

## 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

**A**NTERIOR 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.<sup>1</sup> 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.<sup>1</sup> ACL injuries are associated with several modifiable and non-modifiable risk factors, including female sex<sup>2</sup> (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.<sup>3</sup> Variations in bone morphology, neuromuscular control, genetic profile, and hormonal milieu may play a role.<sup>4,5</sup> 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).<sup>5</sup> 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.<sup>6</sup>

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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

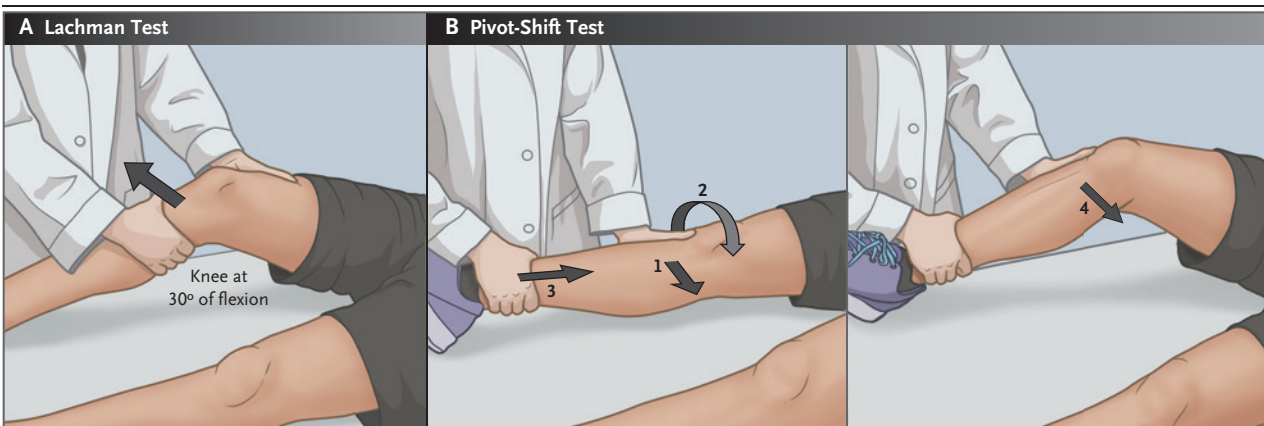
- High-level evidence suggests that recreational athletes can initially be treated nonoperatively or operatively for anterior cruciate ligament (ACL) tears.
- ACL reconstruction is recommended for patients with increased or persistent laxity after nonoperative treatment.
- For ACL reconstruction in top-level 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).

ficiencies of 0.97 and 0.98.<sup>7</sup> 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.<sup>8</sup> 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.<sup>9,10</sup> 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.<sup>11,12</sup> 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).<sup>6</sup>

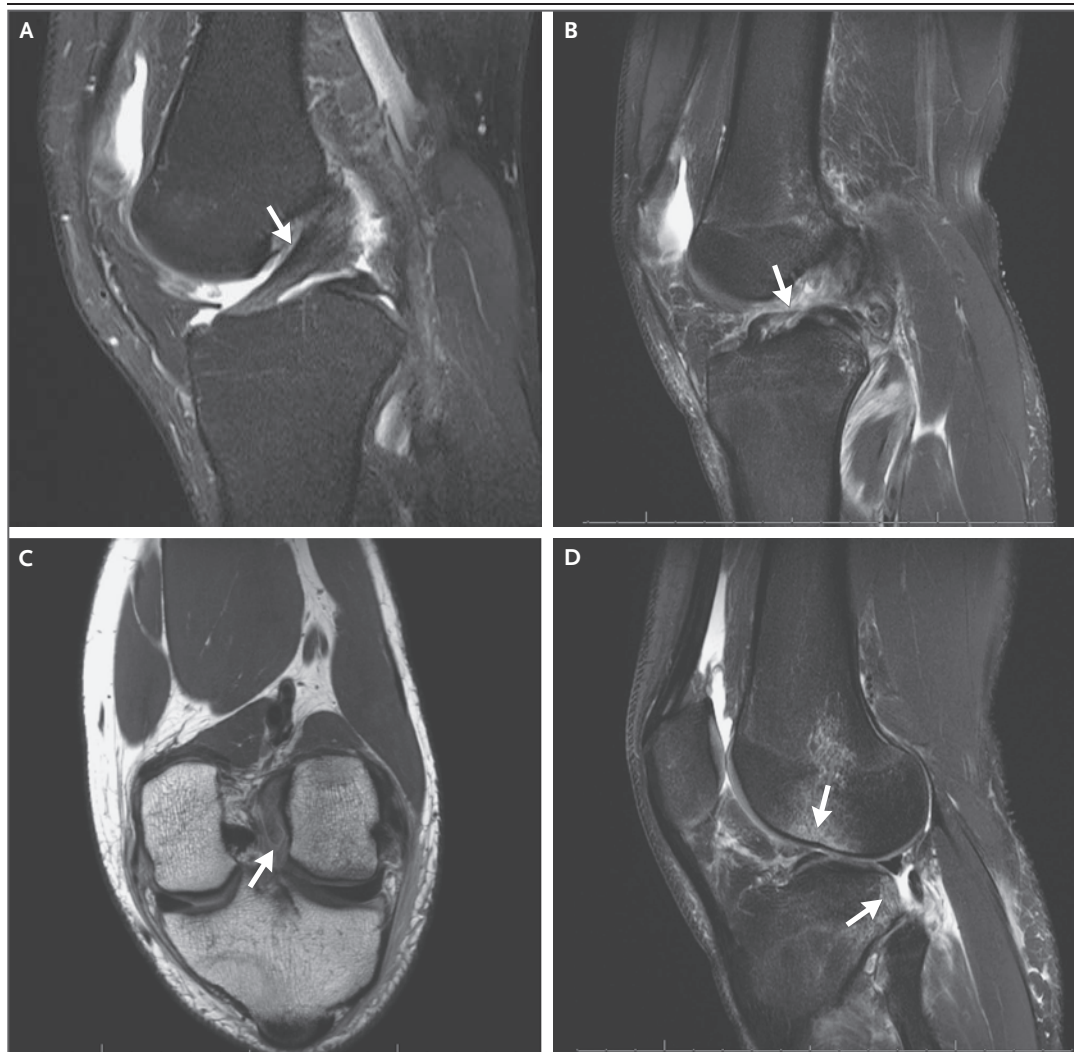
## TREATMENT

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.<sup>13</sup> 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.<sup>14</sup> There were also no statistically significant between-group differences in scores on these subscales of the KOOS at 5 years<sup>15</sup> or in the incidence of meniscal tears requiring surgery or the incidence of radiograph-

ically confirmed arthritis.<sup>15,16</sup> 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)<sup>17</sup> (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.<sup>15,16</sup> 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.<sup>18</sup> 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.<sup>19</sup> Functional braces have not been shown to provide adequate restoration of stability.<sup>20,21</sup>

#### *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.<sup>22</sup> 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.<sup>23</sup> 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.<sup>11</sup> 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<sup>24</sup> recommends 12 weeks of nonoperative treatment for acute isolated ACL tear followed by a reevaluation of the need for surgery.<sup>11</sup> 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.<sup>24</sup>

##### *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).<sup>25,26</sup> 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.<sup>11,16,27</sup> 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.<sup>28</sup> As compared with autografts, allografts have higher costs and higher rates of graft failure and repeat rupture of the ACL, particularly in young athletes.<sup>29</sup> As such, autografts remain the preferred source.<sup>11,30</sup> Either single-bundle or double-



bundle reconstruction, both of which involve both anatomical bundles of the ACL, can be used in ACL reconstruction.<sup>11,27,31</sup> The risk of revision of ACL reconstruction is lower with double-bundle reconstruction (2.0%) than with single-bundle reconstruction (3.2%),<sup>31</sup> but single-bundle reconstruction is less costly.<sup>30,32</sup> 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.<sup>33,34</sup>

Meniscal injuries occur in 26 to 45% of patients with ACL injuries, most commonly in the posterior and peripheral regions.<sup>6</sup> 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.<sup>35</sup> Concomitant collateral ligament injuries occur in 19 to 38% of patients with ACL injuries.<sup>6,16</sup> 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.<sup>6,16</sup> The most severe injuries to the collateral ligament (grade 3 on a scale of 1 to 3) often require surgical treatment.<sup>36</sup> 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.<sup>37</sup>

#### 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 po-

sition 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).<sup>38</sup>

#### 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.<sup>16,39</sup> 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.<sup>16</sup> 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.<sup>40</sup>

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.<sup>11,41,42</sup> 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
<b>Diagnosis</b>	
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
<b>Treatment</b>	
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. <sup>24</sup>	Limited
Either single- or double-bundle reconstruction can be used. Outcomes for the procedures have been shown to be similarly good. <sup>24</sup>	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. <sup>52</sup>	High

\* For more information, see the guidelines from the American Academy of Orthopaedic Surgeons (AAOS).<sup>24</sup> 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.<sup>53</sup>

who returned to play before 9 months.<sup>41</sup> 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.<sup>43</sup>

#### 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.<sup>44</sup> 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.<sup>45</sup> 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.<sup>46,47</sup> Economic analyses suggest that such programs are associated with cost savings of approximately \$100 per athlete per season,<sup>48</sup> with 100 patients requiring this intervention to prevent a single ACL injury.<sup>11</sup>

#### 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.<sup>49,50</sup> 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).<sup>51</sup>

#### GUIDELINES

The American Academy of Orthopaedic Surgeons has guidelines for the treatment of ACL injuries (Table 1).<sup>11,24</sup> 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.<sup>24</sup> 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.

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