CLINICAL PRACTICE

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Anterior Cruciate Ligament Tear

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This Journal *feature begins with a case vignette highlighting a common clinical problem. Evidence supporting various strategies is then presented, followed by a review of formal guidelines, when they exist. The article ends with the authors' clinical recommendations.*

An 18-year-old high-school student presents with an acute knee sprain sustained while playing basketball with friends. She reports having a swollen knee and medial knee pain. On clinical examination, she has limited motion, a palpable effusion, tenderness over the medial joint line, and a positive Lachman test (increased anterior tibial translation with a soft end point). How would you further evaluate and treat this patient?

THE CLINICAL PROBLEM

Anterior cruciate ligament (ACL) tears represent more than 50% of knee injuries and affect more than 200,000 people in the United States each year, with direct and indirect costs greater than $7 billion annually.[1] Young persons participating at high levels of competition are at particular risk; 40% of injuries are attributed to noncontact mechanisms involving pivoting, cutting, or jumping.[1] ACL injuries are associated with several modifiable and nonmodifiable risk factors, including female sex[2] (with risk three times as high as that associated with male sex), young age (with a peak at 16 to 18 years), and earlier, more intense, and more frequent participation in sports.[3] Variations in bone morphology, neuromuscular control, genetic profile, and hormonal milieu may play a role.[4,5] A recent systematic review and meta-analysis of ACL injury reported an incidence of 0.08 in female athletes and 0.05 in male athletes per 1000 exposures, with soccer posing the greatest risk of ACL injury in female athletes (1.1% per season) and football in male athletes (0.8% per season).[5] ACL injuries are often complicated by concomitant injury of the medial collateral ligament (19 to 38%) and lateral (20 to 45%) or medial (0 to 28%) meniscal tears.[6]

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STRATEGIES AND EVIDENCE

ASSESSMENT AND DIAGNOSIS

Patients with ACL tears typically present with acute injury, sometimes with an associated "pop," a sensation of tearing, the immediate onset of effusion, or any combination thereof. Several maneuvers are useful in diagnosis when ACL injury is suspected on physical examination. In the anterior drawer test, the examiner moves the tibia forward with respect to the femur, with the patient's knee at 90 degrees of flexion and the feet flat; excessive anterior translocation indicates a positive test. Better tests are the Lachman test (Fig. 1A) and the pivot-shift test (Fig. 1B), which have reported respective sensitivities of 0.87 and 0.49 and speci-

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KEY CLINICAL POINTS

ANTERIOR CRUCIATE LIGAMENT TEAR

- High-level evidence suggests that recreational athletes can initially be treated nonoperatively or operatively for anterior cruciate ligament (ACL) tears.
- ACL reconstruction is recommended for patients with increased or persistent laxity after nonoperative treatment.
- For ACL reconstruction in top-level athletes, current evidence supports anatomical reconstruction with autografts of the patellar tendon, hamstring, or quadriceps tendon. Concomitant soft-tissue injuries should be repaired.
- The return to sport after ACL reconstruction surgery should occur after a minimum of 9 months and should await the results of return-to-sport testing (e.g., patient performance in tests of symmetric quadriceps strength and hop tests).

ficities of 0.97 and 0.98.[7] The pivot-shift test is a dynamic test of the rotatory laxity of the knee that produces subluxation and reduction (felt as a "clunk") of the lateral tibial plateau.[8] Quantitative pivot-shift testing, in which either translation of the lateral plateau or tibial acceleration is measured, has been validated in a clinical trial and can be used to assess concomitant soft-tissue injuries.[9,10] Although plain radiography is often the first diagnostic step after the physical examination to rule out fracture, dislocation, or both, magnetic resonance imaging (MRI) is strongly recommended as part of the diagnostic evaluation, given its reported high sensitivity and specificity (97% and 100%, respectively) for the detection of ACL injury.[11,12] MRI can also be used to identify associated damage to the meniscus, articular cartilage, and collateral ligaments, any of which, if present, will influence the treatment approach (Fig. 2).[6]

TREATMENT

ACL reconstruction has traditionally been recommended for the restoration of anterior–posterior as well as rotatory knee laxity in young, healthy patients with the desire to engage in pivoting sports (including alpine skiing, baseball, basketball, football, handball, hockey, lacrosse, soccer, and tennis) at a highly competitive level.[13] However, in a randomized trial involving active young patients that compared the outcomes of early ACL reconstruction (i.e., within 10 weeks

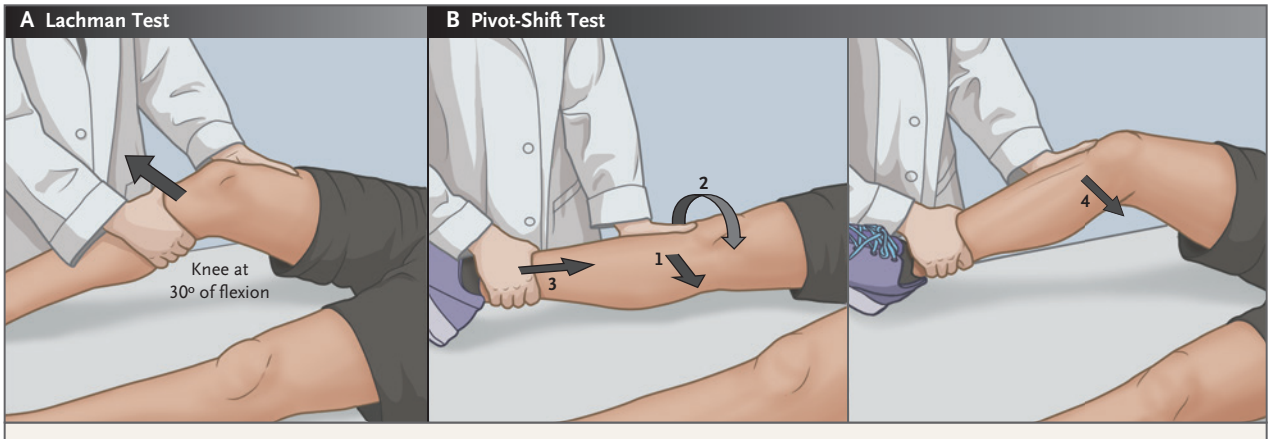

Figure 1. Assessment of ACL Tears.

The Lachman test (Panel A) is performed with the knee at 30 degrees of flexion. Increased anterior translation and a soft end point relative to the contralateral knee indicate injury to the anterior cruciate ligament (ACL). The pivot-shift test begins with the patient's knee relaxed and in extension (Panel B). When assessing the patient's right knee, the examiner's left hand is placed near the knee and the right hand is placed closer to the ankle. Using the left hand, the examiner induces gentle valgus torque (arrow 1) and internal rotation (arrow 2), actions that will force an ACL-deficient knee into an anterior subluxed position. The next motion involves axial compression (arrow 3), which helps to induce knee flexion. After flexion of approximately 30 degrees, the subluxed tibia suddenly reduces to its normal position (arrow 4), signifying a positive pivot-shift test that can be felt and observed by the examiner.

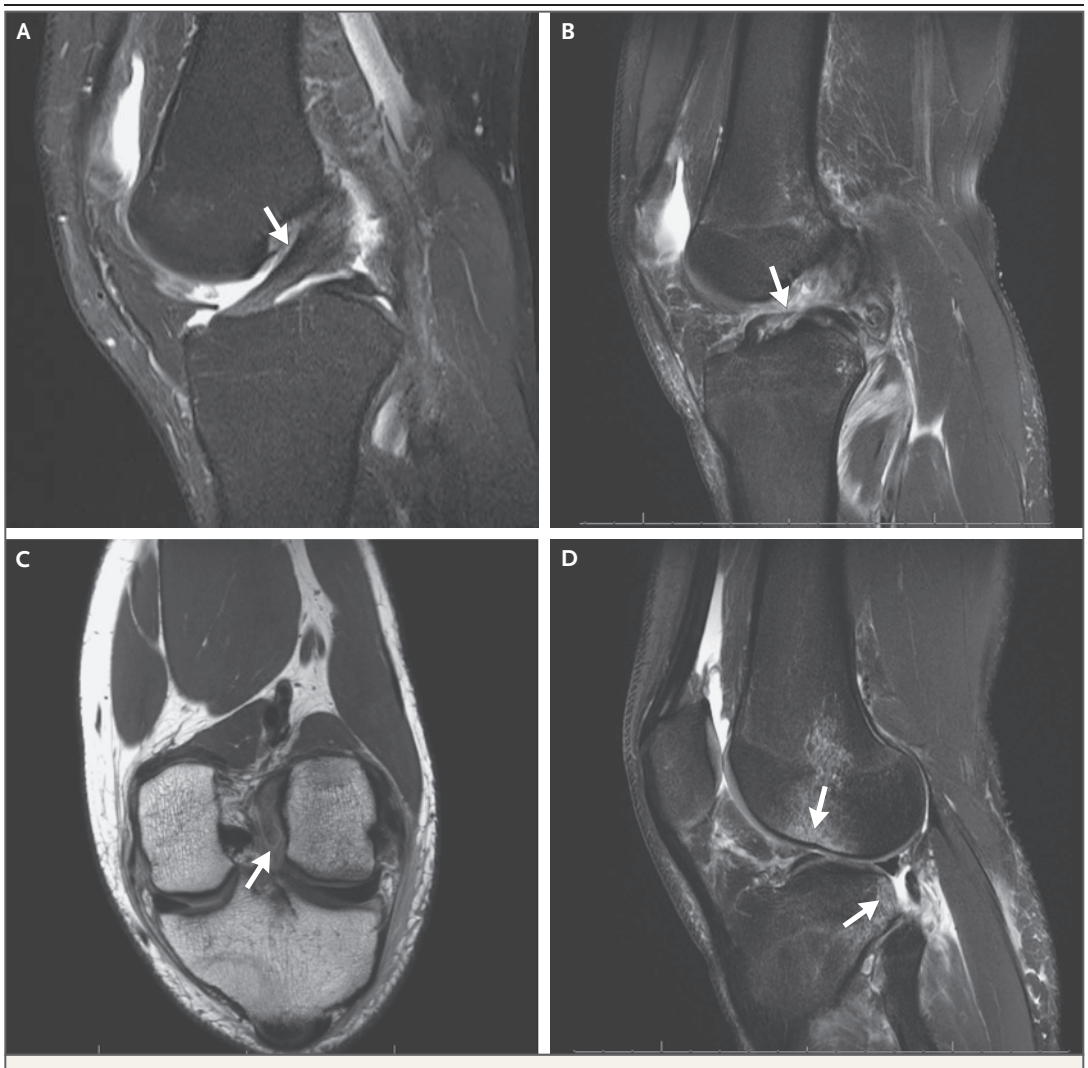

Figure 2. MRIs Showing Normal and Intact ACLs, ACL Tears, and the Typical Bruising Pattern in Bone Associated with ACL Tears.

A normal (intact) anterior cruciate ligament (ACL) is shown in a sagittal image in Panel A (arrow). A sagittal image of an ACL tear is shown in Panel B (arrow), and a coronal oblique image of an ACL tear is shown in Panel C (arrow). A typical pattern of bone bruising associated with an ACL tear is shown in Panel D (arrows).

after injury) with delayed reconstruction (with the inclusion of structured rehabilitation in both groups), no statistically significant between-group differences were reported in average scores on four subscales of the Knee Injury and Osteoarthritis Outcome Score (KOOS): pain, symptoms of instability, function in sports and recreation, and knee-related quality of life.[14] There were also no statistically significant between-group differences in scores on these subscales of the KOOS at 5 years[15] or in the incidence of meniscal tears requiring surgery or the incidence of radiographically confirmed arthritis.[15,16] Many patients were high-level athletes, with a median Tegner activity score of 9, which indicates competitive athletic involvement (scores range from 0 to 10, with a score of 0 indicating sick leave or disability, a score of 5 indicating participation in recreational sports, and a score of 10 indicating participation in competitive sports on a professional level)[17] (for more information on Tegner activity scores, see the Supplementary Appendix, available with the full text of this article at NEJM.org). However, the trial was relatively small

(with a total of 121 patients) and excluded patients who had complete collateral ligament injuries or full-thickness cartilage defects or who required meniscal fixation.[15,16] In addition, half the patients in the optional reconstruction group pursued delayed ACL reconstruction, and those treated nonoperatively had greater knee laxity and more meniscus injuries at final follow-up (13 vs. 1) than those treated operatively. In another report, a matched-pair analysis involving 50 high-level athletes who did or did not undergo ACL reconstruction, those who had reconstruction had less knee laxity than those who did not have reconstruction, but there were otherwise no statistically significant differences in clinical outcomes or costs.[18] Although high-level evidence in favor of surgery is lacking, surgery is recommended as the initial treatment for top-level athletes (Tegner activity score of 10).

Nonoperative Therapy

Nonoperative therapy involves 3 months of supervised physiotherapy; anti-inflammatory medications; range-of-motion training; gradual strengthening of the quadriceps, hamstrings, hip abductors, and core muscles; and a progressive return to activity (see the Supplementary Appendix for more information on rehabilitation without surgery). Reevaluation is recommended 6 to 12 weeks after the initial injury to assess the effectiveness of rehabilitation and to consider the need for delayed ACL reconstruction.[19] Functional braces have not been shown to provide adequate restoration of stability.[20,21]

Operative Strategies

Timing of Surgery

A systematic review that included 3583 patients from observational studies suggested that no statistically significant differences in subjective or objective measures of outcome were related to the timing of ACL surgery.[22] However, the timing of surgery may affect the development and severity of related soft-tissue damage. A retrospective study in which early ACL reconstruction (i.e., within 12 weeks after injury) was compared with later reconstruction showed higher rates of damage to medial meniscal and medial tibiofemoral cartilage in the group receiving later treatment.[23] Similarly, another observational study that included more than 5000 patients showed that the risk of medial meniscal surgery was twice as high when ACL reconstruction was delayed for more than 5 months after injury and six times as high if delayed for more than 1 year; these risks appeared to be greater among patients younger than 17 years of age.[11] It has been hypothesized that restoring anterior–posterior and rotatory knee laxity may prevent subsequent instability and resultant damage to articular cartilage, the meniscus, or both. The American Academy of Orthopaedic Surgeons evidence-based guideline on the management of ACL injuries[24] recommends 12 weeks of nonoperative treatment for acute isolated ACL tear followed by a reevaluation of the need for surgery.[11] When ACL reconstruction is indicated, the guidelines recommend that surgery be performed within 5 months after injury to avoid recurrent instability and resultant additional damage to the meniscus, articular cartilage, or both.[24]

Complications of ACL Reconstruction

The most common complication of ACL reconstruction is superficial wound infection, which occurs in less than 1% of patients. Less common complications include deep joint infection and postoperative hemarthrosis, and the latter sometimes results in quadriceps inhibition (inability to actively contract the quadriceps muscle).[25,26] Loss of motion can also occur as a result of incorrect positioning of the graft (the most common surgical error) or arthrofibrosis (the formation of excessive scar tissue within the joint and in surrounding soft tissues, leading to painful restriction of joint motion).

Surgical Technique

Randomized trials of primary ACL reconstruction have shown that autografts of the hamstrings (the tendons of the semitendinosus and gracilis muscles) and the patellar tendon have similar results, patient-reported outcomes, and incidences of postoperative osteoarthritis on radiography.[11,16,27] The quadriceps tendon is another potential source for grafting and is associated with less damage at the site of tendon harvest than grafts of the patellar tendon and with similar patient-reported outcomes.[28] As compared with autografts, allografts have higher costs and higher rates of graft failure and repeat rupture of the ACL, particularly in young athletes.[29] As such, autografts remain the preferred source.[11,30] Either single-bundle or double-

bundle reconstruction, both of which involve both anatomical bundles of the ACL, can be used in ACL reconstruction.[11,27,31] The risk of revision of ACL reconstruction is lower with double-bundle reconstruction (2.0%) than with single-bundle reconstruction (3.2%),[31] but single-bundle reconstruction is less costly.[30,32] The results of randomized trials suggest that the choice of surgical tunnel drilling technique (transtibial vs. anteromedial portal) is not associated with a statistically significant difference in clinical outcomes.[33,34]

Meniscal injuries occur in 26 to 45% of patients with ACL injuries, most commonly in the posterior and peripheral regions.[6] Case series of meniscus repair at the time of ACL reconstruction have reported good clinical outcomes, exceeding 90% at a minimum of 5 years of follow-up.[35] Concomitant collateral ligament injuries occur in 19 to 38% of patients with ACL injuries.[6,16] Management of concomitant collateral injuries is determined in part by the laxity of the ligament with axial rotation and the response to varus and valgus stress tests.[6,16] The most severe injuries to the collateral ligament (grade 3 on a scale of 1 to 3) often require surgical treatment.[36] When ACL injury is associated with injuries to multiple ligaments of the knee, the available evidence (which is observational) supports early surgical management of all damaged ligaments, arthroscopic ACL reconstruction, and primary open reconstruction of collateral ligaments, either concomitantly or as the first of a two-stage ACL reconstruction procedure.[37]

Rehabilitation

Postoperative rehabilitation follows the same general principles as those described above in relation to nonoperative treatment. Rehabilitation programs consist of measures to establish full range of motion, prevent muscle hypotrophy, diminish pain and swelling, and avoid unnecessary stress to the reconstructed ligament and to any meniscal cartilage repairs. Rehabilitation starts within the first week after surgery, continues for 6 to 9 months, with two or three sessions per week, and includes the following: cryotherapy (ice and compression of soft tissue with an elastic bandage to reduce swelling), immediate weight bearing as tolerated by the patient, eccentric quadriceps strengthening (in which the patient lowers the leg from an extended position against resistance), isokinetic hamstring exercises (contraction at constant speed), closed kinetic-chain (foot is fixed and cannot move) and open kinetic-chain (lower leg swings free) exercises (see the Supplementary Appendix), and neuromuscular and agility training (training geared toward reestablishing muscle control, dynamic joint stability, and movement patterns opposite to those shown to injure the ACL [i.e., avoiding dynamic valgus, which is characterized by the medial or internal collapse of the knee]). Exercises intended to prevent injury are also incorporated into treatment (see the Supplementary Appendix).[38]

RETURN TO PLAY

Whatever the approach to therapy, the patient's activity level may decline after an ACL tear. The athlete's goal after ACL injury is to return to the same level of play (the same Tegner activity level) achieved before surgery. (See Table S1 in the Supplementary Appendix for information on Tegner activity levels.) Data suggest that only 40 to 55% of patients return to the same level of activity or higher after undergoing ACL surgery.[16,39] According to the findings in one randomized trial, the activity level on return to play was on average two Tegner levels below that before injury, independent of treatment choice.[16] However, in a study assessing return to play among European professional soccer players after ACL reconstruction (who presumably had high motivation to return to play and excellent resources for rehabilitation), the rate of return to play was 93%, with 65% of players returning at the same level reported before injury.[40]

Although data from randomized trials to guide the timing of return to sports are lacking, it is generally accepted that return should be delayed for a minimum of 9 months from surgery to optimize biologic graft incorporation and clinical outcomes.[11,41,42] Clearance to return should be based on the player's ability to meet the criteria for return-to-play protocols (e.g., symmetric quadriceps strength and symmetric performance in hop tests). In a cohort study of athletes who underwent ACL reconstruction, rates of reinjury within 2 years were 4.5% in those who met the criteria for return to play and 33% in those who did not ($P=0.08$). Rates of injury were also significantly higher in those

Table 1. Summary of the AAOS Evidence-Based Guidelines for the Diagnosis and Treatment of ACL Injury.*

Stage of Care	Strength of Evidence
Diagnosis	
A relevant history and musculoskeletal examination are effective diagnostic tools for injury of the anterior cruciate ligament (ACL).	High
MRI is useful for the assessment of ACL injury and concomitant injury to ligaments, the meniscus, or articular cartilage.	High
Treatment	
There is limited evidence available to compare the effectiveness of nonoperative treatment of an ACL tear with reconstruction in patients with recurrent instability, but there is support for consideration of ACL reconstruction because the procedure reduces pathologic laxity.	Limited
There is limited evidence to support nonoperative management for less active patients with less laxity.[24]	Limited
Either single- or double-bundle reconstruction can be used. Outcomes for the procedures have been shown to be similarly good.[24]	High
Autografts of the hamstrings (the tendons of the semitendinosus and gracilis muscles) and the patellar tendon have been shown to have outcomes that are similarly good.†	High
Similar outcomes have been reported for autografts and allografts, although the results may not be generalized to all patients.[52]	High

* For more information, see the guidelines from the American Academy of Orthopaedic Surgeons (AAOS).[24] Data published after the release of the AAOS guidelines support the superiority of autografts over allografts with respect to the risk of revision surgery.

† A recent level 2 systematic review of grafts of the quadriceps tendon showed rates of clinical and functional outcomes and graft survival that were similar to grafts of the patella and hamstring tendons.[53]

who returned to play before 9 months.[41] Negative psychological responses (e.g., absence of mental readiness for return to sport or competition) are associated with a lower rate of return to the preinjury level of play after ACL reconstruction.[43]

INJURY PREVENTION

Bracing has been proposed as a means of reducing ACL injury, since the ligament may be subject to much lower peak strain in a functional brace, as has been suggested with the use of a motion-capture system in evaluations of an athlete at high risk for ACL injury.[44] A randomized trial involving more than 21,000 athlete exposures in football (i.e., time on the field, in practice or in game play) showed a significant reduction in overall knee injuries with the use of a prophylactic knee brace, but there were too few ACL injuries to determine whether the brace was beneficial for this specific injury.[45] In meta-analyses of preventive training programs focused on sport-specific training, biomechanics, and proprioception, the programs were shown to significantly reduce the per-season risk of ACL injury.[46,47] Economic analyses suggest that such programs are associated with cost savings of approximately $100 per athlete per season,[48] with 100 patients requiring this intervention to prevent a single ACL injury.[11]

AREAS OF UNCERTAINTY

There is a need for larger randomized trials with longer-term follow-up in which initial surgery (followed by rehabilitation) is compared with a strategy of initial rehabilitation and delayed surgery, as needed, and in which different approaches to ACL reconstruction are assessed. Data from randomized trials are lacking to guide treatment when there are concomitant meniscal and collateral ligament injuries. Data on long-term clinical outcome are needed to better understand the ways in which treatment of ACL-injured knees, subsequent injuries to meniscus and cartilage, and the development of osteoarthritis are related.[49,50] Preliminary studies with short-term follow-up have not indicated that any clinical benefit is gained with the use of platelet-rich plasma augmentation, stem-cell therapy, or primary ACL repair (i.e., suturing the torn ACL to the bone as opposed to grafting it).[51]

GUIDELINES

The American Academy of Orthopaedic Surgeons has guidelines for the treatment of ACL injuries (Table 1).[11,24] The recommendations in this article are largely concordant with these guidelines. However, we recommend autografts over allografts when surgery is performed on the basis of data obtained since the guidelines were published.

CONCLUSIONS AND RECOMMENDATIONS

In a recreational athlete, such as the athlete described in the vignette, whose history and results on physical examination suggest an ACL

injury, MRI is indicated to confirm the diagnosis and to determine whether there are concomitant injuries.[24] Given the limited data showing that immediate ACL reconstruction and initial rehabilitation followed by surgery (if needed) are associated with similar outcomes in such patients, we would discuss with the patient the option of a supervised, structured, accelerated course of rehabilitation as an alternative to immediate reconstruction. If an initial strategy of rehabilitation were chosen, we would recommend serial evaluation of knee function and functional recovery in the first 3 months after the injury. If residual laxity (greater than grade 2) existed at the time of subsequent assessment, we would favor surgery to avoid further damage to articular cartilage and menisci. We would recommend immediate ACL reconstruction for a top-level athlete with the same injury. Whether or not surgery is performed, we would recommend criterion-based (not solely time-based) assessment before the athlete returns to play in order to minimize the risk of reinjury, contralateral injury, or both.

Dr. Musahl reports receiving consulting fees from Smith and Nephew and holding patent 9,949,684 on quantified injury diagnostics, from which no revenues have been or can be accrued to him. No other potential conflict of interest relevant to this article was reported.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

REFERENCES

1. Kaeding CC, Léger-St-Jean B, Magnussen RA. Epidemiology and diagnosis of anterior cruciate ligament injuries. Clin Sports Med 2017;36:1-8.
2. Sutton KM, Bullock JM. Anterior cruciate ligament rupture: differences between males and females. J Am Acad Orthop Surg 2013;21:41-50.
3. Ladenhauf HN, Graziano J, Marx RG. Anterior cruciate ligament prevention strategies: are they effective in young athletes — current concepts and review of literature. Curr Opin Pediatr 2013;25:64-71.
4. Stijak L, Kadija M, Djulejić V, et al. The influence of sex hormones on anterior cruciate ligament rupture: female study. Knee Surg Sports Traumatol Arthrosc 2015;23:2742-9.
5. Gornitzky AL, Lott A, Yellin JL, Fabricant PD, Lawrence JT, Ganley TJ. Sport-specific yearly risk and incidence of anterior cruciate ligament tears in high school athletes: a systematic review and meta-analysis. Am J Sports Med 2016;44:2716-23.
6. Borchers JR, Kaeding CC, Pedroza AD, Huston LJ, Spindler KP, Wright RW. Intra-articular findings in primary and revision anterior cruciate ligament reconstruction surgery: a comparison of the MOON and MARS study groups. Am J Sports Med 2011;39:1889-93.
7. Huang W, Zhang Y, Yao Z, Ma L. Clinical examination of anterior cruciate ligament rupture: a systematic review and meta-analysis. Acta Orthop Traumatol Turc 2016;50:22-31.
8. Galway HR, MacIntosh DL. The lateral pivot shift: a symptom and sign of anterior cruciate ligament insufficiency. Clin Orthop Relat Res 1980;147:45-50.
9. Musahl V, Griffith C, Irrgang JJ, et al. Validation of quantitative measures of rotatory knee laxity. Am J Sports Med 2016;44:2393-8.
10. Musahl V, Burnham J, Lian J, et al. High-grade rotatory knee laxity may be predictable in ACL injuries. Knee Surg Sports Traumatol Arthrosc 2018;26:3762-9.
11. Sri-Ram K, Salmon LJ, Pinczewski LA, Roe JP. The incidence of secondary pathology after anterior cruciate ligament rupture in 5086 patients requiring ligament reconstruction. Bone Joint J 2013;95-B:59-64.
12. Benjaminse A, Gokeler A, van der Schans CP. Clinical diagnosis of an anterior cruciate ligament rupture: a meta-analysis. J Orthop Sports Phys Ther 2006;36:267-88.
13. Moksnes H, Engebretsen L, Eitzen I, Risberg MA. Functional outcomes following a non-operative treatment algorithm for anterior cruciate ligament injuries in skeletally immature children 12 years and younger: a prospective cohort with 2 years follow-up. Br J Sports Med 2013;47:488-94.
14. Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon BD. Knee Injury and Osteoarthritis Outcome Score (KOOS) — development of a self-administered outcome measure. J Orthop Sports Phys Ther 1998;28:88-96.
15. Frobell RB, Roos HP, Roos EM, Roemer FW, Ranstam J, Lohmander LS. Treatment for acute anterior cruciate ligament tear: five year outcome of randomised trial. BMJ 2013;346:f232.
16. Frobell RB, Roos EM, Roos HP, Ranstam J, Lohmander LS. A randomized trial of treatment for acute anterior cruciate ligament tears. N Engl J Med 2010;363:331-42.
17. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. Clin Orthop Relat Res 1985;43:43-9.
18. Meuffels DE, Favejee MM, Vissers MM, Heijboer MP, Reijman M, Verhaar JAN. Ten year follow-up study comparing conservative versus operative treatment of anterior cruciate ligament ruptures: a matched-pair analysis of high level athletes. Br J Sports Med 2009;43:347-51.
19. Hetsroni I, Delos D, Fives G, Boyle BW, Lillemoe K, Marx RG. Nonoperative treatment for anterior cruciate ligament injury in recreational alpine skiers. Knee Surg Sports Traumatol Arthrosc 2013;21:1910-4.
20. Smith SD, Laprade RF, Jansson KS, Arøen A, Wijdicks CA. Functional bracing of ACL injuries: current state and future directions. Knee Surg Sports Traumatol Arthrosc 2014;22:1131-41.
21. Millet CW, Drez DJ Jr. Principles of bracing for the anterior cruciate ligament-deficient knee. Clin Sports Med 1988;7:827-33.
22. Andernord D, Karlsson J, Musahl V, Bhandari M, Fu FH, Samuelsson K. Timing of surgery of the anterior cruciate ligament. Arthroscopy 2013;29:1863-71.
23. Magnussen RA, Pedroza AD, Donaldson CT, Flanigan DC, Kaeding CC. Time from ACL injury to reconstruction and the prevalence of additional intra-articular pathology: is patient age an important factor? Knee Surg Sports Traumatol Arthrosc 2013;21:2029-34.
24. Shea KG, Carey JL, Richmond J, et al. The American Academy of Orthopaedic Surgeons evidence-based guideline on management of anterior cruciate ligament injuries. J Bone Joint Surg Am 2015;97:672-4.
25. Hettrich CM, Dunn WR, Reinke EK, Spindler KP. The rate of subsequent surgery and predictors after anterior cruciate ligament reconstruction: two- and six-year follow-up results from a multicenter cohort. Am J Sports Med 2013;41:1534-40.
26. Bohu Y, Klouche S, Herman S, de Pamphilis O, Gerometta A, Lefevre N. Professional athletes are not at a higher risk of infections after anterior cruciate ligament reconstruction: incidence of sep-

tic arthritis, additional costs, and clinical outcomes from the French Prospective Anterior Cruciate Ligament Study (FAST) cohort. Am J Sports Med 2019;47:104-11.
27. Björnsson H, Samuelsson K, Sundemo D, et al. A randomized controlled trial with mean 16-year follow-up comparing hamstring and patellar tendon autografts in anterior cruciate ligament reconstruction. Am J Sports Med 2016;44:2304-13.
28. Lund B, Nielsen T, Faunø P, Christiansen SE, Lind M. Is quadriceps tendon a better graft choice than patellar tendon? A prospective randomized study. Arthroscopy 2014;30:593-8.
29. Kaeding CC, Pedroza AD, Reinke EK, et al. Change in anterior cruciate ligament graft choice and outcomes over time. Arthroscopy 2017;33:2007-14.
30. Saltzman BM, Cvetanovich GL, Nwachukwu BU, Mall NA, Bush-Joseph CA, Bach BR Jr. Economic analyses in anterior cruciate ligament reconstruction: a qualitative and systematic review. Am J Sports Med 2016;44:1329-35.
31. Svantesson E, Sundemo D, Hamrin Senorski E, et al. Double-bundle anterior cruciate ligament reconstruction is superior to single-bundle reconstruction in terms of revision frequency: a study of 22,460 patients from the Swedish National Knee Ligament Register. Knee Surg Sports Traumatol Arthrosc 2017;25:3884-91.
32. van Eck CF, Gravare-Silbernagel K, Samuelsson K, et al. Evidence to support the interpretation and use of the Anatomic Anterior Cruciate Ligament Reconstruction Checklist. J Bone Joint Surg Am 2013; 95(20):e153.
33. MacDonald P, Kim C, McRae S, Leiter J, Khan R, Whelan D. No clinical differences between anteromedial portal and transtibial technique for femoral tunnel positioning in anterior cruciate ligament reconstruction: a prospective randomized, controlled trial. Knee Surg Sports Traumatol Arthrosc 2018;26:1335-42.
34. Bohn MB, Sørensen H, Petersen MK, Søballe K, Lind M. Rotational laxity after anatomical ACL reconstruction measured by 3-D motion analysis: a prospective randomized clinical trial comparing anatomic and nonanatomic ACL reconstruction techniques. Knee Surg Sports Traumatol Arthrosc 2015;23:3473-81.
35. Bogunovic L, Kruse LM, Haas AK, Huston LJ, Wright RW. Outcome of all-inside second-generation meniscal repair: minimum five-year follow-up. J Bone Joint Surg Am 2014;96:1303-7.
36. Laprade RF, Bernhardson AS, Griffith CJ, Macalena JA, Wijdicks CA. Correlation of valgus stress radiographs with medial knee ligament injuries: an in vitro biomechanical study. Am J Sports Med 2010;38: 330-8.
37. Levy BA, Fanelli GC, Whelan DB, et al. Controversies in the treatment of knee dislocations and multiligament reconstruction. J Am Acad Orthop Surg 2009; 17:197-206.
38. White K, Di Stasi SL, Smith AH, Snyder-Mackler L. Anterior Cruciate Ligament-Specialized Post-Operative Return-to-Sports (ACL-SPORTS) training: a randomized control trial. BMC Musculoskelet Disord 2013; 14:108.
39. Ardern CL, Taylor NF, Feller JA, Webster KE. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. Br J Sports Med 2014;48:1543-52.
40. Waldén M, Hägglund M, Magnusson H, Ekstrand J. ACL injuries in men's professional football: a 15-year prospective study on time trends and return-to-play rates reveals only 65% of players still play at the top level 3 years after ACL rupture. Br J Sports Med 2016;50:744-50.
41. Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study. Br J Sports Med 2016;50:804-8.
42. van Melick N, van Cingel RE, Brooijmans F, et al. Evidence-based clinical practice update: practice guidelines for anterior cruciate ligament rehabilitation based on a systematic review and multidisciplinary consensus. Br J Sports Med 2016;50:1506-15.
43. Ardern CL, Taylor NF, Feller JA, Whitehead TS, Webster KE. Sports participation 2 years after anterior cruciate ligament reconstruction in athletes who had not returned to sport at 1 year: a prospective follow-up of physical function and psychological factors in 122 athletes. Am J Sports Med 2015;43:848-56.
44. Hangalur G, Brenneman E, Nicholls M, Bakker R, Laing A, Chandrashekar N. Can a knee brace reduce the strain in the anterior cruciate ligament? A study using combined in vivo/in vitro method. Prosthet Orthot Int 2016;40:394-9.
45. Sitler M, Ryan J, Hopkinson W, et al. The efficacy of a prophylactic knee brace to reduce knee injuries in football: a prospective, randomized study at West Point. Am J Sports Med 1990;18:310-5.
46. Sadoghi P, von Keudell A, Vavken P. Effectiveness of anterior cruciate ligament injury prevention training programs. J Bone Joint Surg Am 2012;94:769-76.
47. Donnell-Fink LA, Klara K, Collins JE, et al. Effectiveness of knee injury and anterior cruciate ligament tear prevention programs: a meta-analysis. PLoS One 2015;10(12):e0144063.
48. Swart E, Redler L, Fabricant PD, Mandelbaum BR, Ahmad CS, Wang YC. Prevention and screening programs for anterior cruciate ligament injuries in young athletes: a cost-effectiveness analysis. J Bone Joint Surg Am 2014;96:705-11.
49. Cinque ME, Dornan GJ, Chahla J, Moatshe G, LaPrade RF. High rates of osteoarthritis develop after anterior cruciate ligament surgery: an analysis of 4108 patients. Am J Sports Med 2018;46:2011-9.
50. Tsoukas D, Fotopoulos V, Basdekis G, Makridis KG. No difference in osteoarthritis after surgical and non-surgical treatment of ACL-injured knees after 10 years. Knee Surg Sports Traumatol Arthrosc 2016;24:2953-9.
51. Perrone GS, Proffen BL, Kiapour AM, Sieker JT, Fleming BC, Murray MM. Bench-to-bedside: bridge-enhanced anterior cruciate ligament repair. J Orthop Res 2017;35:2606-12.
52. Maletis GB, Chen J, Inacio MC, Funahashi TT. Age-related risk factors for revision anterior cruciate ligament reconstruction: a cohort study of 21,304 patients from the Kaiser Permanente Anterior Cruciate Ligament Registry. Am J Sports Med 2016;44:331-6.
53. Mouarbes D, Menetrey J, Marot V, et al. Anterior cruciate ligament reconstruction: a systematic review and meta-analysis of outcomes for quadriceps tendon autograft versus bone-patellar tendon-bone and hamstring-tendon autografts. Am J Sports Med 2019 February 21 (Epub ahead of print).