Management of the Structurally Intact ACL with Residual Instability

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Diagnosis of Structurally Intact but Abnormally Lax ACL Graft

Firstly, it's important to differentiate between laxity on exam and true symptomatic instability. Inadequate rehabilitation and lack of lower extremity neuromuscular control can result in symptoms of instability, even without any objective evidence of laxity after ACL reconstruction [1]. In contrast, some asymptomatic and fully functional patients may demonstrate positive exam findings of laxity on such tests as the Lachman, anterior drawer, pivot shift tests, and arthrometer measurements.

For patients who have exhausted rehabilitative measures and continue to exhibit symptomatic instability, a follow-up MRI must be obtained to assess integrity of the ACL graft and evaluate for other pathologies. In the setting of an intact graft, the following most common scenarios that can lead to residual instability must be considered:

1. Proper graft position, but insufficient graft tension
2. Improper graft position/orientation
3. Unrecognized or unaddressed additional injuries/conditions

Below, we discuss a step-by-step approach to recognizing and surgically addressing each of the above factors.

Scenario 1: Properly Positioned Graft with Insufficient Tension

One potential cause of an unstable knee with a structurally intact ACL graft is laxity of the graft itself. Detailed physical examination and dedicated imaging are important to rule out additional contributing factors (discussed below), such as erroneous tunnel placement, other ligamentous injuries, and malalignment. Arthroscopic evaluation of the graft will reveal an intact graft in correct position/orientation, with abnormal laxity to probing (case 1, Fig. 6.2). In this case, the graft may be lax for the following reasons: (a) inadequate initial tension, (b) failure of rigid fixation, and (c) graft stretching over time.

Inappropriate Intraoperative Tension

Inadequate initial intraoperative tension on an ACL graft may result from: (a) failure to pretension the graft prior to implantation, (b) failure

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M. J. Alaia, K. J. Jones (eds.), *Revision Anterior Cruciate Ligament Reconstruction*,
https://doi.org/10.1007/978-3-030-96996-7_6

to place the knee into correct position during graft fixation, and (c) failure to apply adequate tension during graft fixation.

Pre-tensioning the graft is important in order to remove the creep (i.e., plastic deformation) prior to implantation. Biomechanical studies show that higher loads and longer application times leave the graft with higher residual tension and lower potential for stretching [2, 3]. In the clinical setting, application of 80–90 N load to the graft for a minimum of 15 minutes is recommended. *Surgical tip:* be sure to re-check and adjust the tension on the graft a few minutes after the initial load is applied – as plastic deformation occurs, the graft stretches slightly, and the tension experienced decreases.

For a single-bundle ACL reconstruction, the graft should be fixed with the knee in full extension, while a reverse Lachman force is applied [4]. Failure to apply this force may result in graft fixation with the tibia in the excessively anterior position (case 1, Fig. 6.1b).

Applying adequate force to the ACL graft during fixation represents a balance between preventing laxity and avoiding over-tightening, with

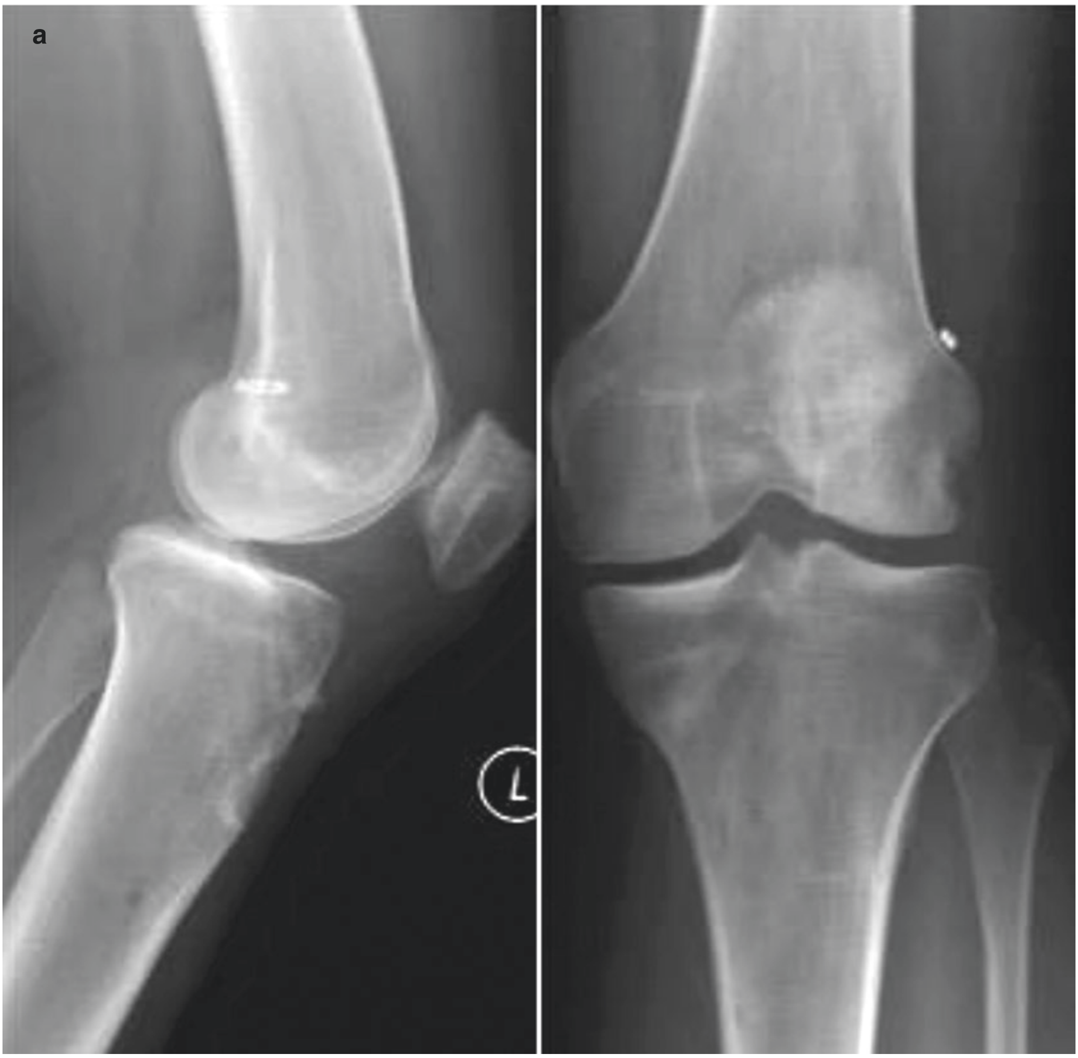

Fig. 6.1 (**a**) Plain radiographs show neutral alignment and appropriate tunnel position. (**b**) MRI confirmed appropriate tunnel position/orientation and an intact graft, but also showed significant (8 mm) anterior tibial translation

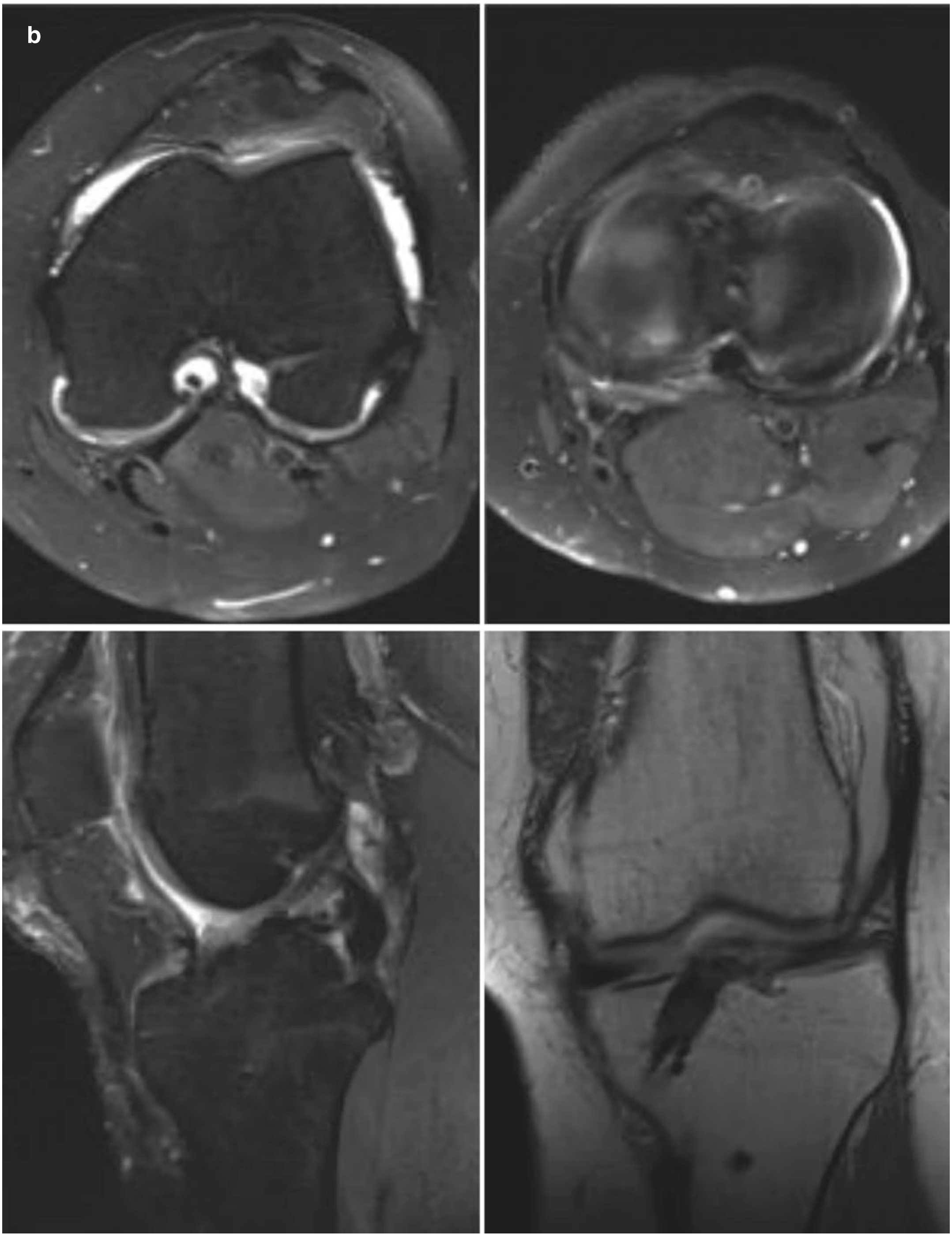

Fig. 6.1 (continued)

a minimum of 20 N of force recommended [5]. It is essential to verify appropriate graft tension at the conclusion of the case by checking knee stability manually via Lachman, anterior drawer, and pivot shift tests and by probing the graft under direct arthroscopic visualization.

Loss of Rigid Graft Fixation (i.e. Graft Slippage)

A wide variety of options for securing the ACL graft exist, broadly divided into the main types of aperture fixation and suspensory fixation. Aperture fixation at the intra-articular opening of the tunnel results in the shortest possible distance of the unfixed graft. Suspensory fixation leaves more of the graft unsecured, allowing a "windshield-wiper effect" and possible tunnel widening, which can theoretically allow the graft to shift into a suboptimal position, potentially producing graft laxity [6, 7]. Additionally, laxity can result when fixation mode itself fails, such as button pull through, adjustable loop lengthening, suture failure, and graft slippage past the interference screw [8, 9].

Graft Stretch

Due to intrinsic properties, some grafts are predisposed to greater likelihood of stretching over time. Studies have shown higher risk of re-rupture with allografts than with autografts [9–11]; additionally, hamstring grafts are more likely to experience stretch than bone-patellar tendon-bone (BPTB) grafts are [8, 9]. Although differences in overall clinical outcomes are debatable, a number of studies have demonstrated greater anterior knee laxity with hamstring grafts, compared to that of BPTB grafts [12–14]. Chapter 5 focuses specifically on graft options for ACL revision reconstruction.

Table 6.1 Surgical tips and tricks

How to manage instability after ACLR with an intact graft		
Why is the knee unstable?	What to do	How to do it
Graft is in good position but too lax Poorly tensioned Failed fixation Graft stretched	Revise the graft	Use same tunnels/sockets (if anatomically placed) Use stiffer graft Ensure maximal pre-tensioning of the graft Ensure reverse Lachman during fixation Use more rigid fixation (consider dual fixation on each side)
Poorly positioned graft Femoral tunnel too anterior Tibial tunnel too posterior Vertical graft	Option 1: Revise completely Option 2: Add PL bundle (for rotational-only instability) Option 3: Add ALL reconstruction	Identify anatomic locations for femoral and tibial tunnels Ensure adequate bone stock for new tunnels or graft old tunnels to rebuild stock Use outside-in or AM portal drilling and fluoroscopic imaging to avoid tunnel collisions
Additional pathology Varus deformity High posterior tibial slope PLC insufficiency Meniscal lesions	HTO De-flexion osteotomy PLC reconstruction Meniscal repair or reconstruction	See respective chapters for details

Surgical Approach to a Properly Positioned Graft with Insufficient Tension

For a symptomatic patient with an ACL graft that is properly positioned but lax on clinical and arthroscopic examination, revision ACL reconstruction is required, as there is currently no clinically proven way to "tighten" such a graft in situ. In this situation, the surgeon must consider and address all possible contributing issues, discussed above, as follows (Table 6.1).

1. If possible, choose a stiffer graft, with lower intrinsic likelihood of stretching. If an allograft was used at index surgery, an autograft should be considered for revision. With a previously used hamstring, consider BPTB or quadriceps tendon (QT).
2. Ensure appropriate graft tension during preparation and implantation. Maintain the graft

under at least 80–90N of tension for at least 15 minutes prior to implantation, re-checking the tension every 4–5 minutes. While the graft is being secured, ensure full knee extension and a reverse Lachman force. Consider using a tensiometer to ensure adequate force application at the time of graft fixation, and verify elimination of the Lachman, anterior drawer, and pivot shift tests afterwards.

3. For securing the graft, choose implants that will ensure optimal tension and rigid fixation and have the least likelihood of any postoperative slippage. Aperture fixation produces the shortest and stiffest grafts, while many currently used suspensory devices allow adding graft tension even after fixation is set. In a revision setting, consider employing two modes of fixation on either the femoral or tibial side or even on both sides. For example, you can secure the graft with a button-loop device on the femur and interference screw on the tibia, add tension as needed from the femoral side, finalize femoral fixation by adding an interference screw, and back up tibial fixation by securing the graft sutures distally (to a post or an anchor).

Scenario 2: Improperly Positioned Graft

If the graft has been malpositioned, residual knee laxity and instability may occur, even with a graft that's properly tensioned, well fixed, and intrinsically stiff. Proper graft function depends on anatomic tunnel position [15–17], and thus, erroneous tunnel placement, which is the most common technical error during ACL reconstruction [18], can result in a graft that is structurally intact but functionally insufficient (i.e., lax).

Femoral Tunnel Too Anterior

A femoral tunnel placed too anteriorly has been found to be an important factor leading to graft failure, occurring in ~30% of revision ACL reconstructions [18]. A too anterior tunnel produces a graft that becomes excessively tight in flexion and loose in extension [19].

Tibial Tunnel Too Posterior

The most common mistake of tibial tunnel placement is a too posterior location, which has been shown to result in higher rates of rotational instability and worse subjective outcomes [20]. In contrast, a too-anteriorly placed tibial tunnel may cause graft impingement on the roof of the intercondylar notch in extension and may lead to loss of terminal extension [17].

Vertical Graft

The classically described vertical graft can be stable in the anterior to posterior plane, but has a rotationally unstable component, as seen with a positive pivot shift phenomenon (case 2, Fig. 6.3). Vertical grafts can result from the femoral tunnel placed too anteriorly, the tibial tunnel placed too posteriorly, or a combination of the two [16, 18].

Surgical Approach to an ACL Graft with Non-anatomic Tunnel Placement

Preoperative confirmation of suspected graft/tunnel malposition as cause for residual laxity should be done with imaging, including plain radiographs (which can show too-anterior femoral and/or too-posterior tibial tunnels), MRI (which can show an intact but vertically oriented graft), and CT scan with 3D reconstructions (which can identify locations and orientation of the tunnels, measure tunnel widening, and assess availability of bone stock for revision reconstruction).

Option 1: Graft Revision

If the structurally intact yet lax ACL graft is believed to be due to tunnel malposition, the most obvious solution is a revision ACL reconstruction with proper tunnel placement. For tunnels that are grossly malpositioned but not significantly widened, there may be enough "real estate" to place entirely new tunnels or sockets in proper anatomic locations. In other cases, convergence between new and old tunnels may be unavoidable – techniques to address this problem are discussed in detail in subsequent chapters.

Option 2: Graft Augmentation

Some vertically oriented grafts provide adequate anterior-posterior stability, but lack rotational stability, resulting in patient complaints of the knee giving out – particularly with pivoting and cutting movements. A careful examination demonstrates negative or grade 1A Lachman and anterior drawer tests, with a positive pivot shift. Imaging and arthroscopic exam confirm a graft that is well-positioned in the sagittal plane, but is too vertical in the coronal plane, thereby adequately replicating the anteromedial (AM) bundle of the ACL, but not the posterolateral (PL) bundle. In this scenario, especially if the graft appears well-vascularized and incorporated, it is reasonable to consider augmentation with a small-size graft to replicate the PL bundle, serving to add rotational stability to an already anteriorly stable knee [21].

To add a PL bundle to an existing vertical graft, a similar technique as used to perform selective bundle reconstruction for partial ACL tears with an intact AM bundle should be used. A 5–7-mm diameter graft is sufficient, as larger grafts may cause impingement; a doubled semitendinosus graft readily serves this purpose.

To ensure adequate rotational stability is restored, it is essential to respect anatomic footprints of the PL bundle on the femur and tibia. On the femoral side, the PL bundle inserts distal to the AM bundle, typically just inferior to the bifurcate ridge [22]. Outside-in or AM portal drilling can both be used to place a femoral socket in this location, avoiding convergence with the existing femoral tunnel; fluoroscopy can be used intraoperatively to verify guide-wire position prior to reaming.

On the tibial side, the insertion of the PL bundle is located about 10 mm posterolateral to the center of the AM bundle [22], just medial to the lateral tibial spine. Compared to the typical angle of the tibial tunnel seen in cases with vertical grafts (which is usually about 20–30 degrees in the coronal plate), the angle of the guide-wire when adding the PL bundle reconstruction should be about 20–30 degrees more oblique (i.e., about 40–60 degrees in the coronal plane). The graft should be secured with the knee in 60–70 degrees of flexion and slight external rotation, with a posterior drawer force applied.

An additional consideration for intact grafts with lack of rotational stability (with adequate anterior stability) is the integrity of the anterolateral ligament (ALL) [23]. For patients with this complaint, if the graft appears to be appropriately oriented, secured, and taught to arthroscopic palpation, consideration can be given to adding ALL reconstruction, which will be discussed separately in Chap. 18.

Scenario 3: Unrecognized or Unaddressed Additional Injuries/Conditions

ACL tears occur frequently in conjunction with other pathologies, including meniscal tears, injuries to other ligaments, lower extremity coronal malalignment, and/or abnormal tibial slope. Failure to recognize and address these issues can result in excessive stress on the ACL graft, leading to graft stretching and laxity, clinical instability, and even graft failure. When encountering a knee with an intact ACL graft and persistent laxity, it is important for the surgeon to perform a thorough workup to identify the aforementioned potential contributing factors and plan accordingly when considering surgical intervention.

Coronal Plane Malalignment

Significant deviations from a normal mechanical axis impart abnormal forces to the knee joint and can contribute to failure of an ACL reconstruction. Varus malalignment, in particular, has been noted in greater proportion of ACL revision cases compared to successful index reconstructions [24–26] and is typically managed with a valgus-producing high tibial osteotomy (HTO), which can be done with a medial opening or lateral closing wedge technique [27, 28]. By correcting alignment, HTO can help normalize knee kinematics, allowing the ACL to function appropriately without excessive stress [29]. Both single-stage and two-stage approaches have been proposed for treating a knee with a failed ACL reconstruction and deformity. In the setting of an intact graft with clinical instability, we feel it best to choose a two-stage approach, as correction of varus deformity (especially if combined with tibial slope decrease) may provide enough stability improvement to obviate the need for graft revision. Details of managing coronal plane deformity are discussed in Chap. 15.

Sagittal Plane Malalignment

Excessively high posterior tibial slope (PTS) increases anterior translation of the tibia in weight-bearing and has been established as an independent predictor of ACL reconstruction failure [30, 31]. It's been reported that a PTS of greater than 12 degrees significantly increases the risk of ACL graft failure [32, 33], whereas biomechanical studies have confirmed that slope-reducing osteotomies decrease ACL graft forces and anterior tibial translation under axial load [34]. A number of clinical studies have shown successful outcomes with ACL revision reconstruction combined with tibial osteotomies that corrected excessive PTS [35, 36]. Sagittal plane deformity is further discussed in Chap. 16.

Additional Ligamentous Injury and Meniscal Deficiency

The most common additional ligamentous insufficiency that contributes to failure of ACL reconstruction is that of the posterolateral corner (PLC) [37]. Careful clinical examination is paramount in identifying this when preparing for ACL revision, as PLC structures may appear intact on imaging, but nevertheless exhibit laxity, especially when the original trauma is chronologically remote. Both isolated PLC reconstruction and those combined with ACL graft revision may be used to address persistent instability in cases of an intact ACL graft with residual instability. Management of the posterolateral corner as part of ACL revision reconstruction is discussed in detail in Chap. 14.

Finally, meniscal deficiency and certain meniscocapsular lesions have been shown to contribute to increased laxity both in ACL-deficient and ACL-reconstructed knees, leading to increased anterior translation and rotation [38–41]. Management of these lesions is discussed in Chaps. 19 and 20.

Summary

Not uncommonly, a patient may present with a clinically failed (i.e., unstable) ACL reconstruction, despite imaging findings of an intact graft. It is the surgeon's job to perform a meticulous evaluation, using detailed history, thorough physical examination, advanced imaging, and sometimes examination under anesthesia, including arthroscopy, to determine the cause for this instability. Dividing the potential causes into three main groups, as described in this chapter, can be helpful to determine the best surgical approach. Grafts that are well positioned may be lax due to failure of fixation, insufficient initial tension, or graft stretching; this scenario requires a revision with a stiffer graft, more rigid fixation, and appropriate intraoperative graft tensioning. Malpositioned grafts usually need to be revised with creation of tunnels in anatomic locations, although in some cases, an isolated posterolateral bundle reconstruction can add rotational stability to an existing graft that demonstrates adequate anterior stability. Finally, other issues that contribute to knee laxity must be sought out and addressed, including varus malalignment, high posterior tibial slope, additional ligamentous injuries, and meniscal deficiency.

Additionally, a surgeon must remember that, from a psychological standpoint, when imaging shows an intact graft, it can be difficult to convince a patient that revision surgery is necessary and that they will need to go through an extensive period of convalescence and rehabilitation all over again. It is, therefore, crucial to engage the patient as an active participant in decision-making, to recognize and acknowledge their goals and expectations, to explain in detail the issues that are contributing to their instability, and to ensure appropriate rehabilitation prior to any repeat surgical intervention.

Case 1

Patient is an 18-year-old collegiate volleyball player who presented 1 year after BTB autograft ACL reconstruction with a medial meniscus repair, complaining of knee pain, mechanical symptoms, and intermittent buckling. She completed a full course of rehabilitation, including a return-to-play protocol with her athletic trainer, and resumed training, but was unable to wean from the brace for athletic participation and did not feel ready to return to competition. Clinical examination demonstrated a normal gait, neutral lower extremity alignment, full range of motion with pain and clicking, tenderness over the medial joint line, and normal strength. Stability examination showed 1B Lachman and anterior drawer tests, while a pivot shift could not be properly assessed due to guarding. The PCL, collateral ligaments, and corners were stable. Imaging showed neutral alignment, good tunnel positions on X-rays (Fig. 6.1), and intact graft in a proper orientation, but with significant anterior tibial translation on MRI (Fig. 6.1b), indicating laxity. Considering these findings, ACL laxity and symptoms of instability were thought to be due to either insufficient initial graft tension (at the time of index surgery) or subsequent graft stretching.

Due to failure of conservative management and significant limitations on her athletic participation, patient was indicated for and elected to proceed with a revision ACL reconstruction. Exam under anesthesia confirmed isolated ACL laxity, with positive Lachman, anterior drawer, and pivot shift tests. Arthroscopy examination showed an intact graft that exhibited significant laxity to probing and anterior tibial translation (Fig. 6.2). Graft orientation and tunnel positions were confirmed to be acceptable. Revision to a quadrupled hamstring autograft was then performed. After the semitendinosus and gracilis tendons were harvested and whipstitched, they were pretensioned at 80–90N for 20–30 minutes. For graft placement, we were able to utilize the same tunnel positions, as the tunnels were well healed from previous BTB graft plugs (Fig. 6.2). The graft was secured to the femur with an adjustable button-loop device. The knee was cycled 20 times and placed into full extension, reverse Lachman force was applied to ensure reduction of the tibia posteriorly, and, while applying maximal manual force to the graft, an interference screw was placed into the tibial tunnel. The knee was cycled again, and the graft was re-tensioned from the femoral side. Excellent graft tension was observed on direct probing (Fig. 6.2) and on stability testing. To decrease the risk slippage, we also secured the distal graft sutures over a post and tied the tensioning sutures on the femoral side.

Patient recovered well, returning to full competition 1 year postoperatively. Her last clinical examination showed no more than 1A Lachman and anterior drawer and a negative pivot shift. She did not complain of any instability sensation or buckling.

Case 2

Patient is a 55-year-old active male who initially injured his knee playing softball and underwent an ACL reconstruction with allograft at an outside institution. He began having recurrent symptoms of instability shortly after weaning from the postoperative brace, and despite extensive rehabilitation, this did not improve. On exam, his gait was normal, and range of motion and strength were full; however, stability examination demonstrated a 2A Lachman, 1A anterior drawer, and a positive pivot shift with a glide. Imaging with plain radiographs (Fig. 6.3) and an MRI (Fig. 6.3b) demonstrated an intact graft in a vertical orientation, largely due to an excessively posterior tibial tunnel position. Due to the patient's persistent symptoms, evidence of instability on exam, and imaging findings of a vertically oriented graft, a decision was made to proceed with revision surgery. Given the patient's

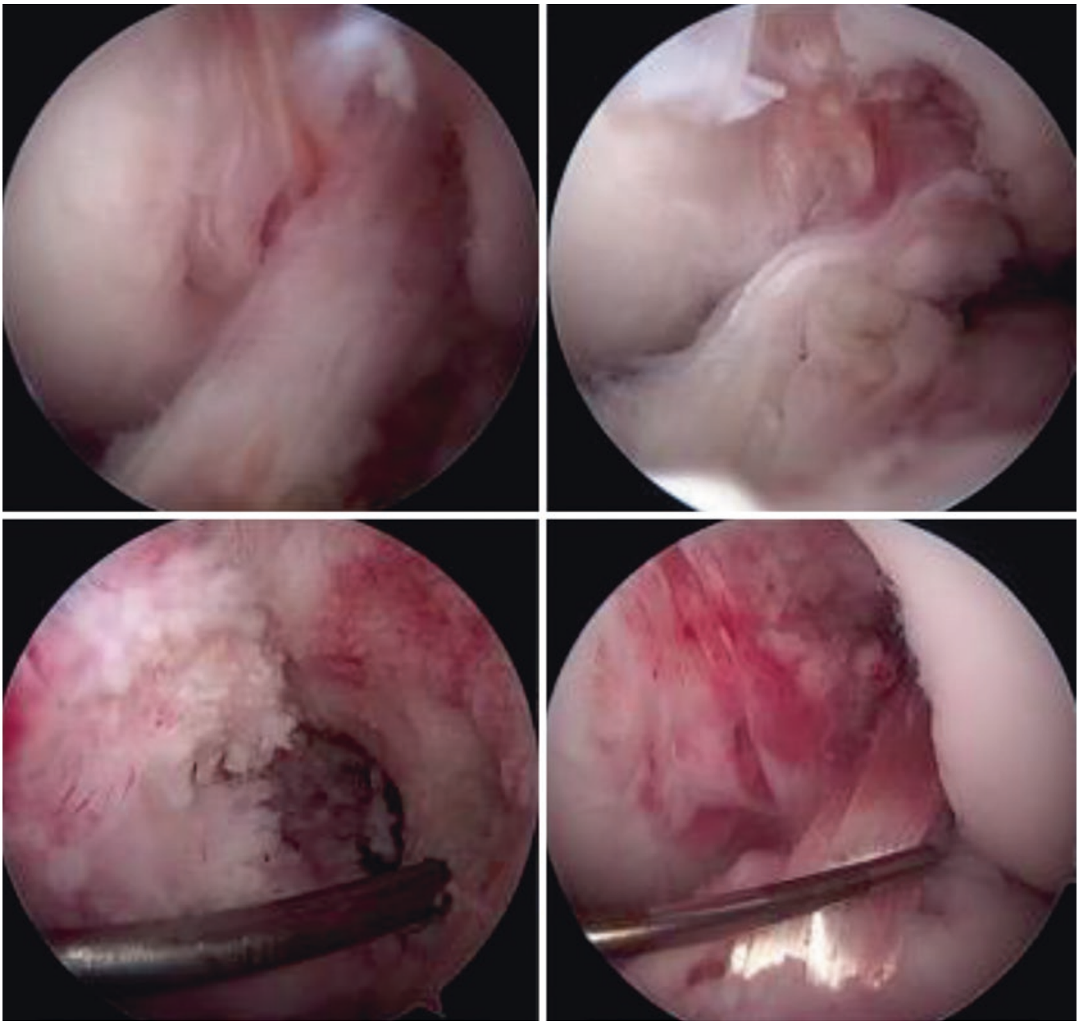

Fig. 6.2 Arthroscopic pictures show an intact graft with significant laxity. The femoral tunnel can be drilled "fresh," as the previous bone plug healed fully. The final graft demonstrated appropriate position and tension

age and activity level, an allograft was selected. Intraoperatively, the previous graft was resected, and completely separate tunnels were drilled (Fig. 6.4), allowing appropriate orientation of the new graft. Secure fixation was obtained on the femoral side with an adjustable button-loop construct, and on the tibial side with an interference screw in the tunnel, backed up by a staple over the distal tail of the graft. At his 1-year follow-up, the patient reported no instability and had a negative Lachman, anterior drawer, and pivot shift tests on exam, and imaging showed appropriate graft orientation and tunnel position (Fig. 6.5).

Fig. 6.3 (**a**) Plain radiographs suggest a vertical orientation of the graft, primarily due to a very posterior position of the tibial tunnel. (**b**) MRI confirms vertical orientation of the graft and shows that it is structurally intact

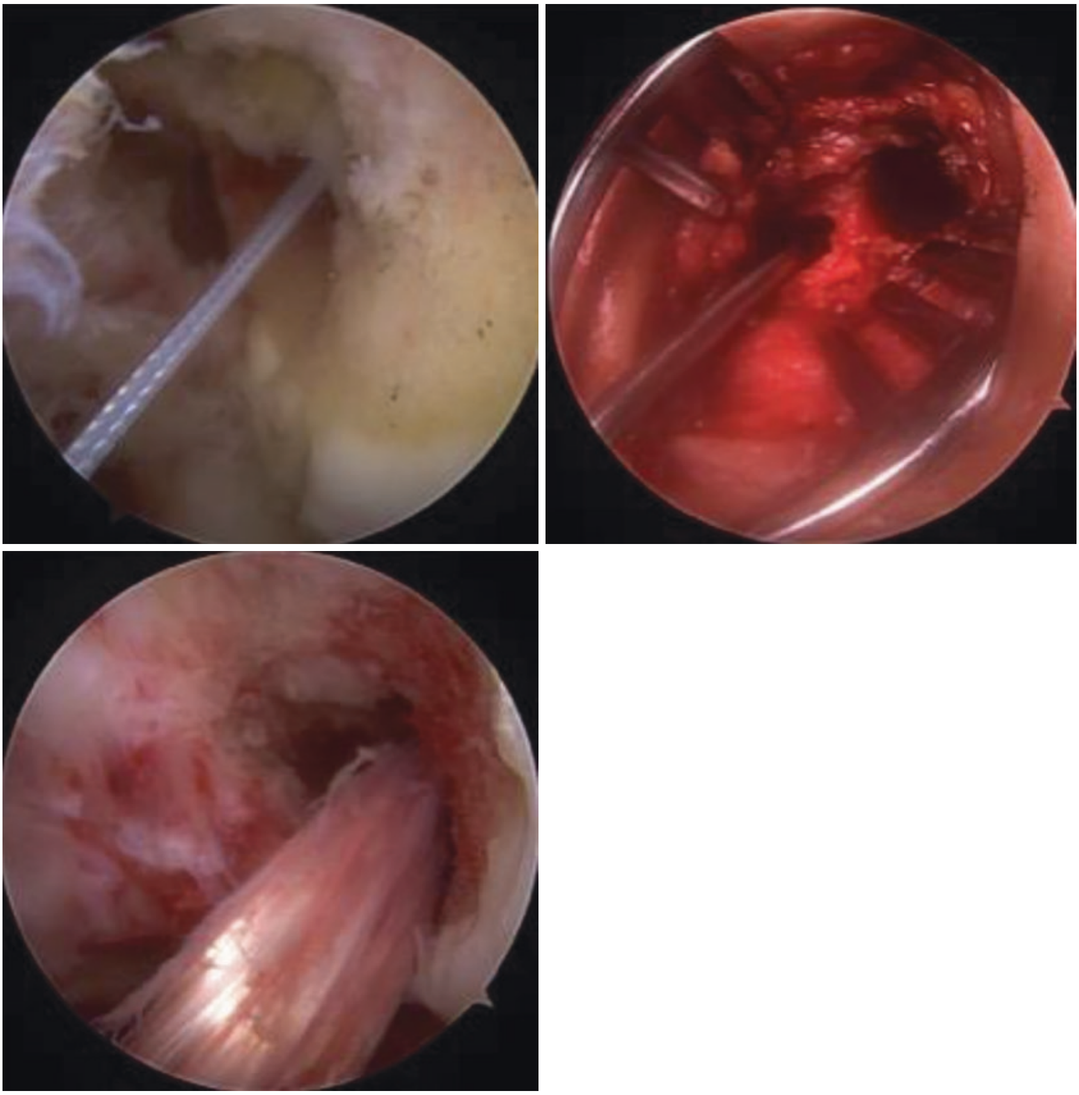

Fig. 6.4 Intraoperative arthroscopy pictures and photographs (left knee). Note the more posterior location of the new femoral tunnel, the more anterior location of the tibial tunnel (metallic suction tip is in the old tunnel), and the proper oblique orientation of the final graft

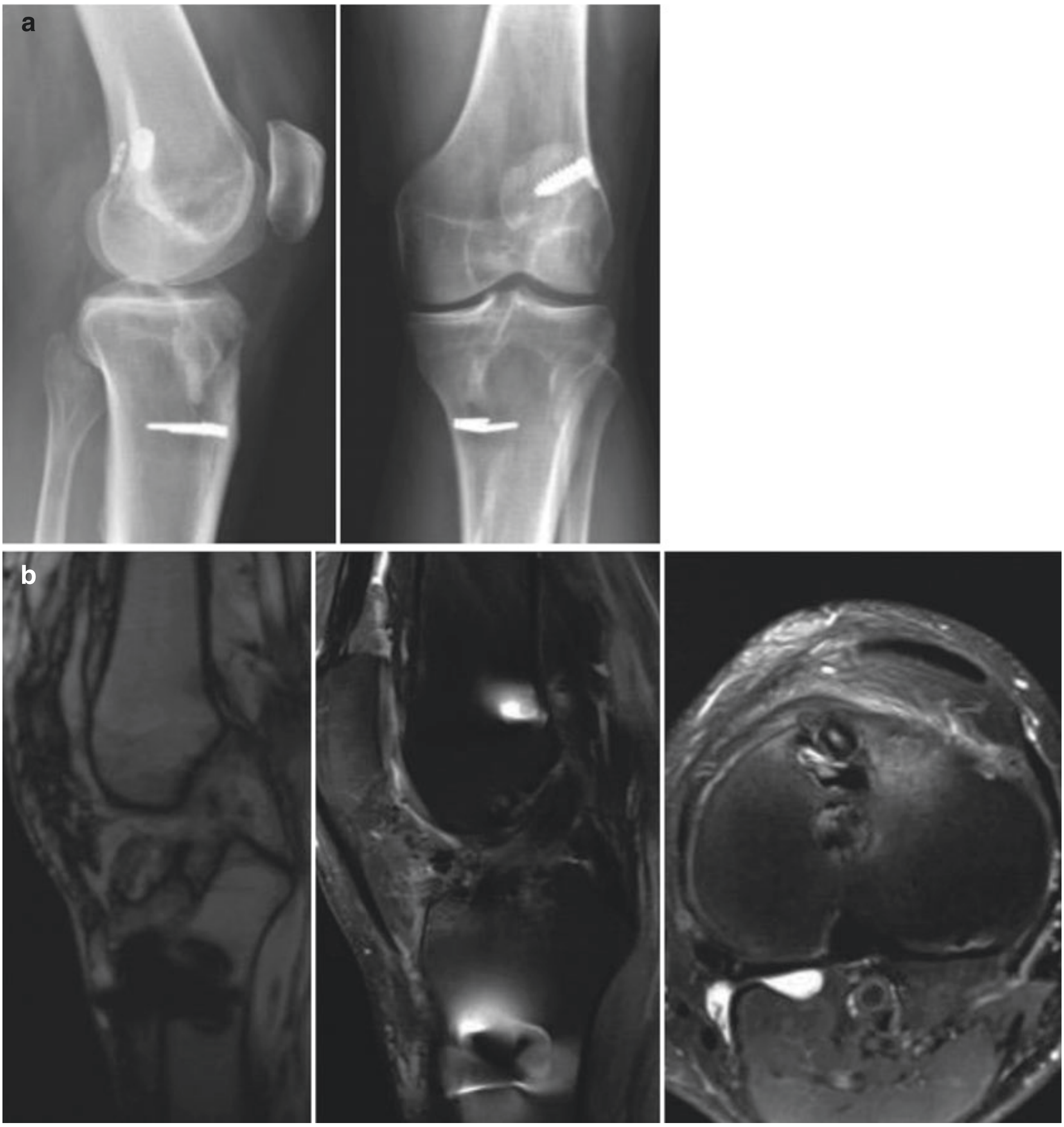

Fig. 6.5 (**a**) One-year postoperative X-rays show proper tunnel position. Note the anterior location of the new tibial tunnel, relative to the old one. (**b**) One-year postoperative MRI shows appropriate orientation of the graft and confirms absence of tunnel convergence

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