Rates of Anterior Cruciate Ligament Rerupture in Adolescent Patients with and without Patella Alta

Danielle Rider, MD[1] Anirudh K. Gowd, MD[2] LeeAnne F. Torres, MD[2] Lisa W. Kaplin, DO[3] Brian R. Waterman, MD[2,4]

[1] Department of Orthopedic Surgery, Wake Forest School of Medicine Ringgold Standard Institution, Bowman Gray Center for Medical Education, Winston-Salem, North Carolina
[2] Department of Orthopaedic Surgery, Wake Forest School of Medicine Ringgold Standard Institution, Winston-Salem, North Carolina
[3] Department of Orthopaedic Surgery, Orthopaedic Surgery and Rehabilitation Associates, Rockledge, Pennsylvania
[4] Department of Orthopaedics, William Beaumont Army Medical Center, El Paso, Texas

Address for correspondence Brian R. Waterman, Department of Orthopaedics, Wake Forest University School of Medicine, Medical Center Boulevard, Winston-Salem, NC 27157-1070 (e-mail: brian.r.waterman@gmail.com).

J Knee Surg

Abstract

The objective of this study was to compare rates of anterior cruciate ligament (ACL) failure among adolescent patients to evaluate patella alta as a high-risk variable. Demographic and surgical data were retrospectively queried for patients ≤18 years of age with primary ACL reconstruction performed at a single academic center between 2011 and 2016 and minimum of 2-year clinical surveillance. Patellar height indices, including Caton–Deschamps index (CDI) and Insall–Salvati index (ISI), were retrospectively calculated from preoperative imaging to assess the presence of patella alta. Failure was defined as (1) ACL graft rerupture, (2) Lachman's grade 2 +, (3) presence of pivot shift, and (4) side-to-side difference of 3 mm on KT-1000 arthrometer. A total of 184 patients (84 females and 100 males) and 192 knees were identified, with an average age of 16.2 ± 1.8 years. Of these, 30 (15.63%) experienced ACL failure. Male sex was the only significant risk factor for rerupture ($p = 0.026$). The mean CDI was 1.06 ± 0.17 and mean ISI was 1.04 ± 0.15. Of the 49 knees that met criteria for patella alta on radiographic evaluation, rerupture occurred in seven (14.29%). Patella alta was not a significant risk factor for ACL failure among adolescent patients ($p = 0.359$ and 0.277). Only male sex was associated with increased rates of ACL failure. Age, graft selection technique, fixation construct, and presence of patella alta were not risk factors for reinjury. This study is a therapeutic case series and reflects level of evidence IV.

Keywords
- anterior cruciate ligament
- patella alta
- Caton–Deschamps index
- Insall–Salvati index
- rerupture

Adolescent anterior cruciate ligament (ACL) injury is becoming more common due to earlier athletic participation, increased physical demands, and greater exposure to at-risk activity.[1–3] As a result, the number of ACL reconstructions is increasing. In the United States, approximately 100,000 adolescent patients undergo ACL reconstruction annually.[4] While adult rates of surgical failure range from 3.2 to 11.1%, adolescent rates are reported to exceed 25% with the highest rates occurring in female soccer players.[5–10]

The underlying etiology of adolescent ACL injury is likely multifactorial given inherent differences in anatomy and

received
June 15, 2021
accepted after revision
April 26, 2022

Thieme Medical Publishers, Inc., 333 Seventh Avenue, 18th Floor, New York, NY 10001, USA

DOI https://doi.org/10.1055/s-0042-1749608.
ISSN 1538-8506.

biomechanics.[11] Trochlear dysplasia, narrow intercondylar notch width, quadriceps contractions, jump-landing mechanics, and patella alta are implicated in increased rates of ACL injury.[12,13] Patella alta is defined by an increased ratio of patellar tendon length to patellar width, resulting in a "high riding" patella above the trochlear groove. While there are multiple methods to quantify increased patellar height, the most common measurements for skeletally immature patients include the Insall–Salvati index (ISI) and Caton–Deschamps index (CDI), with ratios >1.2 indicative of patella alta.[14–16] Patients with patella alta are predisposed to abnormal knee extension and flexion mechanics, resulting in progressive patellofemoral instability and recurrent patellar dislocation.[17]

While several studies have examined this relationship between patella alta and patellofemoral instability, few studies have evaluated the role of patella alta in ACL injuries.[18,19] Thus, the purpose of the present study was to compare rates of secondary ACL failure among adolescent patients with and without patella alta, while controlling for surgical variables. We hypothesized that the presence of patella alta would confer an increased risk of adolescent ACL failure, irrespective of other demographic or surgical factors.

Methods

Study Design

After institutional review board approval, patients with ≤18 years of age undergoing primary ACL reconstruction (Current Procedural Terminology [CPT], code: 29888) for the established diagnosis of acute ACL injury (International Classification of Disease, Ninth Revision [ICD-9], code: 844.2] between January 2011 and December 2016 were retrospectively identified. Exclusion criteria were applied to multiligamentous knee injuries, allograft augmentation or hybrid grafts, and/or individuals with less than two years of clinical follow-up (►**Fig. 1**).

The institution's electronic medical record (EMR) was then examined to confirm the accuracy of procedural coding and to record laterality, graft type, surgical technique, fixation device, associated meniscal debridement, and indicators of ACL failure. For the purposes of this study, ACL failure was defined as (1) graft rerupture, (2) Lachman's grade 2+, (3) presence of pivot shift, and/or (4) side-to-side difference of 3 mm on KT-1000 arthrometer.

Radiographic Analysis

CDI and ISI were retrospectively calculated from preoperative lateral radiographs to determine the presence of patella

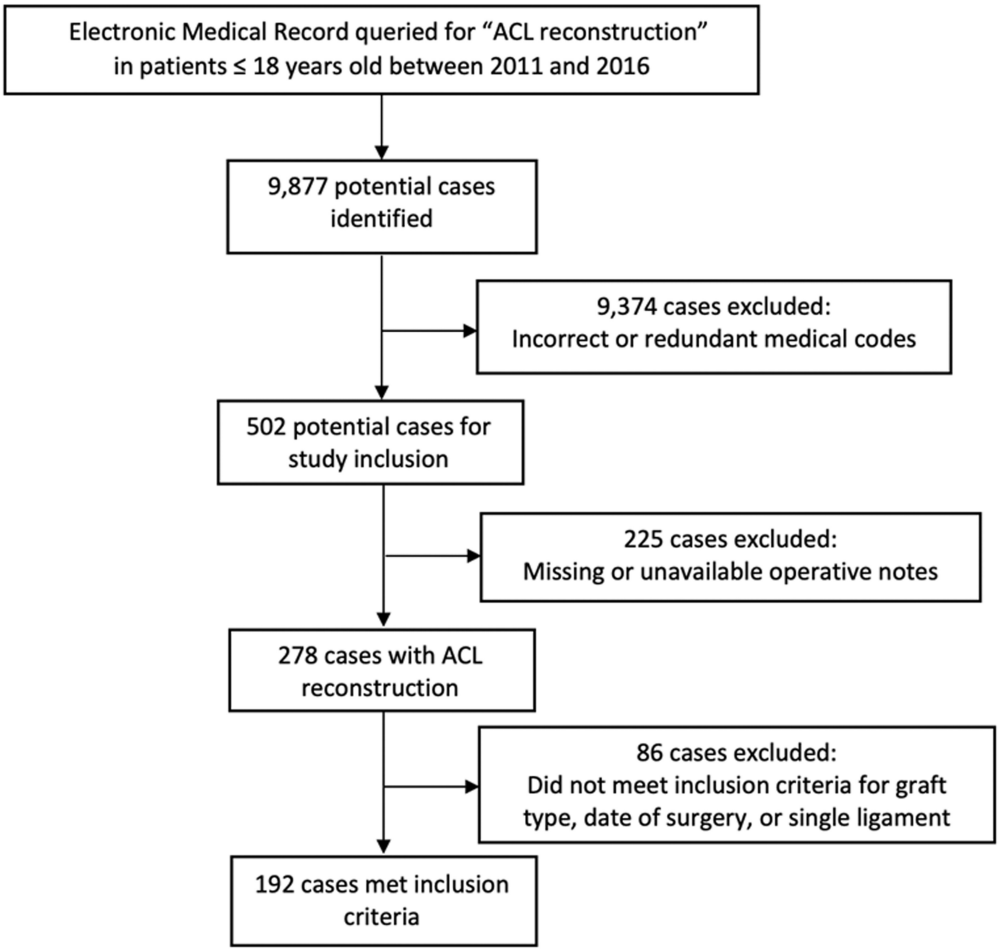

Fig. 1 Study exclusion criteria. ACL, anterior cruciate ligament. *EPIC: Epic systems Inc. (Madison, WI, USA)

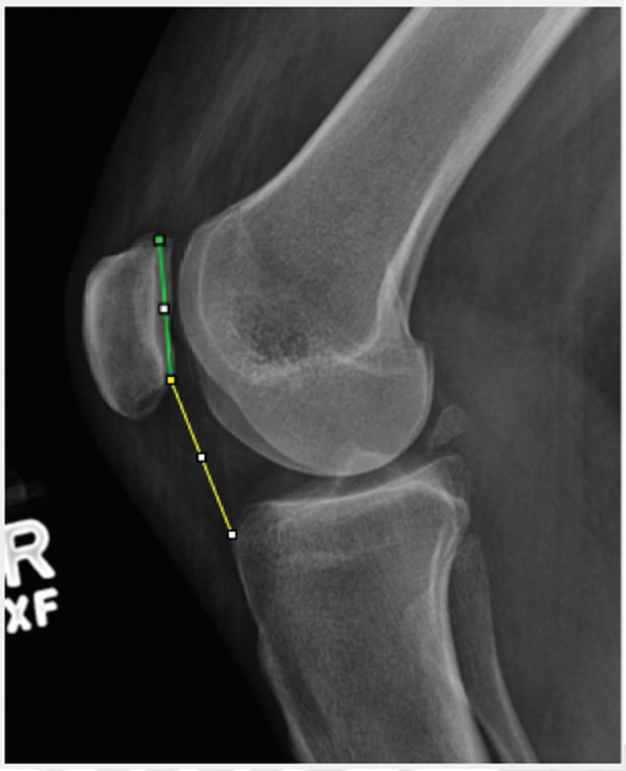

Fig. 2 Caton–Deschamps index (CDI) measurement.

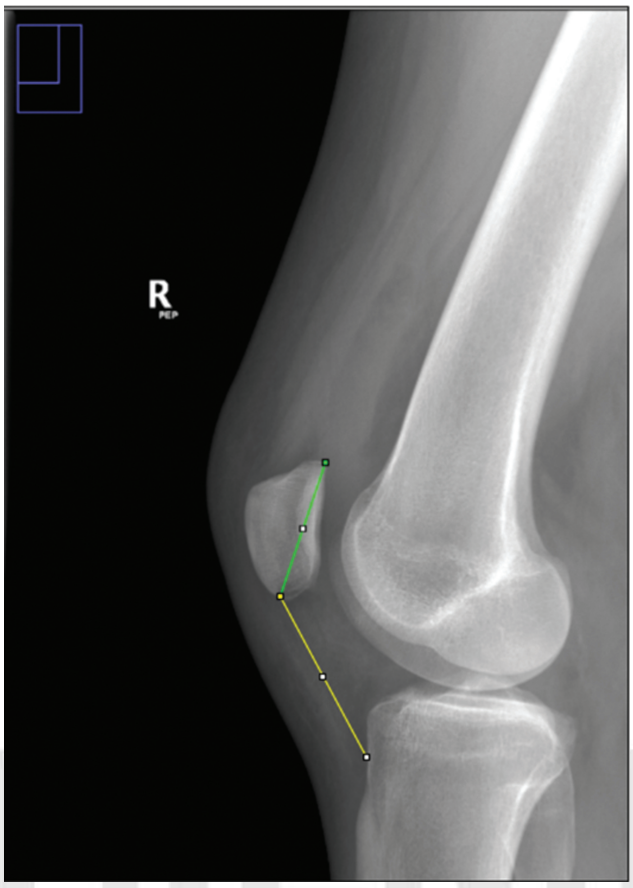

Fig. 3 Insall–Salvati index (ISI) measurement.

alta. All plain radiographs were performed with the knee flexed to 30 degrees. Deidentified images were evaluated by the principal author using ImageJ software (LOCI, University of Wisconsin, WI). CDI was calculated by dividing the length from the patellar tip to the anterior tibial plateau (yellow line) by the diameter of the patellar articulating surface (green line). Patella alta was defined by a ratio >1.2 (►**Fig. 2**). To calculate ISI, the patellar tendon length was measured from the patellar apex to the tibial tuberosity attachment point (yellow line) and divided by the patellar superoinferior diameter (green line). Patella alta was defined by a ratio > 1.2 (►**Fig. 3**). Two measurements were made for each patient and the average was used to increase intrarater reliability.

Statistical Analysis

Univariate analysis was used to determine the association of the independent patient demographic (listed in ►**Table 1**) and surgical variables with ACL failure (►**Table 2**). Variables found to have a p-value of < 0.2 were utilized in the multivariate analysis. Significant independent predictor variables were established as those that sustained p-values < 0.05 with odds ratio (OR) and 95% confidence interval (CI) exclusive of 1. All statistical analyses were performed with the use of SAS software, version 9.4 (SAS Institute, Cary, NC).

Results

Demographics

Among 184 patients (84 females and 100 males), a total of 192 knees with arthroscopy-verified complete ACL rupture were identified within the study period. The mean patient age at the time of surgery was 16.24 ± 1.82 years and mean follow-up from time of surgery was 2.82 ± 0.74 years.

Surgical Outcomes

Of the 192 included knees, 30 (15.63%) experienced subsequent failure defined by rerupture ($n = 22$), laxity > 2+ ($n = 6$), or positive pivot test ($n = 2$). Rerupture occurred in 16 (11.85%) hamstring autografts and 6 (10.53%) patellar tendon autografts. The number of reruptures was equivalent between anteromedial portal ($n = 11$, 12.22%) and outside-in and all-inside techniques ($n = 11$, 10.78%).

Table 1 Patient demographics for ACL reconstruction ($n = 184$)

	n or n (%) or mean ± SD
Patients	184
Female	84 (45.7)
Male	100 (54.3)
Knees	192
Right	104 (54.2)
Left	88 (45.8)
Age (y)	16.2 ± 1.8

Abbreviations: ACL, anterior cruciate ligament; SD, standard deviation.

Table 2 Rerupture rates by surgical parameters ($n = 192$)

		Rerupture ($n = 22$) n (%)	No rerupture ($n = 170$) n (%)
Graft selection	Hamstring autograft ($n = 135$)	16 (11.9)	119 (88.1)
	Patellar tendon autograft ($n = 57$)	6 (10.5)	51 (89.5)
Technique	Anteromedial portal ($n = 90$)	11 (12.2)	79 (87.8)
	Outside-in/all-inside ($n = 102$)	11 (10.8)	91 (89.2)
Fixation	Cortical button ($n = 52$)	5 (9.6)	47 (90.4)
	Interference screw ($n = 62$)	6 (9.7)	56 (90.3)
	Hybrid[a] ($n = 78$)	11 (14.1)	67 (85.9)
Meniscal debridement	Meniscal debridement ($n = 78$)	9 (11.5)	69 (88.5)
	Medial debridement ($n = 32$)	5 (15.6)	27 (84.4)
	Lateral debridement ($n = 37$)	4 (10.8)	33 (89.2)
	Bilateral debridement ($n = 9$)	0 (0.0)	9 (100.0)
	No meniscal debridement ($n = 114$)	13 (11.4)	101 (88.6)

[a]Both cortical button and interference screw fixation.

When assessing fixation, rerupture occurred in 11 (13.92%) hybrids, 6 (9.67%) interference screws, and 5 (9.62%) fixed length cortical suspensory buttons. While cortical button fixation was only used in patients with hamstring autografts ($n = 52$), interference screw fixation was used with both hamstring ($n = 16$) and patellar tendon autografts ($n = 46$). Hybrid fixation, which was defined as the use of both an interference screw and a cortical button, was utilized in 67 patients with hamstring autografts and 11 patients with patellar tendon autografts. Rate of rerupture was also evaluated in relation to concomitant meniscal debridement ($n = 78$). Of these 78 knees, 9 (11.54%) underwent rerupture (►**Table 2**).

On radiographic evaluation, 60 knees had either CDI > 1.2 ($n = 31$) or ISI > 1.2 ($n = 29$) and 11 knees had both CDI > 1.2 and ISI > 1.2. The mean CDI was 1.06 ± 0.17 and mean ISI was 1.04 ± 0.15. In patients who experienced ACL failure, mean CDI was 1.06 ± 0.20 and ISI was 1.07 ± 0.16. Patients who did not experience ACL failure had a similar mean CDI of 1.06 ± 0.17, but a lower ISI of 1.04 ± 0.15. Of the 49 knees with patella alta determined by patellar height indices, 7 (14.29%) experienced rerupture (►**Table 3**).

Multivariate analysis demonstrated an increased rate of ACL rerupture in males (OR = 3.72; 95% CI: 1.32, 10.48) when compared with females. There was no significant increase with age, graft selection, technique, fixation device, or presence of patella alta (►**Table 4**).

Discussion

While patella alta is associated with abnormal knee extensor mechanics, a well-established risk factor for ACL injury, few studies have evaluated abnormal patellar height in patients with ACL injuries.[17,20,21] In a prospective study of 217 patients undergoing arthroscopic knee surgery, Lin et al demonstrated an association between patella baja and ACL tears. The study included an adult patient population and utilized a control group with knee abnormalities including meniscal tears, plicae, and other chondral lesions.[22] However, existing literature does not evaluate patellar height in an adolescent patient population or include surgical outcomes. The current investigation sought to compare rates of ACL failure among adolescent patients to evaluate patella alta as a high-risk variable.

Table 3 Rerupture rates by radiographic and clinical prognosticators ($n = 192$)

	Rerupture ($n = 22$) n (%)	No rerupture ($n = 170$) n (%)
CDI > 1.2 ($n = 31$)	5 (16.13)	26 (83.87)
ISI < 0.8 ($n = 9$)	0 (0.00)	9 (100.00)
ISI > 1.2 ($n = 29$)	5 (17.24)	24 (82.76)
CDI > 1.2 AND ISI > 1.2 ($n = 11$)	3 (27.27)	8 (72.73)
Laxity $> 2+$ ($n = 9$)	3 (33.33)	6 (66.67)
Positive pivot test ($n = 4$)	2 (50.00)	2 (50.00)

Abbreviations: CDI, Caton–Deschamps index; ISI, Insall–Salvati index.

Table 4 Multivariate logistic regression of variables related to re-rupture

	Odds ratio	Confidence interval	*p*-Value
Sex	3.72	1.32, 10.48	0.026
Age (y)	1.02	0.78, 1.33	0.896
Patellar tendon autograft (versus hamstring autograft)	0.76	0.18, 3.29	0.715
Anteromedial portal technique (versus outside-in and all-inside techniques)	1.46	0.54, 3.94	0.458
Interference screw fixation (versus button and hybrid fixation)	0.97	0.16, 5.89	0.978
Meniscal debridement (vs. no meniscal debridement)	1.03	0.42, 2.55	0.099
CDI > 1.2	1.65	0.56, 4.87	0.359
ISI > 1.2	1.81	0.61, 5.38	0.277

Abbreviations: CDI, Caton–Deschamps index; ISI, Insall–Salvati index.

The present study retrospectively measured CDI and ISI from preoperative radiographs with the knee in a standardized 30 degrees of flexion. While radiography does not directly visualize the patellar tendon, the adolescent patient population has a lower incidence of tendon laxity and patellar tendon length can be reliably inferred.[23] Degnan et al reported an association between an increased Insall–Salvati ratio and ACL injury in a pediatric cohort. The investigators found an ISI of 1.16 in patients with ACL tears and 0.99 in the control group.[24] Similarly, the current study demonstrated a MARGINALLY higher mean ISI in patients with ACL failure when compared with those who did not experience failure.

To control for potential confounding factors, the present study also examined sex, age, graft choice, surgical technique, fixation construct, and presence of meniscal tears. The current investigation identified male sex as a risk factor for ACL failure but did not demonstrate an association with the other demographic or surgical variables. The association between female sex and increased risk of ACL failure is well reported, with published rates upward of two- to six-fold higher than male counterparts. Several early studies have also shown increased laxity, graft failure rates, and higher self-reported pain scores when compared with male patients.[24–28] These findings are multifactorial but often attributed to neuromuscular differences, including decreased hamstring strength and increased recruitment of the quadriceps in response to anterior tibia translation.[29] However, more recent studies have described higher rates of ACL rerupture in males when compared with females.[30,31] Schlumberger et al reported male patients were more than twice as likely to suffer from graft rupture after primary reconstruction than females.[32,33] The current study supports these updated findings, with male patients almost three times as likely to rerupture when compared with female patients (risk ratio [RR] = 2.71).

While autograft is widely accepted as superior to allograft for the young athlete under 25 years of age, there is less consensus on the use of bone-patellar-tendon-bone (BPTB) autograft versus hamstring autograft, particularly in an adolescent population.[33–36] Several studies report an increased risk for revision among patients who underwent hamstring tendon autograft reconstruction when compared with BPTB.[37–39] However, these studies did not adjust for sex, age, race, or body mass index (BMI). When accounting for demographic confounders, Bourke et al demonstrated no significant difference in rates of failures between patellar tendon and hamstring autografts.[30] The current study also elucidated no difference in rates of ACL failure when comparing the two types of autograft. Furthermore, the potential morbidity of patella alta on clinical outcomes after ACL reconstruction with either hamstring or BPTB autograft is underdeveloped and ill defined. While several technical modifications have been described for management of graft-tunnel mismatch with autograft BPTB and long patellar tendons (i.e., >50 mm), the rates of rerupture do not seem to be affected by elevated CDI in a high-risk adolescent population in the current study.[40] Additionally, the quadriceps tendon is becoming an increasingly popular soft tissue graft choice for this age group and requires additional studies to evaluate failures.

Prior studies have indicated that graft fixation device does not influence rates of surgical failure after ACL reconstruction, allowing personal experience and institutional preference to guide selection.[41–44] Persson et al studied the risk of revision based on graft fixation in 38,666 patients undergoing ACL reconstruction in Scandinavia. The study found that fixation with fixed length cortical suspensory buttons resulted in the highest 5-year revision rates in patients undergoing ACL reconstruction with hamstring autograft when compared with patellar tendon autograft.[45] However, the current study demonstrated no significant difference in rates of surgical failure between interference screw, cortical suspensory button, or hybrid fixation devices, regardless of autograft selection.

Meniscal status represents one of the most important predictors of patient-reported outcomes and radiographic findings after ACL reconstruction. Trojani et al analyzed the influence of meniscectomies on functional outcomes in patients undergoing primary ACL reconstruction or revision. The study found that patients with preserved menisci had better functional results and knee stability than those who underwent concomitant meniscectomy.[46] However, the study did not assess the relationship between meniscectomy and rates of ACL failure. The present study demonstrated no significant difference in rates of ACL failure among patients

who underwent concomitant meniscectomy when compared with those who did not.

Strengths and Limitations

The current study includes a consistent rehabilitation protocol at a single, high-volume, academic center and offers unique insight regarding ACL failure in a previously underreported adolescent population. However, there are limitations. First, the retrospective nature of the study limited available information and did not include patient reported outcomes. Second, the modest sample size of the study did not provide desired power and likely contributed to the potential for type II error on several variables. A post hoc power analysis was conducted with G*Power 3.1.9.7 (Erdfelder, Faul, & Buchner, 1992). The maximum calculated power (1-β) was 0.584 with a required sample size ranging between 322 and 28,631 to achieve a desired power of 0.80. Third, several surgeries performed prior to the implementation of the institution's electronic medical record system in 2013 did not have accessible operative notes and were subsequently excluded. Fourth, the study included multiple operative surgeons with differing surgical techniques. Finally, the present study did not account for additional confounding factors of open tibial tubercle apophysis, graft size, or graft alignment.

Conclusion

Approximately 11% of adolescent patients undergoing ACL reconstruction experienced subsequent failure. While further research is needed on this topic, the present study found no significant differences in rates of ACL rerupture between patients with and without patella alta. Of the demographic and surgical variables studied, only male sex was associated with increased rates of rerupture.

Conflict of Interest
None declared.

References

1 Buller LT, Best MJ, Baraga MG, Kaplan LD. Trends in anterior cruciate ligament reconstruction in the United States. Orthop J Sports Med 2014;3(01):2325967114563664
2 Dodwell ER, Lamont LE, Green DW, Pan TJ, Marx RG, Lyman S. 20 years of pediatric anterior cruciate ligament reconstruction in New York State. Am J Sports Med 2014;42(03):675–680
3 Milewski MD, Beck NA, Lawrence JT, Ganley TJ. Anterior cruciate ligament reconstruction in the young athlete: a treatment algorithm for the skeletally immature. Clin Sports Med 2011;30(04):801–810
4 Mall NA, Chalmers PN, Moric M, et al. Incidence and trends of anterior cruciate ligament reconstruction in the United States. Am J Sports Med 2014;42(10):2363–2370
5 Aichroth PM, Patel DV, Zorrilla P. The natural history and treatment of rupture of the anterior cruciate ligament in children and adolescents. A prospective review. J Bone Joint Surg Br 2002;84 (01):38–41
6 Koizumi H, Kimura M, Kamimura T, Hagiwara K, Takagishi K. The outcomes after anterior cruciate ligament reconstruction in adolescents with open physes. Knee Surg Sports Traumatol Arthrosc 2013;21(04):950–956
7 Magnussen RA, Meschbach NT, Kaeding CC, Wright RW, Spindler KP. ACL graft and contralateral ACL tear risk within ten years following reconstruction: a systematic review. JBJS Rev 2015;3 (01):1–8
8 Peterson DC, Ayeni OR. Pediatric anterior cruciate ligament reconstruction outcomes. Curr Rev Musculoskelet Med 2016;9 (04):339–347
9 Sanders TL, Pareek A, Hewett TE, et al. Long-term rate of graft failure after ACL reconstruction: a geographic population cohort analysis. Knee Surg Sports Traumatol Arthrosc 2017;25(01): 222–228
10 Allen MM, Pareek A, Krych AJ, et al. Are female soccer players at an increased risk of second anterior cruciate ligament injury compared with their athletic peers? Am J Sports Med 2016;44(10): 2492–2498
11 Souryal TO, Moore HA, Evans JP. Bilaterality in anterior cruciate ligament injuries: associated intercondylar notch stenosis. Am J Sports Med 1988;16(05):449–454
12 Renstrom P, Ljungqvist A, Arendt E, et al. Non-contact ACL injuries in female athletes: an International Olympic Committee current concepts statement. Br J Sports Med 2008;42(06):394–412
13 Shelbourne KD, Davis TJ, Klootwyk TE. The relationship between intercondylar notch width of the femur and the incidence of anterior cruciate ligament tears. A prospective study. Am J Sports Med 1998;26(03):402–408
14 Caton J, Deschamps G, Chambat P, Lerat JL, Dejour H. Patella infera. Apropos of 128 cases [in French]. Rev Chir Orthop Repar Appar Mot 1982;68:317–325
15 Insall J, Salvati E. Patella position in the normal knee joint. Radiology 1971;101(01):101–104
16 Phillips CL, Silver DA, Schranz PJ, Mandalia V. The measurement of patellar height: a review of the methods of imaging. J Bone Joint Surg Br 2010;92(08):1045–1053
17 Akgün AS, Agirman M. Associations between anterior cruciate ligament injuries and patella alta and trochlear dysplasia in adults using magnetic resonance imaging. J Knee Surg 2021;34(11): 1220–1226
18 Ntagiopoulos PG, Bonin N, Sonnery-Cottet B, Badet R, Dejour D. The incidence of trochlear dysplasia in anterior cruciate ligament tears. Int Orthop 2014;38(06):1269–1275
19 Wiggins AJ, Grandhi RK, Schneider DK, Stanfield D, Webster KE, Myer GD. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. Am J Sports Med 2016;44(07):1861–1876
20 Kujala UM, Osterman K, Kvist M, Aalto T, Friberg O. Factors predisposing to patellar chondropathy and patellar apicitis in athletes. Int Orthop 1986;10(03):195–200
21 Insall J, Goldberg V, Salvati E. Recurrent dislocation and the high-riding patella. Clin Orthop Relat Res 1972;88:67–69
22 Lin CFJ, Wu JJ, Chen TS, Huang TF. Comparison of the Insall-Salvati ratio of the patella in patients with and without an ACL tear. Knee Surg Sports Traumatol Arthrosc 2005;13(01):8–11
23 Schweitzer ME, Mitchell DG, Ehrlich SM. The patellar tendon: thickening, internal signal buckling, and other MR variants. Skeletal Radiol 1993;22(06):411–416
24 Degnan AJ, Maldjian C, Adam RJ, Fu FH, Di Domenica M. Comparison of Insall-Salvati ratios in children with an acute anterior cruciate ligament tear and a matched control population. AJR Am J Roentgenol 2015;204(01):161–166
25 Corry IS, Webb JM, Clingeleffer AJ, Pinczewski LA. Arthroscopic reconstruction of the anterior cruciate ligament. A comparison of patellar tendon autograft and four-strand hamstring tendon autograft. Am J Sports Med 1999;27(04):444–454
26 Noojin FK, Barrett GR, Hartzog CW, Nash CR. Clinical comparison of intraarticular anterior cruciate ligament reconstruction using

autogenous semitendinosus and gracilis tendons in men versus women. Am J Sports Med 2000;28(06):783–789
27 Gobbi A, Domzalski M, Pascual J. Comparison of anterior cruciate ligament reconstruction in male and female athletes using the patellar tendon and hamstring autografts. Knee Surg Sports Traumatol Arthrosc 2004;12(06):534–539
28 Salmon LJ, Refshauge KM, Russell VJ, Roe JP, Linklater J, Pinczewski LA. Gender differences in outcome after anterior cruciate ligament reconstruction with hamstring tendon autograft. Am J Sports Med 2006;34(04):621–629
29 Tuman JM, Diduch DR, Rubino LJ, Baumfeld JA, Nguyen HS, Hart JM. Predictors for hamstring graft diameter in anterior cruciate ligament reconstruction. Am J Sports Med 2007;35(11):1945–1949
30 Wojtys EM, Huston LJ, Taylor PD, Bastian SD. Neuromuscular adaptations in isokinetic, isotonic, and agility training programs. Am J Sports Med 1996;24(02):187–192
31 Bourke HE, Salmon LJ, Waller A, Patterson V, Pinczewski LA. Survival of the anterior cruciate ligament graft and the contralateral ACL at a minimum of 15 years. Am J Sports Med 2012;40(09):1985–1992
32 Andernord D, Björnsson H, Petzold M, et al. Surgical predictors of early revision surgery after anterior cruciate ligament reconstruction: results from the Swedish national knee ligament register on 13,102 patients. Am J Sports Med 2014;42(07):1574–1582
33 Schlumberger M, Schuster P, Schulz M, et al. Traumatic graft rupture after primary and revision anterior cruciate ligament reconstruction: retrospective analysis of incidence and risk factors in 2915 cases. Knee Surg Sports Traumatol Arthrosc 2017;25(05):1535–1541
34 Nelson IR, Chen J, Love R, Davis BR, Maletis GB, Funahashi TT. A comparison of revision and rerupture rates of ACL reconstruction between autografts and allografts in the skeletally immature. Knee Surg Sports Traumatol Arthrosc 2016;24(03):773–779
35 Engelman GH, Carry PM, Hitt KG, Polousky JD, Vidal AF. Comparison of allograft versus autograft anterior cruciate ligament reconstruction graft survival in an active adolescent cohort. Am J Sports Med 2014;42(10):2311–2318
36 Borchers JR, Pedroza A, Kaeding C. Activity level and graft type as risk factors for anterior cruciate ligament graft failure: a case-control study. Am J Sports Med 2009;37(12):2362–2367
37 Krych AJ, Jackson JD, Hoskin TL, Dahm DL. A meta-analysis of patellar tendon autograft versus patellar tendon allograft in anterior cruciate ligament reconstruction. Arthroscopy 2008;24(03):292–298
38 Maletis GB, Inacio MCS, Desmond JL, Funahashi TT. Reconstruction of the anterior cruciate ligament: association of graft choice with increased risk of early revision. Bone Joint J 2013;95-B(05):623–628
39 Reinhardt KR, Hetsroni I, Marx RG. Graft selection for anterior cruciate ligament reconstruction: a level I systematic review comparing failure rates and functional outcomes. Orthop Clin North Am 2010;41(02):249–262
40 Verma NN, Dennis MG, Carreira DS, Bojchuk J, Hayden JK, Bach BR Jr. Preliminary clinical results of two techniques for addressing graft tunnel mismatch in endoscopic anterior cruciate ligament reconstruction. J Knee Surg 2005;18(03):183–191
41 Freedman KB, D'Amato MJ, Nedeff DD, Kaz A, Bach BR Jr. Arthroscopic anterior cruciate ligament reconstruction: a metaanalysis comparing patellar tendon and hamstring tendon autografts. Am J Sports Med 2003;31(01):2–11
42 Drogset JO, Straume LG, Bjørkmo I, Myhr G. A prospective randomized study of ACL-reconstructions using bone-patellar tendon-bone grafts fixed with bioabsorbable or metal interference screws. Knee Surg Sports Traumatol Arthrosc 2011;19(05):753–759
43 Gifstad T, Drogset JO, Grøntvedt T, Hortemo GS. Femoral fixation of hamstring tendon grafts in ACL reconstructions: the 2-year follow-up results of a prospective randomized controlled study. Knee Surg Sports Traumatol Arthrosc 2014;22(09):2153–2162
44 Frosch S, Rittstieg A, Balcarek P, et al. Bioabsorbable interference screw versus bioabsorbable cross pins: influence of femoral graft fixation on the clinical outcome after ACL reconstruction. Knee Surg Sports Traumatol Arthrosc 2012;20(11):2251–2256
45 Persson A, Gifstad T, Lind M, et al. Graft fixation influences revision risk after ACL reconstruction with hamstring tendon autografts. Acta Orthop 2018;89(02):204–210
46 Trojani C, Sbihi A, Djian P, et al. Causes for failure of ACL reconstruction and influence of meniscectomies after revision. Knee Surg Sports Traumatol Arthrosc 2011;19(02):196–201

