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Original Research

Increased posterior tibial slope is an independent risk factor of anterior cruciate ligament reconstruction graft rupture irrespective of graft choice

Christian A. Cruz, MD [a,*], Brian J. Mannino, MD [a], Andrew Pike, MD [a], David Thoma, MD [b], Kenneth Lindell, MD [b], Yehuda E. Kerbel, MD [c], Austin McCadden, MD [a], Andrew J. Lopez, MD [a], Craig R. Bottoni, MD [a]

[a] Department of Orthopaedic Surgery, Tripler Army Medical Center, Honolulu, HI, USA
[b] Department of Radiology, Tripler Army Medical Center, Honolulu, HI, USA
[c] Department of Orthopaedic Surgery, University of Pennsylvania, Philadelphia, PA, USA

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ABSTRACT

Introduction: Anterior cruciate ligament (ACL) reconstruction failure remains a commonly seen complication despite advances in technique and graft options. Recently, several studies have shown that the inclination of the tibial plateau in the sagittal plane affects the stability of the knee joint. The purpose of this study was to determine if an increased posterior slope of the tibia is associated with failure of ACL reconstruction irrespective of the graft used.
Methods: From June 2002 to August 2003, a total of 100 patients with a symptomatic ACL-deficient knee were randomised to receive either a hamstring autograft or posterior tibialis allograft. All allografts were from a single tissue bank, aseptically processed, and fresh-frozen without terminal irradiation. ACL graft failures requiring reoperation with a minimum of 10-year follow-up were identified via telephone survey. Lateral radiographs of the knee of all patients were reviewed, and the slope of the tibia was measured using a standardised technique. Two fellowship-trained orthopaedic sports medicine specialists, one board-certified general orthopaedic surgeon, and two fellowship-trained musculoskeletal radiologists measured the tibial slope in all patients.
Results: At a minimum of 10-year follow-up, there were four (8.3%) autograft and 13 (26.5%) allograft failures that required revision reconstruction. The overall average tibial slope of the nonfailure cohort was 9.4°. The overall average tibial slope of the failure cohort was 11.9° ($P = 0.0002$). The average slope of the allograft failures was 11.5°compared with an average slope of 9.6° in the nonfailures ($P = 0.01$). The average slope of the autograft failures was 13.1° compared with 9.3° in the nonfailures ($P = 0.011$). The mean difference in tibial slope measurements was 0.665 (95% confidence interval: 0.569–0.750). The interrater reliability, as measured by the intraclass correlation coefficient, for tibial slope was 0.898 (95% confidence interval: 0.859–0.928). The Cronbach α was 0.904.
Conclusion: In a prospective, randomised trial of ACL reconstructions using either autograft or allograft, failures were associated with a significantly increased slope of the tibia compared with the nonfailures at 10-year follow-up.

What are the new findings?

- Irrespective of graft choice, posterior tibial slope is an independent risk factor for anterior cruciate ligament graft failure.
- This study's findings support the recent literature that an increased posterior tibial slope results in a greater risk of graft failure after anterior cruciate ligament reconstruction.

Introduction

Anterior cruciate ligament (ACL) reconstruction failure remains a commonly seen outcome despite advances in technique and graft options. In addition, revision ACL reconstruction is associated with worse outcomes when compared with primary reconstruction. Previous studies indicate that graft rupture can occur at rates as high as 18.9% [1]. There are multiple risk factors for ACL reconstruction failure, including allograft use in young patients, female sex, improper tunnel positioning, and higher body mass index [2]. Advances in operative technique and graft

* Corresponding author. 1 Jarrett White Rd, Honolulu, HI 96859, USA. Tel.: +808-433-3557.
E-mail address: chcruz93@gmail.com (C.A. Cruz).

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choices have sought to limit the extrinsic factors that contribute to ACL graft failure; however, until recently, the intrinsic risk factors have not been fully elucidated.

Recent studies have shown that the declination of the tibial plateau slope in the sagittal plane affects the in-situ stress on the ACL. Griffin et al. demonstrated that an increased posterior tibial slope under load resulted in anterior displacement of the tibia relative to the femur [3]. Follow-up studies have confirmed that increased tibial slope leads to a significantly increased amount of in-situ stress on both the native ACL and an ACL graft [4]. Further investigations by Salmon et al. showed that adolescents with a tibial slope of >12° were 11 times more likely to sustain an ACL graft failure [5]. In addition, adults in this study with a tibial slope of >12° were seven times more likely to sustain an ACL graft failure.

To date, there is limited data on whether the type of graft used for ACL reconstruction modifies this deleterious effect of increased tibial slope. To our knowledge, there are no studies that examine the effect of tibial slope as an independent risk factor after ACL reconstruction using different grafts. The purpose of this study was to compare the effect of tibial slope in patients who underwent ACL reconstruction with either hamstring autograft or tibialis posterior tendon allograft in a prospective randomised trial with minimum 10-year follow-up. We hypothesised that there would be a greater degree of posterior tibial slope in the ACL graft failures compared to nonfailures.

Methods

The original prospective randomised study and the subsequent long-term follow-up of these subjects were approved by the institutional review board and the Human Use Committee at our institution. Investigators adhered to the policies for the protection of human subjects as prescribed in 45 Code of Federal Regulation 46.

Patients aged ≥18 years who presented with symptomatic ACL deficiency, confirmed by magnetic resonance imaging (MRI), were eligible for participation in the study. Multiligamentous injuries, previous knee ligament surgery, and time remaining locally for follow-up of <6 months were exclusion criteria. Participating subjects were randomised by study design using sealed envelopes to receive an ACL reconstruction with either one of two soft tissue graft types, tibialis posterior allograft, or hamstring autograft. All allografts were obtained from the same American Association of Tissue Banks–certified tissue bank (Musculoskeletal Transplant Foundation) (Fig. 1). All the allografts were freshly frozen, aseptically harvested, and were not terminally irradiated. All patients had preoperative clinical examination by the senior author, knee radiographs, and an MRI to confirm ACL deficiency and to identify concomitant meniscal and/or chondral pathology (Table 1).

Operative procedure

The operative technique is thoroughly detailed in the original published manuscript by Bottoni et al [1]. In brief, all procedures were performed via the same technique by one of two attending surgeons. For the autograft group, the hamstring harvest was performed through a longitudinal incision over the Pes Anserinus. The doubled semitendinosus and gracilis tendons were sized to determine the smallest diameter through which they would fit. The smallest diameter that allowed the graft to pass was determined with the graft sizing block (Arthrex, Inc, Naples, FL).

All of the allografts were maintained frozen in a commercially available freezer until the operation. After complete thawing in warm saline with antibiotic, the allograft was prepared on both ends with #5 Ethibond suture in a locking Krackow stitch. The size of the doubled graft was then determined, and the graft was placed on 15 pounds of tension using the Graftmaster board (Smith & Nephew, Inc. Andover, MA) until needed.

A 5.5 mm shaver (Tomcat, Stryker Endoscopy, San Jose, CA) was used

Fig. 1. Posterior tibial slope measurement using digital lateral radiographs.

Table 1
Demographic data of all subjects by group. The average age of surgery in the autograft cohort was 28.9 ± 5.8 compared with 29.2 ± 5.5 cohort. In the autograft cohort, there were 41 males and 7 females compared with 43 males and 6 females in the allograft group. The mechanism of injury between the two cohorts is described. Finally, there was no difference between the two cohorts when comparing rates of microfracture, MMD (medial meniscal debridement), MMR (medial meniscal repair), LMD (lateral meniscal debridement), LMR (lateral meniscal repair), and tourniquet time.

	Autograft	Allograft	p-value
Age at surgery (years)	28.9 ± 5.8	29.2 ± 5.5	0.872
Gender	Female = 7, male = 41	Female = 6, male = 43	0.774
Side	Right = 22, left = 26	Right = 29, left = 20	0.225
Mechanism of injury			0.786
Sports	42	42	
Military training	4	2	
Fall	2	0	
MVC	2	0	
Meniscal path (yes)	35 (72.9%)	33 (67.3)	0.658
Chondral path (yes)	22 (45.8%)	17 (34.7%)	0.304
Microfracture (yes)	7 (14.6%)	3 (6.3%)	0.317
MMD	19 (39.6%)	16 (33.3%)	0.672
MMR	7 (14.6%)	7 (14.6%)	1.000
LMD	19 (39.6%)	17 (34.7%)	0.677
LMR	3 (6.3%)	0 (0.000%)	0.117
Tourniquet Time (min)	70.5 ± 19.1	64.7 ± 22.4	0.188

both to remove the residual ACL stump and to perform a minimal notchplasty. Enough bone was removed to adequately visualise the “over-the-top” position on the posterior aspect of the lateral wall of the intercondylar notch. A tibial ACL guide was then introduced into the knee, and a guide pin was placed in the posterior aspect of the ACL tibial footprint. An oblique tibial tunnel as described by Howell et al. [6]

allowed appropriate positioning of the femoral tunnel at the 10 or 2 o'clock position for the right and left knees, respectively. The graft was secured first in the femur with a metal cross pin (Transfix-Arthrex, Inc., Naples, FL). The knee was cycled while tension was maintained on the graft distally for a minimum of 10 cycles. With the knee at 30° of flexion, tibial fixation consisted of a bioabsorbable interference screw (Bioscrew, Arthrex, Inc.) of the same diameter as the tibial tunnel. The graft or remaining sutures were secured by an extra-articular bicortical 6.5 mm screw and spiked washer inserted in the proximal tibia just distal to the opening of the tibial tunnel. Care was taken to ensure incisions were similar in appearance irrespective of graft type used.

Rehabilitation

Patients were all admitted overnight and discharged after physical therapy consultation the following day. Patients used cryotherapy continuously for the first week (Cryocuff, AirCast/DJO Global, Vista, CA). Emphasis was placed on maintaining knee extension and regaining quadriceps control. A drop-lock brace (DJO Global) locked in full extension was used for the first 4 weeks and then discontinued thereafter. Postoperatively, all patients followed a standardised rehabilitation protocol supervised by a physical therapist blinded as to the specific graft type used. Of note, both techniques used similar incisions; therefore, there was no obvious outward indication of the graft type used. Full weight bearing was allowed immediately except in cases where meniscal repair or microfracture was performed. Weight bearing was fully restricted for 6 weeks after microfracture and for 4 weeks after meniscal repair. Full active motion was encouraged in all cases except when a meniscal repair was performed. In these patients, knee flexion was restricted to 90° for the first 4 weeks, then unrestricted thereafter.

Patient evaluations

Study patients completed all preoperative evaluations in the visit immediately preceding surgery. They were then seen at 3, 14, and 30 days postoperatively and then monthly until released to full unrestricted activity. At their latest follow-up, which was a minimum of 10 years, patients were either examined in person or, if unable to follow up in person, were contacted telephonically and via internet survey to assess graft status, if they had sustained a graft rupture, and if they had undergone revision surgery. A failure was defined as an ACL graft rupture confirmed by either MRI imaging or clinical examination.

Radiographic measurements

The posterior tibial slope (PTS) was measured on digital lateral knee radiographs. Radiographs were obtained immediately postoperatively. It was calculated from the angle between a line drawn tangentially to the medial tibial plateau and the proximal anatomical axis of the tibia. The anatomical axis of the tibia was determined from a line connecting two points measured from the mid-cortical diameters of the tibia at two points, 7 cm and 15 cm distal to the knee joint (Fig. 1). Two fellowship-trained orthopaedic sports medicine specialists, one board-certified general orthopaedic surgeon, and two fellowship-trained musculoskeletal radiologists measured the tibial slope in all patients. All measurers were blinded to which graft the patient received as well as to which patients had an ACL graft failure.

Statistical analysis

The data were analysed using Microsoft Excel and SPSS (IBM, Armonk, NY). An unpaired t-test was used to assess for differences in radiographic outcome measures between the graft failure and nonfailure groups. From the original study, power analysis was conducted using NCSS-PASS version 1.0 (NCSS LLC). Equal variance was assumed with both standard deviations equal to 10. The alpha error selected was 0.05 with a 2-tailed possibility of directional difference and a difference between means of 5 points on the 100 point Lysholm score. With 50 patients in each group, the power achieved was 70%, but with a difference in means of 6 points, the power was 85%[1]. In all analyses, $P < 0.05$ was considered significant. Post-hoc power analysis with graft failure being the variable of interest was performed. Based on an effect size of 0.5 and an alpha value of 0.8, a minimum of 53 patients per study group was required to achieve a power of 0.8. The interrater reliability of tibial slope measurements was calculated using the intraclass correlation coefficient (ICC) with mixed two-way measures and absolute agreement. Internal consistency of the slope measurements was determined using the Cronbach α. Patients were excluded from analysis if data were missing for one or more raters (n = 5, 5.2%).

Results

Anterior cruciate reconstruction failures

From June 2002 to August 2003, a total of 99 consecutive patients (100 knees) with an ACL tear and symptomatic knee instability were enrolled in the study. The average age of the patients at the time of surgery was 28.9 years in the autograft group and 29.2 years in the allograft group. Of the study group, 95% of the patients were active-duty military status at the time of surgery. There were 86 male and 13 female patients. One hundred knees were randomised via sealed envelopes; 50 knees underwent ACL reconstruction using a 4-stranded hamstring autograft and 50 underwent reconstruction with a tibialis posterior tendon allograft. The minimum follow-up was 10 years (126 months). Of the 100 patients, 16 patients (16%) failed their index operation and sustained graft failure requiring revision ACL reconstruction. Of these graft failures, 13 were allografts (26.5%), and four were autografts (8.3%; $P = 0.03$).

Posterior slope measurements

The mean angle of the average tibial slope of the nonfailure cohort was 9.4° ± 2.2. The overall average tibial slope of the failure cohort was 11.9° ± 2.0 ($P = 0.002$). In the autograft cohort, the failures averaged a tibial slope of 13.1° ± 1.8 compared with 9.3° ± 2.1 in the nonfailures ($P = 0.01$; Fig. 2). The average slope of the allograft failures was 11.5° ± 2.0 compared with an average tibial slope of 9.6° ± 2.4 in the allograft nonfailures ($P = 0.01$; Fig. 3).

Interobserver reliability

The mean difference in tibial slope measurements was 0.665° (95% CI: 0.569–0.750). The interrater reliability, as measured by the ICC for tibial slope, was 0.898 (95% CI: 0.859–0.928). The Cronbach α was 0.904.

Discussion

The most significant was our finding that in both allograft and autograft reconstructions, there was a statistically significant difference in the tibial slopes between the failure and nonfailure groups. In the autograft group, failures had an average PTS of 13.1° compared with 9.3° in the nonfailures. In addition, the allograft failures had an average PTS of 11.5°, whereas the nonfailures had an average of 9.6°. This study also demonstrated excellent interobserver reliability of tibial slope measurements with an ICC of 0.898 and Cronbach α of 0.904. Therefore, our study demonstrates PTS in the sagittal plane is an easily measurable variable that should be considered a risk factor for ACL graft failure irrespective of ACL graft choice.

Recent literature has demonstrated that there is an increased risk of anterior cruciate graft failure in patients who have a greater PTS [2,4,7–14]. Our results add to these findings by demonstrating that an

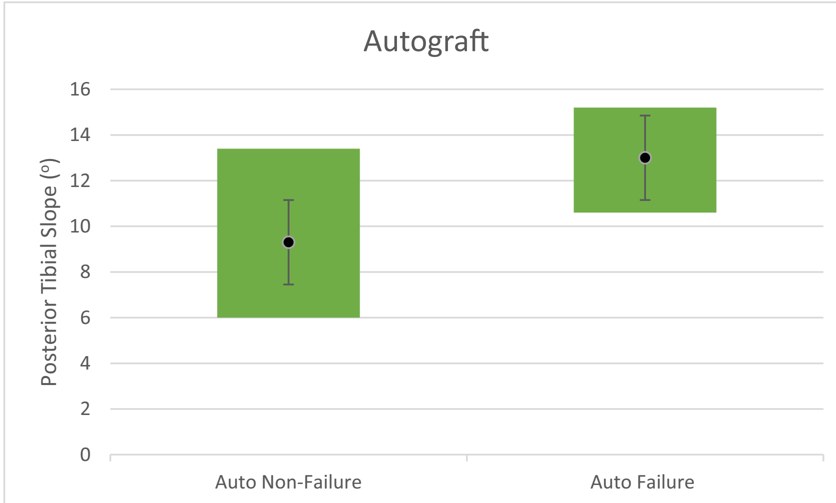

Fig. 2. Posterior tibial slope comparison between autograft failures which averaged a tibial slope of 13.1° ± 1.8 compared with 9.3° ± 2.1 in the nonfailures (*P* = 0.01). In the autograft nonfailure group n = 46 and in the failure group n = 4. The central black dot represents the average PTS.

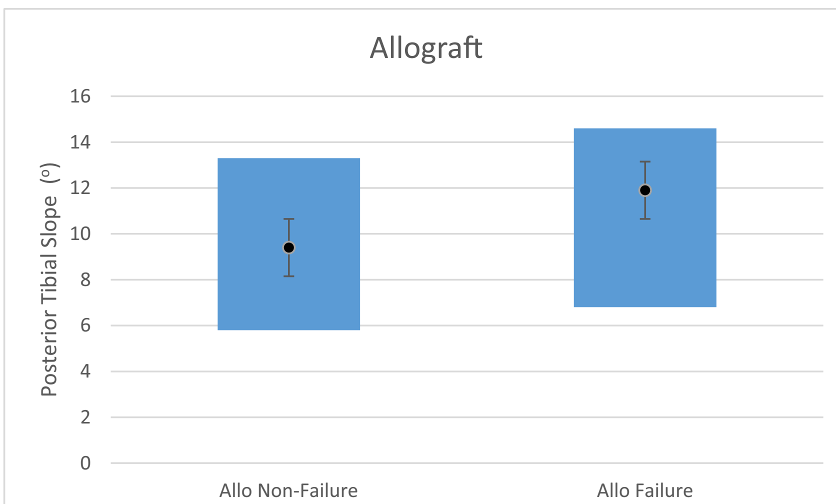

Fig. 3. Average posterior tibial slope comparison between allograft failures which averaged 11.5° ± 2.0 compared with 9.6° ± 2.4 in the allograft nonfailures (*P* = 0.01). In the allograft nonfailure group n = 33 and in the failures n = 13. The central black dot represents the average PTS.

increase in the PTS increases the risk of ACL graft failure and revision surgery regardless of whether the surgeon is using allograft or autograft. Therefore, the findings of this study suggest that allograft ACL reconstructions are at risk for failure with a PTS of ≥11.5° and that autograft ACLs are susceptible at ≥12°.

Several authors have advocated that a tibial slope >12° is pathologic, recommending surgical correction [1,15–18]. An increased PTS is suggested to result in increased tension on the ACL, therefore making it more susceptible to rerupture. Salmon et al. reported that adults with a PTS of >12° were seven times more likely to injure their contralateral ACL and had a higher incidence of graft reruptures than patients with a PTS <12° [5]. In addition, they reported that adolescents with a PTS of >12° were 11 times more likely to sustain a graft rupture. Furthermore, several additional studies have reported that a PTS >12° significantly increases the odds of an ACL graft injury [11,19]. This study supports the current literature in that a PTS >12° should be considered pathologic.

Anterior wedge osteotomy has been described as an operative technique to correct for pathologic PTS. Dejour et al. reported nine patients who had undergone a second rupture of an ACL reconstruction [7,8], all of whom had a PTS >12°. All patients underwent an anterior closing-wedge osteotomy at the time of ACL reconstruction, decreasing the PTS from 13.2° ± 2.6° to 4.4° ± 2.3° [10]. Sonnery-Cottet et al. reported on five patients at 32 months postoperatively from a slope-reducing anterior closing-wedge osteotomy in combination with an ACL reconstruction [20]. They concluded that an ACL reconstruction in combination with a proximal anterior closing-wedge osteotomy can restore stability and function of the knee as well as prevent rerupture. Based on the recent clinical and biomechanical data, a slope-decreasing osteotomy should decrease the tibial slope to <6° in patients with ACL graft failures [20]. Our data supports the suggestion that patients who sustain an ACL graft failure with a PTS >12° should be considered candidates for a slope-decreasing osteotomy.

Limitations

In this study, our only end point was ACL graft failure and based upon a cohort of patients randomised to one of two grafts with the same postoperative rehabilitation protocol. This study does not account for intraoperative factors that may have contributed to failure, including tunnel placement, graft length/thickness, or fixation failure. In addition, not all radiographs were perfect lateral radiographs of the knee. With differences in rotation, there was a decreased accuracy of PTS measurements.

Conclusion

We found that there was a statistically significant difference in the PTS in patients who had clinical failure after ACL reconstruction, irrespective of graft type. Our findings support the recent literature that an increased PTS results in a greater risk of graft failure after ACL reconstruction.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Craig R. Bottoni reports a relationship with Arthrex Inc that includes: consulting or advisory and speaking and lecture fees. C.R.B. has received honoraria from the Musculoskeletal Transplant Foundation.

References

[1] Bottoni CR, Smith EL, Shaha J, Shaha SS, Raybin SG, Tokish JM. Autograft versus allograft anterior cruciate ligament reconstruction: a prospective, randomized clinical study with a minimum 10-year follow up. Am J Sports Med 2015;43: 2501–9. https://doi.org/10.1177/0363546515596406.

[2] Hashemi J, Chandrashekar N, Mansouri H, et al. Shallow medial tibial plateau and steep medial and lateral tibial slopes. Am J Sports Med 2010;38(1):54–62. https://doi.org/10.1177/0363546509349055.

[3] Giffin J, Vogrin T, Zantop T, Woo S, Harner C. Effects of increasing tibial slope on the biomechanics of the knee. Am J Sports Med 2004;32(2):376–82. https://doi.org/10.1177/0363546503258880.

[4] 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 02/2019;47(2):296–302. https://doi.org/10.1177/0363546518820302.

[5] Salmon LJ, Heath E, Akrawi H, Roe JP, Linklater J, Pinczewski LA. 20-year outcomes of anterior cruciate ligament reconstruction with hamstring tendon autograft: the catastrophic effect of age and posterior tibial slope. Am J Sports Med 2018;46(3):531–43. https://doi.org/10.1177/0363546517741497.

[6] Howell SM. Principles for placing the tibial tunnel and avoiding roof impingement during reconstruction of a torn anterior cruciate ligament. Knee Surg Sports Traumatol Arthrosc 1998;6(Suppl 1):S49–55. https://doi.org/10.1007/s001670050223.

[7] Dejour D, Saffarini M, Demey G, Baverel L. Tibial slope correction combined with second revision ACL produces good knee stability and prevents graft rupture. Knee Surg Sports Traumatol Arthrosc 2015;23(10):2846–52. https://doi.org/10.1007/s00167-015-3758-6.

[8] Dejour H, Bonnin M. Tibial translation after anterior cruciate ligament rupture: two radiological tests compared. J Bone Joint Surg Br 1994;76(5):745–9. https://pubmed.ncbi.nlm.nih.gov/8083263/.

[9] Pinczewski LA, Salmon LJ, Jackson WF, von Bormann RB, Haslam PG, Tashiro S. Radiological landmarks for placement of the tunnels in single-bundle reconstruction of the anterior cruciate ligament. J Bone Joint Surg Br 2008;90(2):172–9. https://doi.org/10.1302/0301-620X.90B2.20104.

[10] Shultz SJ, Schmitz RJ. Tibial plateau geometry influences lower extremity biomechanics during landing. Am J Sports Med 2012;40(9):2029–36. https://pubmed.ncbi.nlm.nih.gov/8083263/. pmid: 8083263.

[11] Todd MS, Lalliss S, Garcia ES, DeBerardino TM, Cameron KL. The relationship between posterior tibial slope and anterior cruciate ligament injuries. Am J Sports Med 2010;38(1):63–7. https://doi.org/10.1177/0363546509343198.

[12] Wang Y-l, Yang T, Zeng C, et al. Association between tibial plateau slopes and anterior cruciate ligament injury: a meta-analysis. Arthroscopy 2017;33(6): 1248–1259.e4. https://doi.org/10.1177/0363546509343198.

[13] Weinberg DS, Williamson DFK, Gebhart JJ, Knapik DM, Voos JE. Differences in medial and lateral posterior tibial slope. Am J Sports Med 2017;45:106–13. https://doi.org/10.1177/0363546516662449.

[14] Wordeman SC, Quatman CE, Kaeding CC, Hewett TE. In vivo evidence for tibial plateau slope as a risk factor for anterior cruciate ligament injury. Am J Sports Med 2012;40(7):1673–81. https://doi.org/10.1177/0363546512442307.

[15] Andernord D, Desai N, Björnsson H, Ylander M, Karlsson J, Samuelsson K. Patient predictors of early revision surgery after anterior cruciate ligament reconstruction: a cohort study of 16,930 patients with 2-year follow-up. Am J Sports Med 2014; 43(1):121–7. https://doi.org/10.1177/0363546514552788.

[16] Bates NA, Nesbitt RJ, Shearn JT, Myer GD, Hewett TE. Posterior tibial slope angle correlates with peak sagittal and frontal plane knee joint loading during robotic simulations of athletic tasks. Am J Sports Med 2016;44(7):1762–70. https://doi.org/10.1177/0363546516639303.

[17] Chalmers PN, Mall NA, Moric M, et al. Does ACL reconstruction alter natural history? A systematic literature review of long-term outcomes. J Bone Joint Surg Am 2014;96(4):292–300. https://doi.org/10.2106/JBJS.L.01713.

[18] Mitchell JJ, Cinque ME, Dornan GJ, et al. Primary versus revision anterior cruciate ligament reconstruction: patient demographics, radiographic findings, and associated lesions. Arthroscopy 2018;34(3):695–703. https://doi.org/10.1016/j.arthro.2017.08.305.

[19] Webb JM, Salmon 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):2800–4. https://doi.org/10.1177/0363546513503288.

[20] Sonnery-Cottet B, Mogos S, Thaunat M, et al. Proximal tibial anterior closing wedge osteotomy in repeat revision of anterior cruciate ligament reconstruction. Am J Sports Med 2014;42(8):1873–80. https://doi.org/10.1177/0363546514534938.