusions in noncontact ACL injury. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(6):2000-2008.

57. Li R, Yuan X, Fang Z, Liu Y, Chen X, Zhang J. A decreased ratio of height of lateral femoral condyle to anteroposterior diameter is a risk factor for anterior cruciate ligament rupture. *BMC Musculoskelet Disord*. 2020;21(1):402.

58. Li Y, Hong L, Feng H, Wang QQ, Zhang H, Song YG. Are failures of anterior cruciate ligament reconstruction associated with steep posterior tibial slopes? A case control study. *Clin Med J (Engl)*. 2014;12(14):2649-2653.

59. Lipps DB, Wilson AM, Ashton-Miller JA, Wojtys EM. Evaluation of different methods for measuring lateral tibial slope using magnetic resonance imaging. *Am J Sports Med*. 2012;40(12):2731-2736.

60. Li Y, Youm YS, Cho D, et al. Does posterior tibial slope affect graft rupture following anterior cruciate ligament reconstruction? *Arthroscopy*. 2018;34(7):2152-2155.

61. Li H, Chen S, Tao H, Li H, Chen S. Correlation analysis of potential factors influencing graft maturity after anterior cruciate ligament reconstruction. *Orthop J Sports Med*. 2014;2(10):232596711453552.

62. Li K, Li J, Zheng X, et al. Increased lateral meniscal slope is associated with greater incidence of lateral bone contusions in noncontact ACL injury. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(6):2000-2008.

63. Lipps DB, Wilson AM, Ashton-Miller JA, Wojtys EM. Evaluation of different methods for measuring lateral tibial slope using magnetic resonance imaging. *Am J Sports Med*. 2012;40(12):2731-2736.

64. Mansori AE, Lording T, Schneider A, Dumas R, Servien E, Lustig S. Incidence and patterns of meniscal tears accompanying the anterior cruciate ligament injury: possible local and generalized risk factors. *Int Orthop*. 2018;42(9):2113-2121.

65. Marouane H, Shiraishi-Adi A, Adouni M, Hashemi J. Steeper posterior tibial slope markedly increases ACL force in both active gait and passive knee joint under compression. *J Biomech*. 2014;47(6):1353-1359.

66. Matsuda S, Miura H, Nagamine R, et al. Posterior tibial slope in the normal and varus knee. *Am J Knee Surg*. 1999;12(3):165-168.

67. Mitchell BC, Slow MY, Bastron T, et al. Predictive value of the magnetic resonance imaging-based coronal lateral collateral ligament sign on adolescent anterior cruciate ligament reconstruction graft failure. *Am J Sports Med*. 2021;49(4):935-940.

68. Nagai K, Tashiro Y, Herbst E, et al. Steeper posterior tibial slope correlates with greater tibial tunnel widening after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(12):3717-3723.

69. Nakazato K, Taketomi S, Inui H, Yamagami R, Kagwachki C, Tanaka S. Lateral posterior tibial slope and length of the tendon within the tunnel are independent factors to predict tibial tunnel widening following anatomic anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2021;29(11):3818-3824.

70. Nakayama H, Genc Y, Kato M. Increased lateral tibial slope markedly increases ACL force in both active gait and passive knee joint under compression. *J Biomech*. 2014;47(6):1353-1359.

71. Nakayama H, Genc Y, Kato M. Increased lateral tibial slope markedly increases ACL force in both active gait and passive knee joint under compression. *J Biomech*. 2014;47(6):1353-1359.

72. Shafizadeh S. Increased medial and lateral tibial posterior slopes are associated with greater incidence of lateral bone contusions in noncontact ACL injury. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(6):2000-2008.

73. Shafizadeh S. Increased medial and lateral tibial posterior slopes are associated with greater incidence of lateral bone contusions in noncontact ACL injury. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(6):2000-2008.

74. Shafizadeh S. Increased medial and lateral tibial posterior slopes are associated with greater incidence of lateral bone contusions in noncontact ACL injury. *Knee Surg Sports Traumatol Arthrosc*. 2020;28(6):2000-2008.

75. Oshima T, Putnis S, Grasso S, Klasan A, Parker DA. Graft size and orientation within the femoral notch affect graft healing at 1 year after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2018;46(10):3188-3195.

76. Pangaud C, Laumonerie P, Dagneaux L, et al. Knee Surg Sports Traumatol Arthrosc. 2011;19(suppl 1):S109-S114.

77. Pietrini SD, Laprade RF, Griffith CJ, Wijdicks CA, Ziegler CG. Radiographic identification of the primary posterolateral knee structures. *Am J Sports Med*. 2009;37(3):542-551.
98. Todd MS, Lalliss S, Garcia E, DeBerardino TM, Cameron KL. The relationship between posterior tibial slope and anterior cruciate ligament injuries. J Am Sports Med. 2010;38(1):63-67.

99. Tradati D, Mouton C, Urhausen A, Beel W, Nührenbörger C, Seil R. Lateral meniscal slope negatively affects post-operative anterior tibial translation at 1 year after primary anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2020;28(11):3524-3531.

100. Utschneider S, Gottinger M, Weber P, et al. Development and validation of a new method for the radiologic measurement of the tibial slope. Knee Surg Sports Traumatol Arthrosc. 2011;19(10):1643-1648.

101. Vasta S, Andrade R, Pereira R, et al. Bone morphology and morphology of the lateral femoral condyle is a risk factor for ACL injury. Knee Surg Sports Traumatol Arthrosc. 2018;26(9):2817-2825.

102. Vyas S, van Eck CF, Vyas N, Fu OH, Otsuka NY. Increased medial tibial slope in teenage pediatric population with open physis and anterior cruciate ligament injuries. Knee Surg Sports Traumatol Arthrosc. 2011;19(3):372-377.

103. Waiwaiolo A, Gurbani A, Motamedi K, et al. Relationship of ACL injury and posterior tibial slope with patient age, sex, and race. Orthop J Sports Med. 2016;4(11):2325867116678552.

104. Webb JM, Salomon LJ, Leclerc E, Pinczewski LA, Roe JP. Posterior tibial slope and further anterior cruciate ligament injuries in the anterior cruciate ligament-reconstructed patient. Am J Sports Med. 2013;41(12):2800-2804.

105. Winkler PW, Vivacqua T, Thomassen S, et al. Quadriceps tendon autograft is becoming increasingly popular in revision ACL reconstruction. Knee Surg Sports Traumatol Arthrosc. 2022;30(1):149-160.

106. Winkler PW, Wagala NN, Hughes JD, Lesniak BP, Musahl V. A high tibial slope, allograft use, and poor patient-reported outcome scores are associated with multiple ACL graft failures. Knee Surg Sports Traumatol Arthrosc. 2022;30(1):139-148.

107. Wordeman SC, Quatman CE, Kaeding CC, Hewett TE. In vivo evidence for tibial plateau slope as a risk factor for anterior cruciate ligament injury: a systematic review and meta-analysis. Am J Sports Med. 2012;40(7):1673-1681.

108. Yoo JH, Chang CB, Shin KS, Seong SC, Kim TK. Anatomical references to assess the posterior tibial slope in total knee arthroplasty: a comparison of 5 anatomical axes. J Arthroplasty. 2008;23(4):586-592.

109. Yoon KH, Kim JH, Kwon YB, Kim EJ, Kim SG. Re-revision anterior cruciate ligament reconstruction showed more laxity than revision anterior cruciate ligament reconstruction at a minimum 2-year follow-up. Knee Surg Sports Traumatol Arthrosc. 2020;28(6):1909-1918.

110. Yoon KH, Park SY, Park JY, et al. Influence of posterior tibial slope on clinical outcomes and survivorship after anterior cruciate ligament reconstruction using hamstring autografts: a minimum of 10-year follow-up. Arthroscopy. 2020;36(10):2718-2727.

111. Yue L, Lei H, Hua F, Qianqian W, Hui Z, Guanyang S. Are failures of anterior cruciate ligament reconstruction associated with deep posterior tibial slopes? A case control study. Chin Med J (Engl). 2014;127(4):2649-2653.

112. Zeng G, Yang T, Wu S, et al. Is posterior tibial slope associated with noncontact anterior cruciate ligament injury? Knee Surg Sports Traumatol Arthrosc. 2016;24(3):830-837.

113. Ziegler CG, DePhillipio NN, Kennedy MI, Dekker TJ, Dornan GJ, LaPrade RF. Beighton score, tibial slope, tibial subluxation, quadriceps circumference difference, and family history are risk factors for anterior cruciate ligament graft failure: a retrospective comparison of primary and revision anterior cruciate ligament reconstructions. Arthroscopy. 2021;37(1):195-205.

114. Zikria B, Johnson A, Hafezi-Nejad N, et al. Association between MRI-based tibial slope measurements and musculoskeletal degeneration of the anterior cruciate ligament: a propensity score-matched case-control study. Orthop J Sports Med. 2020;8(11):2325867120962804.