# 13 Coronal Malalignment and Revision Anterior Cruciate Ligament Reconstruction

Paul M. Incan and Matthew J. Matava

## Introduction

Reconstruction of the anterior cruciate ligament (ACL) is uniformly successful with long-term failure rates of approximately 10% (range, 2–26%) [1–3]. In general, the primary cause of failure can be due to either traumatic reinjury, biologic failure of graft incorporation, or surgical error. In some cases, a combination of these factors may be responsible. It has been widely assumed, based on expert opinion and case series, that the majority of failures can be attributed to either identifiable trauma or tunnel malposition [4, 5]. Osseous malalignment may also be a contributing cause of ACL reconstruction failure due to the tensile strain it places on the graft. This excessive tensile force may occur in the sagittal plane due to an elevated posterior tibial slope [6, 7]. As axial loading through the tibiofemoral joint occurs, vertical shear forces are converted to anteriorly directed tibial translation resulting in increased ACL strain.

Coronal plane malalignment is more commonly encountered in the revision setting and may be due to either congenital bilateral, or acquired unilateral, genu varum or valgum. This chapter will focus on coronal plane malalignment, which may be either a causative factor in primary ACL reconstruction failure or the end result of associated meniscal and/or chondral injury in these patients. In both cases, the unaddressed malalignment may compromise the revision reconstruction and exacerbate any preexisting cartilage damage. Surgical strategies must consider both the technical aspects of the revision reconstruction and the influence of a concurrent realignment procedure, which increases the complexity and risk for complications.

Individuals undergoing revision ACL reconstruction are significantly more likely to demonstrate varus malalignment than individuals undergoing primary reconstruction [8]. Noyes and Barber-Weston found that varus malalignment was a factor contributing to ACL reconstruction failure in 25% of their patients [9]. Varus malalignment has also been shown to predict the development of medial compartment osteoarthritis [10]. The status of the menisci and the alignment of the lower extremity are both likely to influence the prevalence of chondrosis in the medial and lateral tibiofemoral compartments at the time of revision reconstruction. Knees undergoing revision surgery have been shown to have more concomitant intra-articular injuries than knees undergoing primary reconstruction [11]. Ninety percent of knees undergoing revision ACL reconstruction have been found to have meniscal or chondral injury, and 57% had both [12]. Meniscal injury [13, 14] and the amount of

P. M. Incan · M. J. Matava (✉)
Department of Orthopaedic Surgery, Washington University School of Medicine, St. Louis, MO, USA


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meniscus removed at the time of prior surgery [15] have been shown to be associated with the subsequent development of arthrosis. Partial meniscectomies occurring prior to revision ACL reconstruction are associated with a higher rate of chondrosis at the time of revision surgery compared with previous meniscal repair or no prior meniscal surgery [16]. Therefore, progressive coronal plane malalignment may arise from the associated meniscal and/or chondral damage from the prior injury and surgery.

Alternatively, tibiofemoral degeneration may be the result of an unaddressed coronal malalignment at the time of the primary reconstruction [4]. Irrespective of etiology, clinical and radiographic assessment of coronal plane alignment is a necessary component of the evaluation and management of patients requiring revision ACL reconstruction in order to prevent failure of the revision graft and to relieve symptoms resulting from tibiofemoral degeneration [17].

## Coronal Plane Malalignment and Primary ACL Failure

The relationship between coronal malalignment and ACL graft failure must be understood from a biomechanical perspective. In the static knee, varus malalignment increases the tensile force on the ACL by up to 25% and is greatest with the knee in full extension [18]. This effect is exacerbated in patients with associated posterolateral ligamentous insufficiency [9]. Axial loading of the maligned knee during gait results in a dynamic varus force (increased adduction moment) [19], leading to cyclical lateral joint space diastasis [18]. This "varus thrust" results in increased tensile force transmitted to the ACL graft throughout the gait cycle, with ACL tension increasing linearly as the mechanical axis medializes [18, 20]. A pathologic condition is created that is functionally opposite of the mechanically neutral knee, which demonstrates joint space compression with axial load [18]. Furthermore, as the lateral soft tissues of the knee (i.e., the posterolateral corner [PLC], joint capsule, and iliotibial band) experience cyclical loading and resultant attenuation, lateral joint space separation may be accentuated resulting in even greater tension on the ACL throughout the gait cycle [21]. Therefore, varus malalignment results in both static and dynamic ACL graft strain, which may predispose the graft to either attritional or acute failure. Interestingly, the forces resulting from the elevated adduction moments associated with a varus thrust have not correlated with static alignment radiographs [19].

The spectrum between osseous malalignment and dynamic soft tissue attenuation is best conceptualized through the principle of the "primary," "double," and "triple varus" knee, as conceptualized by Noyes [21]. In the "primary varus" knee, the deformity is limited to the osseous alignment of the lower extremity [21]. Though such skeletal malalignment may be seen as an anatomic variant, the 30–40% rate of concurrent medial meniscal tears seen with ACL rupture [4, 22, 23] and resultant acceleration in chondral degeneration [24] may account for the relatively high rate of primary varus seen in patients undergoing revision ACL reconstruction [8]. With increasing osseous malalignment, the lateral soft tissues attenuate, as discussed above, allowing the lateral femoral condyle to separate ("lift-off") from the lateral tibial plateau during gait, resulting in the "double varus" knee. The quadriceps, biceps femoris, iliotibial band, and gastrocnemius muscles act dynamically to resist the adduction moment encountered during the gait cycle in an attempt to reduce the lateral condylar lift-off. If this dynamic restraint is insufficient, then lateral tibiofemoral separation ensues. Skeletal varus combined with insufficiency of the PLC [25] resulting in lateral tibiofemoral separation (dynamic varus) may be associated with recurvatum in extension resulting in the "triple varus" knee [21]. In these patients, varus recurvatum results in excessive external tibial rotation and hyperextension due to long-standing insufficiency of the PLC and often the ACL and/or posterior cruciate ligament (PCL). In these patients, both the ACL and PLC insufficiency must be corrected in addition to the osseous malalignment.

## Clinical Evaluation

The physical examination for the patient being evaluated for a revision ACL reconstruction has been thoroughly outlined in prior chapters. The comprehensive assessment of a patient with a failed ACL reconstruction begins with an inspection of standing alignment and gait. It is imperative that the patient's lower extremities are exposed during the examination. Simple observation of the patient standing upright with the feet comfortably apart can provide information as to the presence of unilateral or bilateral coronal plane malalignment. Unilateral malalignment is usually an acquired deformity, whereas bilateral malalignment is more likely a normal anatomic variant. Bilateral malalignment results in either a "bow-legged" (genu varum) or a "knock-kneed" posture (genu valgum). An assessment of gait can be performed in any office setting and is most commonly accomplished while the patient simply walks down a hallway.

The most common gait abnormality in these patients is a varus thrust, described previously, which consists of a visible increase in tibiofemoral varus during the weight-bearing phase of the gait cycle with return to neutral alignment during the late stance phase [26]. Varus recurvatum may also be noted in the sagittal plane as an indicator of advanced insufficiency of the PLC resulting in hyperextension and external tibial rotation seen in the "triple varus" knee. A valgus thrust is less common and usually encountered with chronic attenuation of the superficial medial collateral ligament (sMCL). It is an exacerbation or abrupt onset of valgus malalignment during the stance phase, with a return to a more neutral alignment during lift-off and the swing phase of gait. In theory, a valgus thrust increases the compressive load transmitted to the lateral tibiofemoral compartment, potentially contributing to lateral compartment osteoarthritis. A formal gait analysis is typically reserved for those patients with significant gait alterations or for those in whom formal attempts at correction have been unsuccessful. Any preexisting gait abnormality should be corrected prior to the revision surgery with a 6-week program of gait training under the guidance of an experienced physical therapist. Correction of a varus thrust can be addressed with maintenance of a toe-out position during the gait cycle while maintaining a shortened stride length with the knee in 5° of flexion on initial heel strike. Failure to correct any preexisting gait abnormality will place the revision ACL graft and posterolateral structures at risk.

It is important to emphasize that the physical examination in these patients should be comprehensive in order to diagnose all clinically relevant conditions that may affect the final outcome (Table 13.1). The patellofemoral joint should be evaluated as a potential source of pain and instability due to the combined effects of increased external tibial rotation and varus recurvatum. Medial compartment pain and crepitus with varus malalignment may indicate articular cartilage and/or meniscal damage or insufficiency. Lateral compartment pain is more commonly due to soft tissue tensile overload but may also result from articular cartilage and meniscal damage with valgus malalignment.

Knee range of motion and instability testing should be compared with the contralateral knee. The Lachman test is performed at 30° of knee flexion and is the most sensitive test to detect ACL insufficiency. The pivot shift test is most specific for ACL insufficiency and is recorded on a scale of 0–3, with a grade of 0 indicating no pivot shift; grade 1 represents a pivot glide; grade 2 is defined as a distinct "clunk" indicative of subluxation of the posterior aspect of the lateral tibial plateau over the lateral femoral condyle; and grade 3 is represented as gross impingement of the lateral tibial plateau against the lateral femoral condyle. The anterior drawer is also assessed but is the least sensitive or specific test for ACL insufficiency.

The PCL is evaluated with direct observation of posterior tibial subluxation with the knee at 90° of flexion ("sag sign") compared to the contralateral knee. The medial tibiofemoral step-off is palpated with the knee at 90° with a 1 cm step-off considered normal and lesser amounts indicative of progressive posterior tibial subluxation. The posterior drawer test is also performed at 90° of flexion to confirm (1) the status of the PCL and

**Table 13.1** Physical examination tests in the evaluation of patients with combined ACL insufficiency and coronal plane malalignment

| |
|---|
| Standing alignment |
| Gait assessment |
|   Varus thrust |
|   Varus recurvatum thrust |
| Active and passive range of motion |
| Patellofemoral examination |
|   Alignment |
|   Tracking |
|   Compression pain |
|   Crepitus |
| Anterior cruciate ligament |
|   Lachman exam at 30° |
|   Pivot shift |
|   Anterior drawer |
| Posterior cruciate ligament |
|   "Sag" sign |
|   Tibiofemoral step-off |
|   Posterior drawer |
|   Quadriceps active test |
| Varus stress |
|   Varus laxity at 30° *only* indicates isolated LCL injury |
|   Varus laxity at 0° and 30° indicates both LCL and ACL injury |
| Dial test |
|   >10° external rotation asymmetry at 30° only consistent with isolated PLC injury |
|   >10° external rotation asymmetry at 30°and 90° consistent with PLC and PCL injury |
| External rotation recurvatum |
|   Leg falls into external rotation and recurvatum when suspended by great toe in supine position |
|   More common with chronic, multi-ligament injuries (i.e., ACL/PCL and PLC) |
| Posterolateral drawer test |
|   Combined posterior drawer and external rotation force results in an increase in posterolateral tibial translation |
| Reverse pivot shift test |
|   External rotation and valgus force applied to tibia as the knee is extended from 90° with a palpable clunk as the lateral tibial plateau reduces past the lateral femoral condyle at 20° of flexion to a reduced position in full extension |

*ACL* anterior cruciate ligament, *LCL* lateral collateral ligament, *PLC* posterolateral corner

(2) that the tibia is not posteriorly subluxated indicating a partial or complete PCL tear which may give a false positive anterior drawer test. Posterior tibial translation is confirmed with the quadriceps active test in which the tibia translates anteriorly at 80° of flexion with active quadriceps.

Insufficiency of the lateral collateral ligament (LCL) is assessed by the application of varus stress at 0° and 30° of knee flexion. The quality of the endpoint and degree of lateral joint space opening (in millimeters) are compared to the contralateral normal knee. Patients with combined insufficiency of the ACL and LCL will have increased laxity at both 0° and 30° of knee flexion. It is important to distinguish true ligamentous laxity with varus stress from the false positive ("pseudolaxity") caused by loss of the lateral compartment articular cartilage. This can be avoided by initially applying a valgus and axial load. With pseudolaxity, the lateral joint opening noted with a varus stress returns the limb from a relative valgus alignment to a more neutral position and confirms the absence of true lateral ligamentous damage. The dial test is performed at both 30° and 90° of flexion with the patient prone or supine to indicate damage to the PLC. An asymmetric increase of 10° in the foot-thigh angle with the knee at 30° is indicative of isolated deficiency of the PLC, whereas a positive test at both 30° and 90° of flexion is indicative of combined injury to the PLC and PCL. The external rotation recurvatum test is positive for combined severe injury to the PLC and ACL when the knee falls into hyperextension and external tibial rotation while the lower limb is suspended from the great toe. The reverse pivot shift is indicated by a palpable reduction of the externally mal-rotated lateral tibial plateau across the lateral femoral condyle at 20° as the knee is extended from 90° to full extension.

An increase in medial joint space opening is also assessed at both 0° and 30° of flexion to identify associated damage to the sMCL in patients with valgus malalignment. The quality of the endpoint and degree of joint space opening (in millimeters) are determined and compared to the contralateral normal knee. Similar to assessing the lateral soft tissues, a false positive result may occur from "pseudolaxity" attributed to medial compartment narrowing associated with articular cartilage loss. This can be avoided by conducting the exam first with a varus and axial load applied. With pseudolaxity, the medial joint opening noted with a valgus stress returns the limb from a relative varus alignment to a more neutral position and confirms the absence of true medial ligamentous damage.

## Radiographic Evaluation

### Plain Radiographs

Initial radiographic evaluation of the knee should include an anteroposterior (AP), 30° lateral, patellofemoral (Merchant), and 45° flexion-weight-bearing posteroanterior (Rosenberg) [27] views. The lateral radiograph requires reasonable superimposition of the femoral condyles as alterations in patellar "height" may occur with high tibial osteotomy (HTO) [28]; therefore, presence of preexisting patella alta or baja must be appreciated. For this purpose, the Blackburn-Peel and Caton-Deschamps ratios produce the most reliable means of quantifying patellar height both preoperatively and following surgical intervention [29]. Additionally, elevated posterior tibial slope (>12°) should also be noted on the lateral radiograph because of the potentially deleterious effects it has on the ACL graft [30] discussed previously that may be corrected concurrently with coronal plane realignment [31]. An AP view with the knee in full extension may not show significant joint space narrowing since most condylar wear is present between 30° and 60° of knee flexion which is best identified with the 45° flexion, weight-bearing view (Fig. 13.1). Excessive medial or lateral compartment joint space narrowing greater than 50% of the articular cartilage thickness represents a relative contraindication to an osteotomy, as the articular degeneration is likely too great to be relieved solely by a realignment procedure [8].

Comprehensive radiographs can provide relevant information regarding the presence of hardware from prior surgery as well as femoral and tibial tunnel placement and their dimensions. Bone tunnel widening is theorized to be due to a complex interplay between biologic factors (i.e., synovial fluid-derived cytokines, inflammatory mediators, thermal necrosis) and mechanical stress (i.e., graft motion ["bungee cord" effect], non-aperture fixation, graft tension) [32–34]. Seen most commonly with the use of allograft tissues [34] and soft tissue grafts, tunnel expansion does not appear to be the cause of ACL graft failure but may affect the technical aspects of the revision reconstruction (Fig. 13.2).

Full-length standing AP radiographs from the hips to the ankles with the feet 10″ apart should also be performed on all patients considered for revision ACL reconstruction [17]. Though some surgeons may prefer standing single-leg or supine full-length radiographs [35], we prefer bilateral whole-limb radiographs for the evaluation of limb alignment (Fig. 13.3). Subtle positional changes of the extremity can significantly alter the mechanical axis measurements [36]. Therefore, reference foot templates on the radiograph platform and centering the patella over the femoral condyles may be necessary to ensure reproducible radiographs [8, 17].

The mechanical axis of the lower extremity is defined by a line connecting the center of the femoral head to the middle of the tibial plafond. In individuals with a neutral mechanical axis, this line should intersect the mid-line of the tibial plateau between the tibial spines [37]. Coronal plane deformity may be quantified as a percentage of tibial width where the mechanical axis intersects the tibia plateau. By convention, 0% indicates the medial tibial cortex, and 100% represents the lateral tibial cortex [38]. The mechanical axis of the femur is represented by a line connecting the center of the femoral head and the intercondylar notch. The mechanical axis of the tibia is represented by a line connecting the center of the tibial plafond and bisecting the tibial plateau (Fig. 13.4). These axis lines intersect to form the mechanical tibiofemoral angle, which normally forms essentially a straight line as the normal angle has been shown to be $-0.7 \pm 3°$ [37]. Increasing varus or valgus deformity, defined as the apex of the deformity at the tibiofemoral joint, results in an increase or decrease of this angle, respectively. As discussed below, the tibio-

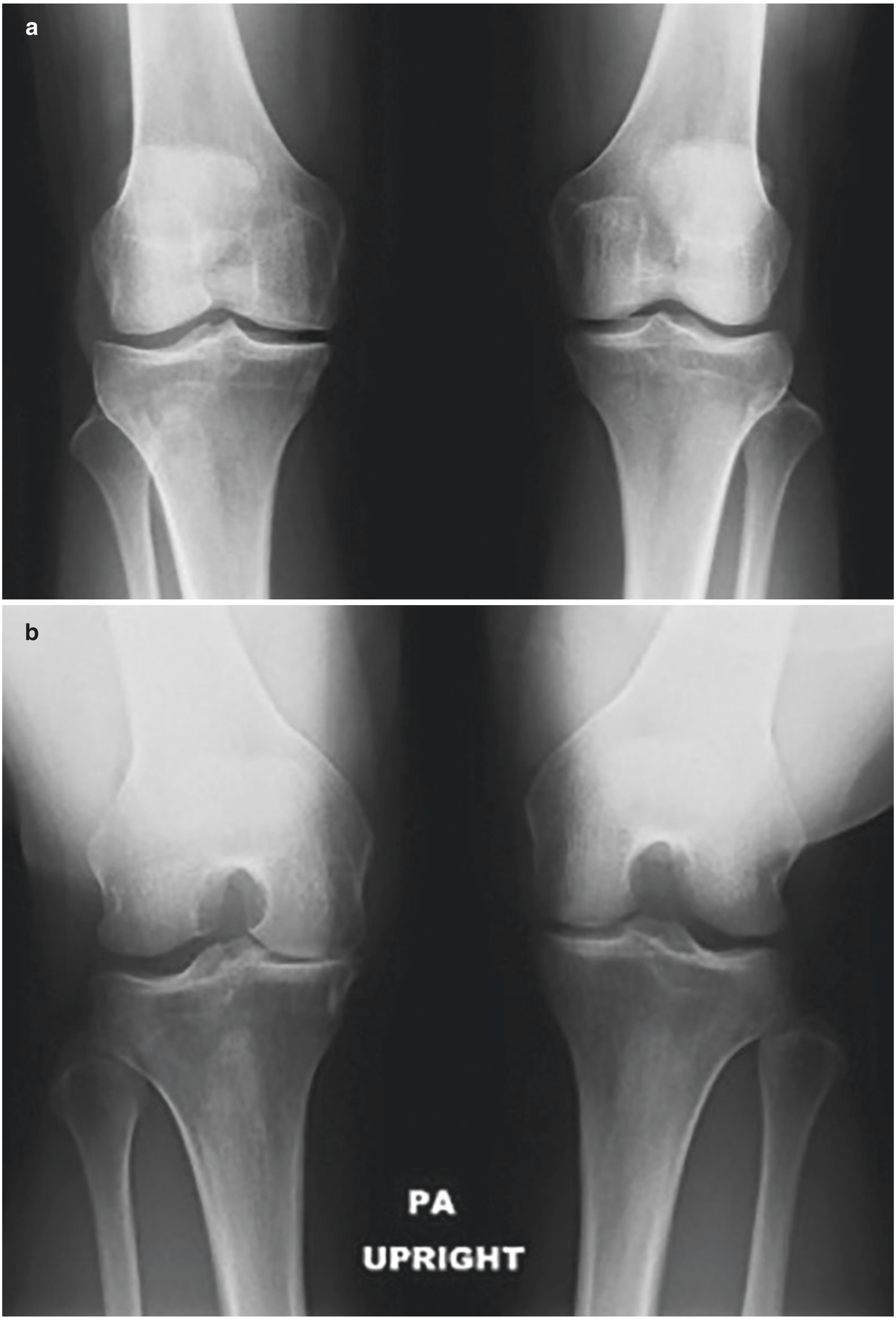


**Fig. 13.1** Radiographs showing the importance of the flexion weight-bearing view in the same patient. (**a**) AP weight-bearing view showing maintenance of joint space. (**b**) 40° PA weight-bearing view illustrating loss of medial joint space of the right knee

**Fig. 13.2** AP radiograph showing femoral and tibial tunnel expansion often seen in patients undergoing revision ACL reconstruction

femoral angle becomes vital for preoperative templating for deformity correction.

A joint convergence angle may be quantified by comparing a line across the femoral condyles and a line across the tibial plateau. In patients with a neutral mechanical axis, such lines should be grossly parallel, and 0–3° of medial convergence is considered normal [37]. In the "double" and "triple varus" knee, attenuation of the posterolateral soft tissues yields asymmetric lateral joint space diastasis increasing the medial convergence angle. As demonstrated in prior biomechanical studies [18, 19], this joint space diastasis is dynamic; thus, varus stress radiographs may be required to more accurately quantify the contribution of lateral condylar lift-off to a patient's varus deformity.

**Fig. 13.3** Full-length standing AP radiographs from the hips to the ankles used to assess lower extremity alignment

## Magnetic Resonance Imaging

In addition to a complete radiographic assessment of the knee, magnetic resonance imaging (MRI) is obtained to provide relevant information regarding ACL status, associated ligamentous deficiencies, and meniscal and articular cartilage damage. Ferromagnetic implants will interfere with the quality and accuracy of MR images. To reduce MR artifact from metal instrumentation, use of a smaller field strength magnet (1.5T rather than 3.0T) is recommended as artifact is directly proportional to field strength. Inversion recovery/STIR (short tau inversion recovery) sequences are less prone to metal artifact, whereas normal frequency-selective fat suppression sequences and gradient echo sequences should be avoided as they are more prone to metal artifact.

**Fig. 13.4** The mechanical axis of the femur (solid white line) is represented by a line connecting the center of the femoral head and the intercondylar notch. The mechanical axis of the tibia (dashed white line) is represented by a line connecting the center of the tibial plafond and bisecting the tibial plateau

While some ACL grafts may be partially intact, they can be functionally incompetent if attenuated or misplaced. The location and diameter of prior bone tunnels in the sagittal and coronal planes must be considered prior to a revision reconstruction. For instance, a non-dilated tunnel placed too vertically in the intercondylar notch may lead to functional ACL instability despite the graft being intact on MRI (Fig. 13.5). In this case, the patient may demonstrate a positive pivot shift but have a normal Lachman examination. Alternatively, well-placed tibial and femoral tunnels created at the prior surgery may be excessively dilated (≥13 mm in diameter) necessitating a staged bone grafting prior to the revision surgery (Fig. 13.6).

**Fig. 13.5** Coronal T1-weighted MRI showing vertical femoral tunnel with hardware in place

**Fig. 13.6** Coronal T1-weighted MRI showing femoral and tibial tunnel expansion

Magnetic resonance imaging will detect both new and previously treated meniscal and articular cartilage pathology in the revision setting [4]. Advanced degenerative articular cartilage wear must be distinguished from contained focal defects. The former may be a contraindication to an osteotomy, while the latter may be corrected by an articular cartilage reconstructive procedure depending on the size, depth, and location of the defect. Meniscal irregularity from prior meniscectomy may be indistinguishable from a new tear on MRI. Significant meniscal resection that is symptomatic may indicate the need for concurrent meniscal allograft transplantation given the chondroprotective effect the meniscus has on the articular cartilage as well as its role as a secondary stabilizer to anterior tibial translation and rotational stability [39, 40]. A gadolinium-enhanced MRI arthrogram is reserved for those patients who have undergone a prior meniscal repair in which a recurrent tear cannot be distinguished from the scar tissue from a healed tear.

## Computerized Tomography

Computerized tomographic (CT) imaging has a limited role in the preoperative evaluation of patients being considered for a revision ACL reconstruction and realignment procedure given its limited utility and radiation exposure. However, in those patients with tunnel widening that requires more detailed three-dimensional imaging to quantify tunnel size, CT is the imaging modality of choice (Fig. 13.7). It is also useful in patients who undergo a staged bone grafting of a dilated tunnel, as it is more sensitive than plain radiographs or MRI to graft consolidation (Fig. 13.8). A CT arthrogram may also be useful in the rare patient in whom an MRI is precluded because of metallic implants elsewhere in the body that may be affected by the magnetic field. While its sensitivity is inferior to MRI, a CT arthrogram can provide general information about meniscal and articular cartilage status.

**Fig. 13.7** Coronal CT image showing femoral and tibial tunnel expansion

**Fig. 13.8** Sagittal CT image showing consolidation of bone graft used to fill expanded tunnels prior to revision ACL reconstruction

## Operative Indications and Contraindications

### Indications

A combined revision ACL reconstruction and osteotomy is indicated for those younger (less than 60 years of age), active patients with instability symptoms coupled with coronal plane malalignment. Osteotomy initially gained wide acceptance for active patients with uni-compartmental osteoarthritis in whom a knee replacement (partial or total) is contraindicated because of their relatively young age.

Varus malalignment is corrected with a proximal ("high") tibial osteotomy (HTO); valgus malalignment is corrected with a distal femoral osteotomy (DFO). An HTO is also recommended for those patients with ACL insufficiency and associated physiologic genu varum in whom the malalignment would put undue tensile strain on the revision ACL graft. Patients considered for this combined procedure should have a history of functional instability with pivoting activities, a physical examination consistent with ACL insufficiency, and corresponding imaging studies confirming this diagnosis. The goal of the osteotomy in those patients with uni-compartmental osteoarthritis is to correct the mechanical abnormality by redistributing weight-bearing loads away from the involved arthritic compartment. Patients with varus malalignment are over-corrected into valgus. Patients with valgus malalignment are corrected only to a neutral mechanical axis as iatrogenic creation of genu varum would potentially strain the graft and increase compressive loads to the medial compartment. Patients undergoing revision ACL reconstruction who have the anatomic variant of bilateral varus or valgus alignment but no articular cartilage damage should also be corrected to neutral and not over-corrected to either compartment. Ideally, an osteotomy should only be performed in those patients with symptomatic mild-to-moderate osteoarthritis. Those with associated meniscal deficiency and/or focal uni-compartmental chondral defects can be treated either concurrently with the osteotomy and ACL reconstruction or in a staged fashion depending on the complexity of the procedure and comfort level of the surgeon.

### Contraindications

The main contraindication to a combined revision ACL reconstruction and an HTO or DFO is advanced cartilage loss of the medial or lateral tibiofemoral compartments, respectively. In general, the majority of the compartment should have articular cartilage coverage. An uncorrected full-thickness cartilage defect of the tibia or femur greater than 15 mm ×15 mm is a contraindication to an osteotomy and is better addressed with a uni-compartmental arthroplasty and revision ACL reconstruction except in those patients too young (<50 years of age) or active for this procedure. Complete loss of medial or lateral joint space on 45° flexion, weight-bearing radiographs is also a contraindication. Other contraindications are cavitary defects of the medial or lateral tibial plateau, loss of flexion or extension >10°, tibial subluxation, and uncorrected complete or near-complete meniscectomy in the involved compartment.

Patients over the age of 60 who are candidates for a partial or total knee replacement are better served with this more definitive procedure. Patients with a body mass index (BMI) over 35 will likely not be symptomatically improved if they have arthritic symptoms in addition to instability. Concurrent patellofemoral arthritis is a relative contraindication to this procedure. Severe patellofemoral symptoms will not be improved following an HTO or DFO, while mild symptoms are not a contraindication to this procedure. Asymptomatic patellofemoral articular cartilage damage is not a contraindication despite the fact that these patients may develop patellofemoral symptoms over time. Medical contraindications to an osteotomy include inflammatory arthropathies that cause diffuse cartilage wear of all three knee compartments, diabetes mellitus, and malnutrition.

Non-compliance with rehabilitation restrictions and use of nicotine products are also contraindications. Nicotine use in the setting of an opening wedge tibial or femoral osteotomy (discussed below) is a significant risk factor for delayed union and nonunion because of the open void created that must fill with bone. An opening wedge HTO requires an incision on the medial aspect of the tibial plateau where there is limited subcutaneous soft tissue causing an elevated risk for wound healing complications in the setting of nicotine use or other factors that may interfere with wound healing. Cessation of smoking for at least 8 weeks is strongly recommended prior to an osteotomy and can be checked by serum or urine cotinine levels – a nicotine metabolite.

## Correction of Varus Malalignment and ACL Insufficiency

### Preoperative Considerations

Correction of varus malalignment is most readily accomplished with an HTO as most varus deformities are due to proximal tibia vara. This procedure has evolved over the past four decades, but at the present time, the two most common procedures involve either a medial opening wedge or a lateral closing wedge. Historically, the lateral closing wedge osteotomy was the predominant method despite the fact that it possesses several technical challenges that may compromise the final outcome. As a result, there has been increased interest in the medial opening wedge over the past several years for a variety of reasons independent of concurrent ACL revision surgery. Advantages of an opening wedge HTO include:

- Only a single bone cut is required.
- Less soft tissue disruption.
- No disruption of the proximal tibiofibular joint or fibular osteotomy is required.
- No risk to the peroneal nerve.
- The correction can be fine-tuned intraoperatively to achieve optimal alignment.
- Patellar height is maintained.
- Ideal if a PLC reconstruction is required by avoidance of fibular disruption.
- Preexisting patella alta may be corrected.

A medial opening wedge osteotomy is not without issues. Potential disadvantages of this technique in the setting of a revision ACL reconstruction include:

- Potential need for cortico-cancellous autograft or allograft
- Higher risk of delayed union/nonunion due to the need for increased bone consolidation
- Risk for fracture propagation with loss of the lateral cortical hinge or intra-articular extension into the lateral compartment
- Tendency to increase posterior tibial slope
- Exacerbation of preexisting patella baja
- Theoretical increased risk of wound complications in patients with compromised healing (i.e., smokers, diabetics)
- Delayed weight-bearing required during bone consolidation

### Timing Issues

Consideration has to be given for patients with combined ligament deficiencies and malalignment such as the double varus and triple varus knee in which the HTO must be coupled with a revision ACL reconstruction and lateral ligamentous reconstructions. In patients with the double varus knee, the osteotomy and revision ACL reconstruction can be performed at one time depending on the experience and comfort level of the surgeon. Correction of the varus malalignment often causes a contracture of the lateral soft tissue structures once the weight-bearing tensile load is reduced by placing the mechanical axis in a position of relative valgus [21]. This would make reconstruction of the lateral ligamentous restraints unnecessary in patients with only moderate lateral ligamentous deficiencies (i.e., 6–8 mm of lateral joint space opening with varus stress). However, a lateral compartment gap greater than 10 mm with varus stress during arthroscopy would preclude a single-stage procedure as the residual lateral ligamentous deficiencies would place undue tensile strain on the ACL graft. Patients with the triple varus variant have a complex problem that is best treated in a staged fashion since a single-stage HTO and revision ACL and PLC reconstruction pose significant complications (i.e., arthrofibrosis, loss of fixation). In these patients, the HTO is performed first, and the revision ACL reconstruction and PLC can be addressed later once the osteotomy has healed.

## Hardware and Tunnel Issues

As a general rule, preparation of the ACL revision graft should be deferred until after the removal of all potentially problematic hardware and it is confirmed that there is adequate bone stock available to drill the revision tunnels. It is imperative that all equipment needed for potential hardware removal is available prior to surgery. Most metallic interference screws can be removed with a large fragment (3.5 mm) screwdriver. Stripped screws may require reverse-threaded screw removal instrumentation for removal. Alternatively, these screws can be removed with a coring reamer 1–2 mm larger in diameter than the screw (Fig. 13.9). Bioabsorbable screws can potentially be left in place or drilled through during the revision procedure and the osteotomy. Non-aperture cortical fixation devices typically do not interfere with the revision graft or the osteotomy and can be left alone.

The index bone tunnels will be either anatomic and in the appropriate location, completely non-anatomic without contacting the new tunnel, or overlapping with the new tunnel potentially creating a "snowman" tunnel. Fixation hardware will likely require removal if located in an anatomic location or in an overlapping tunnel since it will interfere with drilling and placement of the revision hardware. Screws or other hardware located in femoral tunnels that are completely non-anatomic can be left in place in order to avoid a cavitary defect that may compromise fixation of the revision graft or require bone grafting (Fig. 13.10).

**Fig. 13.10** Lateral x-ray showing misplaced femoral screw from primary reconstruction (black arrow) left in place as it did not interfere with placement of the revision screw (white arrow)

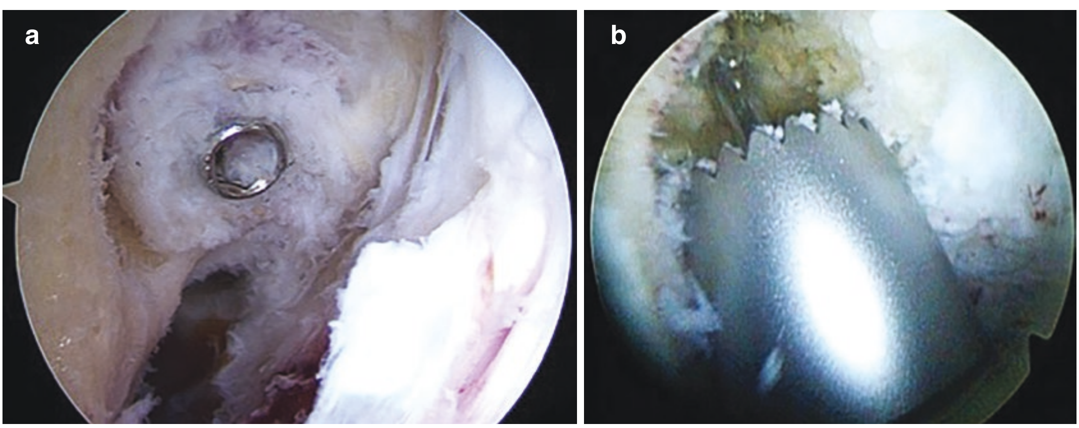


**Fig. 13.9** (**a**) Retained femoral hardware. (**b**) Coring reamer used to remove stripped femoral screw

All metallic tibial hardware should be removed even if grossly non-anatomic as it will likely interfere with the tibial osteotomy or the revision graft and their associated fixation.

Once all hardware is removed, the index femoral and tibial tunnels should be assessed for their potential interference with the revision tunnels. A combination of shavers, burrs, curettes, and thermal ablation is used to remove all soft tissue remnants from the femoral notch and tibial plateau in order to adequately assess the quality of bone stock present. Tunnels that were anatomically appropriate without evidence of expansion on preoperative imaging can be reliably used for the revision tunnel. In general, our preference is to create a revision tunnel that is 1 mm in diameter larger than the prior tunnel in order to remove all sclerotic bone and achieve a viable cancellous surface (Fig. 13.11). Compaction drills can be useful to avoid bone loss and strengthen the surrounding bone to support interference fixation. Femoral tunnels that are ≤12 mm that result from overlapping tunnels can be filled with a larger bone plug from either a bone-patellar tendon-bone (B-PT-B) graft, quadriceps tendon-patellar bone (QT-B) graft, or Achilles allograft. Supplemental allograft chips or cortico-cancellous strips can also be placed adjacent to the bone plug, as can "stacked" interference screws to fill the bone void. Tibial tunnels that are ≤12 mm can also be bone grafted after the osteotomy is complete and before the ACL graft is secured. Interference screw fixation may be feasible in these cases depending on the type of HTO performed (opening wedge vs. closing wedge). However, an opening wedge HTO often requires suspensory cortical fixation with a screw and washer because of the presence of hardware from the HTO.

Tunnels that are ≥13 mm in diameter in any plane on preoperative imaging usually require a staged bone graft, especially if there is widening of the tunnel aperture (usually femoral) or "ballooning" of the tunnel. In these cases, reliable fixation cannot be achieved with either interference screws or suspensory cortical devices because of the potential "windshield wiper" effect of graft motion within the tunnel (Fig. 13.12). The tunnel surface is abraded back to bleeding bone and grafted with either allograft dowels, cancellous allograft chips, or iliac crest

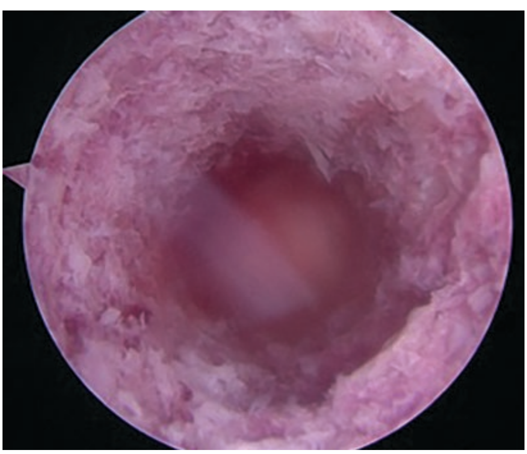

**Fig. 13.11** Arthroscopic view of tibial tunnel showing circumferential cancellous bone

**Fig. 13.12** Dilated, vertical femoral, and tibial tunnels greater than 13 mm in diameter may benefit from a staged bone graft prior to the revision ACL reconstruction

cortico-cancellous bone. An allograft dowel will provide structural support and can be inserted either through the anteromedial portal for the femoral side or directly through a metaphyseal window on the tibial side. Cancellous allograft chips can be inserted through a cut-off syringe or arthroscopy cannula with the graft impacted with a plunger or bone tamp. Demineralized bone matrix with reverse phase medium (StimuBlast®, Arthrex Inc., Naples, FL) can be added to the cancellous chips to resist fluid irrigation and displacement of the graft (Fig. 13.13). Tunnels that

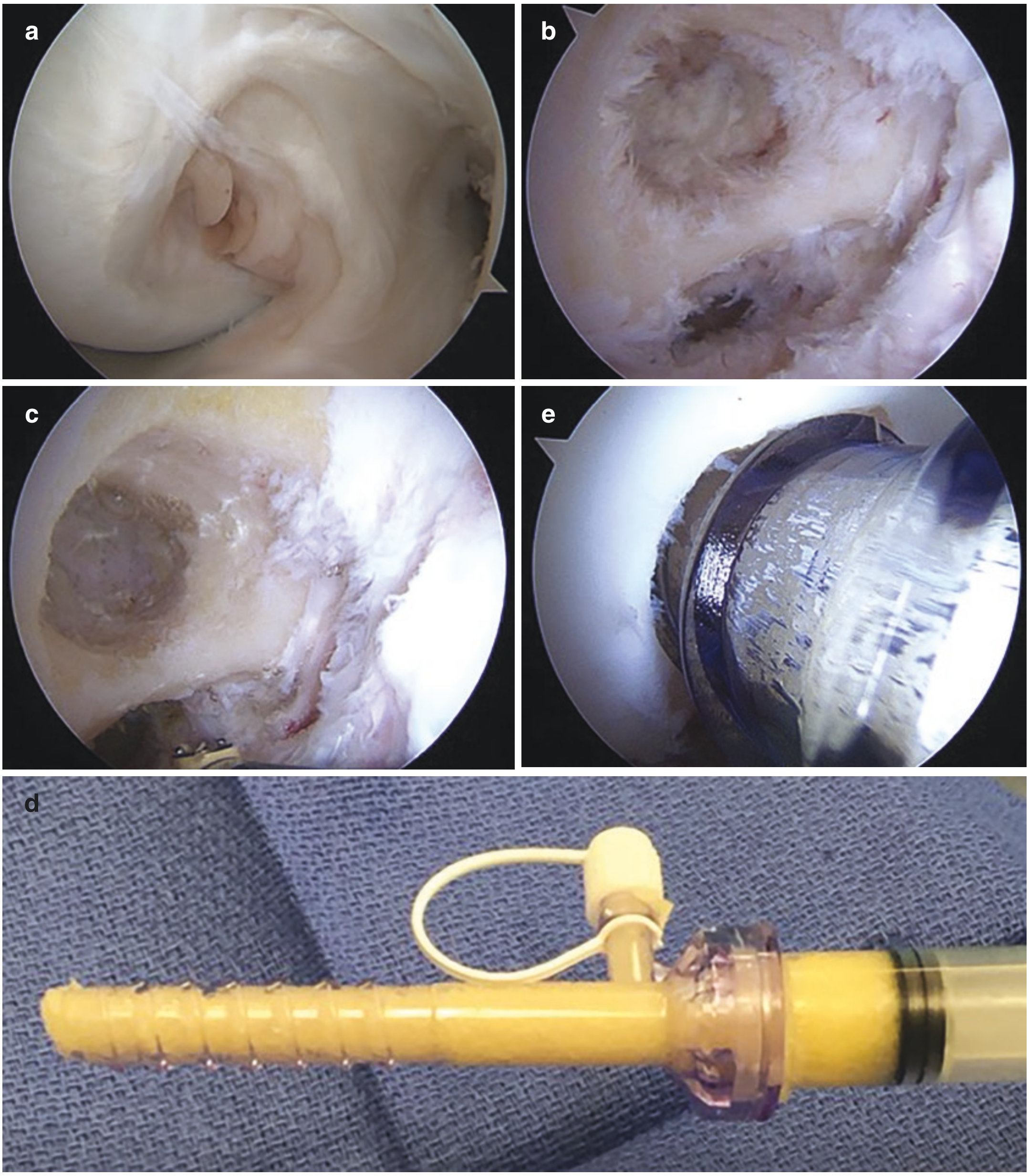

**Fig. 13.13** Staged grafting of femoral and tibial tunnels. (**a**) Non-functional ACL graft. (**b**) Tunnel with residual graft and fibrous tissue debrided (**c**) Dilated femoral tunnel following complete graft removal. (**d**) Syringe with StimuBlast® demineralized bone matrix (Arthrex Inc., Naples, FL) and cancellous allograft chips placed inside arthroscopy cannula for ease of insertion. (**e**) Injection of StimuBlast and cancellous chips into femoral tunnel. (**f**) Dilated femoral tunnel filled with StimuBlast/allograft bone. (**g**) Tibial tunnel being filled similar to femoral tunnel. (**h**) Filled tibial tunnel. (**i**) Revision femoral tunnel drilled 5 months following grafting

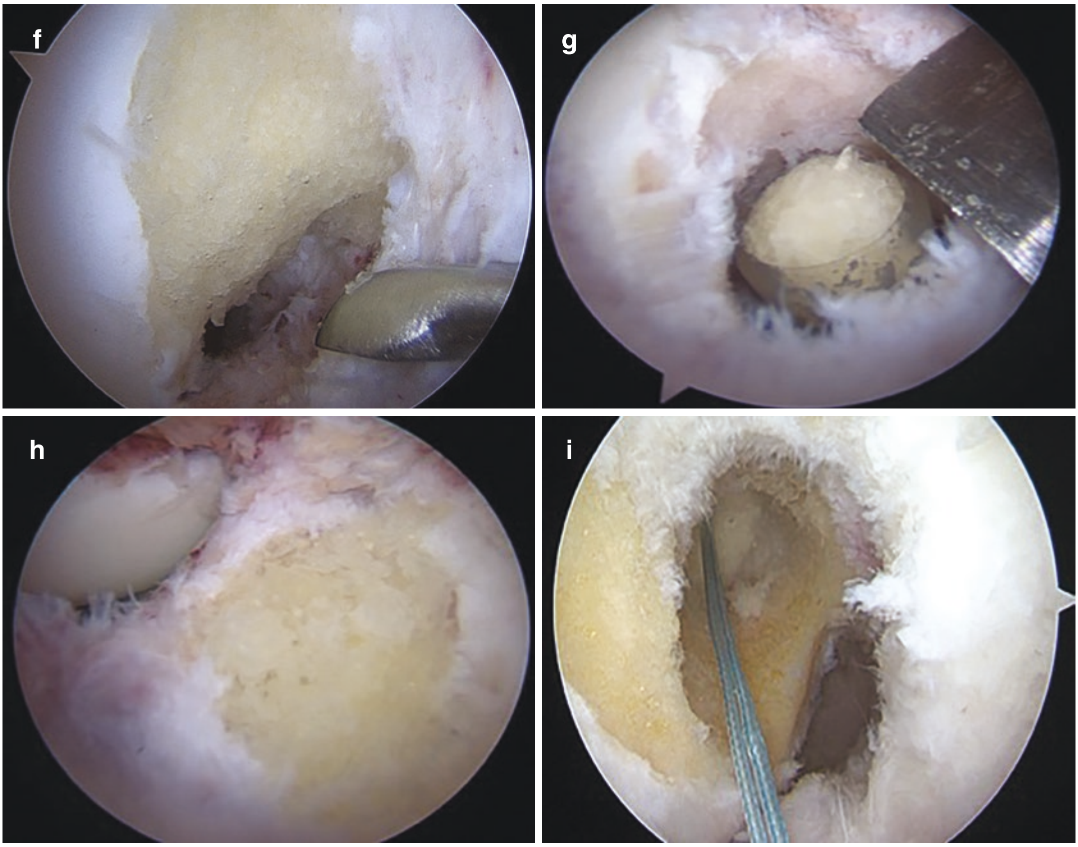


**Fig. 13.13** (continued)

undergo a staged bone grafting are usually consolidated by 4–6 months as determined by plain radiographs or CT imaging (Fig. 13.14).

## Graft Issues

It is imperative that the operative record from any prior ACL surgery is available since patients are often uncertain when asked about prior grafts. The choice of the revision graft is dependent on several factors. Prior graft harvest must be taken into consideration when choosing a revision graft in order to avoid wound healing complications associated with prior incisions that are closely parallel or that may cross any new incisions. Activity level is the most important factor when considering a primary ACL graft but may be less relevant in the setting of a concurrent osteotomy where decreased activity level is anticipated. Cosmesis, though a consideration, is the least important factor when choosing a revision graft.

Surgical options include the ipsilateral B-PT-B or quadriceps tendon autograft (with or without patellar bone plug) if the extensor mechanism is intact after the primary ACL reconstruction. A B-PT-B graft is not recommended if an HTO is also performed given the compromised tibial attachment of the remaining patellar tendon at the site of the osteotomy. If the B-PT-B or quadriceps tendon graft has already been harvested, re-harvest of these grafts is not recommended as they will be comprised predominantly of scar tissue rather than native tendon. An ipsilateral hamstring autograft, with or without a supplemental soft tissue allograft, can be considered in these patients and has the advantage of not being susceptible to graft-tunnel mismatch or requiring

**Fig. 13.14** Coronal CT scan showing consolidated tibial tunnel following bone grafting

interference fixation. Caution should be exercised in using a soft tissue graft if there is any evidence of tunnel widening since fixation and graft incorporation may be compromised. A contralateral B-PT-B or quadriceps tendon graft can also be used in the revision setting since prior skin incisions are not a factor and use of allograft tissues is avoided. Some patients are hesitant to consider surgery on the contralateral limb and would prefer to use an allograft. If an allograft is chosen, our preference is to use an Achilles tendon allograft since it is a robust graft that allows bone-to-bone healing and can accommodate a bone tunnel of any size. Patients who opt for an allograft should be apprised of the potential decreased success rate, risk for disease transmission, delayed incorporation, inflammatory immune response, and expense associated with allograft tissues [41].

## Preoperative Planning

Preoperative planning for an HTO is achieved first by the calculation of the mechanical axis from full-length radiographs from the center of the femoral head to the center of the tibial plafond. In patients with varus malalignment, the mechanical axis passes medial to the medial tibial spine. The goal of an HTO is to move this weight-bearing line into the lateral compartment to unload the compromised medial compartment and to reduce tensile strain of the ACL graft and lateral soft tissues.

The Picture Archiving and Communication System (PACS) software can be very helpful in calculating the degree and amount of correction. A line is drawn across the widest portion of the proximal tibia with the medial cortex representing 0% and the lateral cortex 100% of this distance. The preferred location of the realigned mechanical axis is a point 62% of the width of the tibial plateau from medial to lateral, which equates to 3°–5° of mechanical valgus. This point, commonly referred to as the Fujisawa point [42], is half-way between a neutral mechanical axis (50%) and a point 75% across the tibial plateau in which nearly all weight-bearing forces are concentrated solely on the lateral compartment. One line representing the femoral weight-bearing line is drawn from the center of the femoral head to the 62% point, and a second line representing the tibial weight-bearing line is drawn from the center of the talus to this same point [43]. The angle formed by these two lines represents the angle of correction to achieve the desired mechanical axis (Fig. 13.15). If there is excessive lateral ligamentous laxity increasing the degree of varus alignment, the difference in the congruence angle formed by a line parallel to the tibial plateau and a second line along the condylar articular surface is subtracted from this correction angle.

The angle of correction is converted into millimeters of “opening” of the osteotomy by drawing a line across the tibia representing the anticipated site, angle, and length of the osteot-

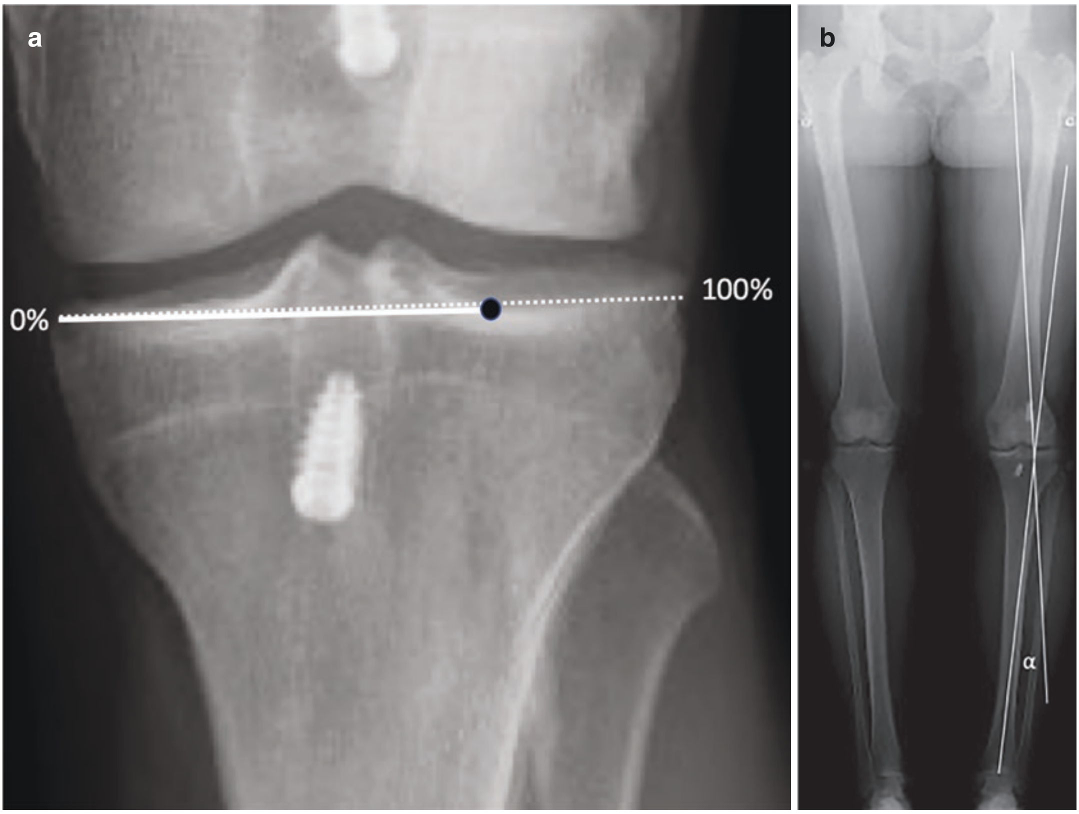


**Fig. 13.15** Determination of desired mechanical axis following an HTO. (**a**) Calculation of the Fujisawa point which is 62% of the tibial plateau width from medial to lateral. This is the desired location for the realigned mechanical axis. (**b**) Full-length x-ray showing the calculated degree of correction for the amount of varus malalignment in order to put the realigned mechanical axis at the 62%ile of the tibial plateau width

omy. The length of this line is superimposed on the tibial weight-bearing line, and the distance at this location between the femoral and tibial weight-bearing lines is the amount of opening or closing of the osteotomy required to achieve the desired angular correction (Fig. 13.16).

## Medial Opening Wedge High Tibial Osteotomy and Revision Anterior Cruciate Ligament Reconstruction: Surgical Technique

A combined opening wedge HTO and revision ACL reconstruction is a complicated procedure that is infrequently performed even by experienced knee surgeons. It is imperative that all equipment is available, including a fluoroscopic unit and a radiolucent table. Our preference is to use a large C-arm that is positioned on the opposite side of the patient. The patient is positioned supine with the operating room table flexed to 90° and a thigh holder placed on the proximal thigh to allow hyperflexion of the knee. Some surgeons prefer to perform all arthroscopic procedures with the knee in full extension. If a contralateral graft harvest is planned, then both lower extremities are prepped and draped free. If not, then sequential compression pumps are placed on the contralateral lower extremity for deep venous thrombosis prophylaxis. A tourniquet is used selectively, as necessary. Prophylactic antibiotics are given within 1 hour of the planned surgery in all patients.


**Fig. 13.16** The angle of desired correction (α) is converted into millimeters of "opening" of the osteotomy. A line across the tibia represents the anticipated site, angle, and length of the osteotomy (solid black line). The length of this line is superimposed on the tibial weight-bearing line, and the distance at this location between the femoral and tibial weight-bearing lines is the amount of opening, in millimeters, required to achieve the desired angular correction (dashed black line)

## Surgical Technique

A routine knee arthroscopy is performed with standard portals to assess all compartments, debride or repair any meniscal pathology, address any chondral lesions, confirm the absence of a functional ACL, and assess the lateral compartment for any full-thickness cartilage lesions >15 mm that would preclude an HTO. If a cartilage restoration procedure is to be performed, it is typically done concurrently with the osteotomy.

The intercondylar notch is debrided of all nonviable ACL graft material to fully assess the femoral tunnel for expansion and to identify, and potentially remove, prior hardware. A notchplasty is often not necessary in a revision procedure but can be done to enhance visualization of the femoral tunnel site. At this stage, the surgeon must decide whether to proceed with the planned revision or perform a staged bone grafting, as discussed previously. If it is decided to proceed with the procedure, the revision ACL graft can be harvested from either the ipsilateral lower extremity or contralateral limb if an autograft is selected. Our goal is to harvest a revision graft that is 1 cm larger in diameter than the primary graft.

The revision femoral tunnel aperture is identified that would be in the center of the native ACL. This is sometimes difficult to identify in a revision setting. Therefore, a site is chosen that is at approximately the 1:30 or 10:30 position on the lateral wall of the intercondylar notch in a left or right knee, respectively. A guide pin is drilled with the assistance of a femoral offset guide through the anteromedial (AM) portal with the knee hyperflexed to 105° to prevent posterior wall "blowout" during tunnel drilling that may occur in lesser degrees of flexion. Alternatively, an outside-in technique can be used to create the femoral tunnel that is oriented away from the prior tunnel. A low-profile drill of appropriate diameter is used to create the femoral tunnel to a depth commensurate with the bone plug or the revision graft or at least 20 mm for a soft tissue graft. A Beath pin is used to pass a #2 shuttle suture out the lateral thigh that is left in the AM portal for later retrieval.

The operating table is fully extended if previously flexed and a new sterile drape applied under the knee, as is a foam knee wedge to elevate the operative limb above the contralateral lower extremity for fluoroscopic viewing. A 6–8 cm incision is made just distal to the medial joint line mid-way between the tibial tubercle and posterior edge of the proximal tibia. A needle tip electrocautery is used to carefully dissect the medial border of the patellar tendon to identify its insertion. Dissection is carried sharply down to the pes anserinus with identification and incision of the overlying sartorial fascia. In the setting of hamstring autograft, the underlying gracilis and semitendinosus can be identified and harvested to create a quadrupled graft [44]. The pes anserinus and sMCL are sharply dissected longitudinally and reflected posteriorly to the posterior tibial border. An elevator is used to release the sMCL to the flare of the medial tibial plateau. An osteotomy opening greater than 5 mm typically requires distal transection of the sMCL. A Z-retractor is placed behind the tibia to reflect the soft tissue envelope.

Our preferred technique is to use the opening wedge plate system (Arthrex Inc., Naples, FL). A perforated guide pin is drilled under fluoroscopic visualization starting 4 cm distal to the medial joint line at a 15° oblique angle across the proximal tibia at the predetermined location on the medial tibial metaphysis at which the radiographic corrections were calculated. The pin should be at or proximal to the tibial tubercle and directed at the proximal tibiofibular joint at least 1.5 cm distal to the lateral joint line. A second pin is drilled to an equal depth parallel to the first pin using the proprietary drill guide rotated posteriorly to match the slope of the tibial plateau. Lateral imaging is obtained to confirm adequate placement of both pins which should be parallel to the tibial plateau. The guide should be oriented to place the osteotomy just proximal to the patellar tendon insertion so that the osteotomy site is under compression with quadriceps contraction. A retractor is placed under the patellar tendon and the Z-retractor reoriented at the level of the osteotomy to protect the popliteal neurovascular bundle. An oscillating saw is used to begin the osteotomy under fluoroscopic visualization with care taken to make a precise single cut. The anterior and posterior tibial cortices are cut with a ¾-inch osteotome which is advanced medially under fluoroscopic guidance to a distance 1 cm from the lateral tibial cortex, which should correspond to the predetermined length of the osteotomy. Discontinuity of the anterior and posterior cortices is confirmed when there is slight separation of the proximal and distal bone fragments with gentle valgus force. Passage of a Kirschner wire across the lateral tibial cortex can be used to cause a "greenstick" effect which will allow opening of the osteotomy while maintaining continuity of the bone.

A calibrated wedge osteotome is inserted as far posterior as possible in the osteotomy in order to affect only coronal alignment (Fig. 13.17). More anterior placement would inadvertently increase the posterior tibial slope as a consequence of the medial tibial cortex being oriented at a 45° angle to the plane of the posterior tibial cortex that creates a triangular shape to the proximal tibia (Fig. 13.18) [38]. The osteotome is gen-

**Fig. 13.17** Calibrated wedge osteotome used to open the osteotomy site the desired degree of correction in millimeters


**Fig. 13.18** Osteotomy plate placed too anteriorly which will inadvertently increase the tibial slope


**Fig. 13.19** Fracture of the lateral tibial cortex following an opening wedge HTO

**Fig. 13.20** Fracture of the lateral tibial cortex following an opening wedge HTO stabilized with a staple

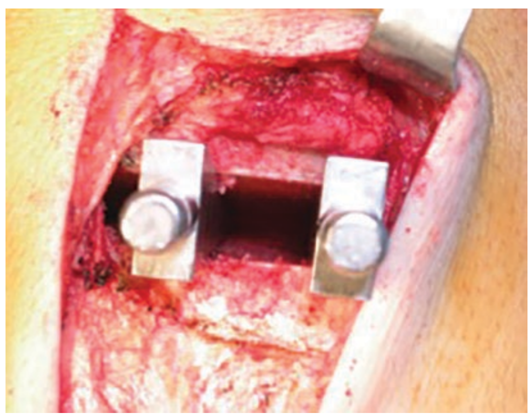

**Fig. 13.21** Tines of the wedge osteotome left in place to allow for plate insertion

tly advanced with a mallet laterally under fluoroscopic guidance to allow stress relaxation of the osteotomized tibial bone as it is opened. If the osteotome is advanced too forcefully, an iatrogenic fracture can occur through the lateral cortex or proximally into the lateral compartment (Fig. 13.19). If this occurs, a single staple or two-holed plate can provide stability to complete the osteotomy (Fig. 13.20).

Confirmation of appropriate realignment may be evaluated by placing a rigid guide rod from the center of the femoral head to the middle of the tibial plafond under fluoroscopic visualization. An axial load is applied to the foot, and the lower extremity is externally rotated 10° to provide a true assessment of lower limb alignment. Satisfactory realignment should result in the rod crossing the tibial plateau just lateral to the lateral tibial spine 62% of the distance across the tibial plateau. We have not found use of an electrocautery cord (as recommended by some authors) stretched from the center of the femoral head to the center of the tibial plafond to be particularly helpful due to its lack of rigidity [45].

If the realignment is satisfactory, the handle of the osteotome is removed, while the two wedge tines remain in the tibia to preserve the opening wedge (Fig. 13.21). Based on preoperative mea-


**Fig. 13.22** Titanium Puddu plate (Arthrex Inc., Naples, FL) with sloped tooth to maintain opening of the osteotomy to the appropriate degree while preserving the tibial slope

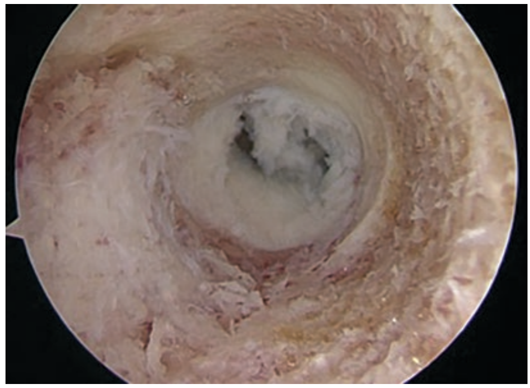

**Fig. 13.23** Arthroscopic view within the ACL tibial tunnel following the HTO confirming absence of hardware that may interfere with graft passage

surements, a four-hole stainless plate with appropriate-sized tooth that will maintain the calculated degree of correction is inserted (Fig. 13.22). Multiple tooth thicknesses are available from 5 to 17.5 mm. The tooth can be either straight or sloped to maintain the slope of the tibial plateau. Alternatively, a titanium plate with locking screws can be used if bone density is in question. A single 6.5 mm cancellous screw is placed in the proximal posterior hole parallel to the osteotomy as far posterior as possible, and two 4.5 mm bi-cortical screws are directed distally through the distal holes. The proximal anterior screw is not inserted until the ACL tibial tunnel is drilled. Anteroposterior and lateral fluoroscopic images are obtained to confirm adequate placement of all hardware. If appropriately created, the osteotomy gap should be approximately twice as wide posterior to the plate as it is anterior in order to prevent an inadvertent increase of the tibial slope which would increase the strain transmitted to the revision ACL graft [46].

An alternative option for an opening wedge HTO consists of a nonabsorbable polyetheretherketone (PEEK) implant and screws (iBalance®, Arthrex, Inc., Naples, FL) that are buried within the tibial bone in order to prevent irritation of the overlying soft tissue envelope. A benefit of this system is that the proximal screws can be oriented in a more proximal direction to avoid the tibial ACL tunnel. The ACL graft can also be passed through and secured to the PEEK implant if desired.

Once fixation is complete, an arthroscopic tibial guide is placed at the center of the tibial ACL footprint, and a guide pin is inserted. If the prior bone tunnel is filled with soft tissue, pin purchase may be compromised. Advancing the guide pin into the room of the intercondylar notch will stabilize it for drilling. The guide pin should be anterior to the HTO plate and screws. The appropriately sized compaction drill is used to complete the tibial tunnel. An arthroscope can be inserted into the tunnel to confirm circumferential cancellous bone and the absence of the HTO hardware (Fig. 13.23). Shavers and thermal ablation devices should be used to debride all non-viable fibrous tissue which would affect graft-tunnel healing. The drill is left in place, and the knee is fully extended to confirm the absence of notch impingement. The final proximal cancellous screw is inserted into the plate with the drill still in the tunnel so that graft interference is avoided.

The shuttle suture is retrieved through the tibial tunnel and used to pull the revision ACL graft into the joint. Femoral fixation is accomplished with either interference screws or suspensory cortical fixation depending on graft type, surgeon preference, and femoral bone stock. Supplemental fixation may be required in certain situations. The knee is cycled from 0° to 90° to confirm isometricity, lack of impingement, and satisfactory fixation. Distal fixation is performed with the knee in 10° of flexion with 10 lbs. of traction to the distal graft sutures and a posterior drawer applied to the tibia. Interference screw fixation or cortical fixation is used depending on graft type, surgeon preference, and potential interference from the HTO screw(s).

**Fig. 13.24** Final HTO construct with plate in place and osteotomy site filled with a synthetic bone graft substitute

Once the plate and graft are secured, bone graft or a bone graft substitute can be placed anterior and posterior to the plate. Some surgeons do not use any bone graft material, except for larger defects. Our preference is to use morselized cancellous allograft chips to fill the defect and cortical allograft bone or synthetic osteoconductive bone graft substitute to provide cortical support (Fig. 13.24).

After copious irrigation, the deep soft tissue flap and overlying fascia are reapproximated to the sleeve of soft tissue remaining on the tibial cortex. Residual MCL laxity is not typically an issue even if it is released during the exposure. Following dermal and subcuticular closure, a soft dressing is placed, and the limb is wrapped with a compressive ACE bandage from the foot to the thigh. A long-leg hinged knee brace is used to protect the osteotomy and is locked in full extension.

## Lateral Closing Wedge High Tibial Osteotomy and Revision Anterior Cruciate Ligament Reconstruction: Surgical Technique

Lateral closing wedge HTO was historically the most common method used for coronal plane realignment in the young, active patient. Despite the recent increased interest in the opening wedge technique, both lateral closing wedge and medial opening wedge osteotomies demonstrate similar clinical outcomes and complication profiles [47, 48]; therefore, the chosen technique is largely driven by surgeon preference.

Similar to the medial opening wedge osteotomy, the lateral closing wedge technique has several advantages and disadvantages in the setting of a revision ACL reconstruction. These advantages include:

- Cortical contact allowing for potentially earlier weight-bearing
- Faster healing
- Theoretically reduced risk of delayed union/nonunion
- More secure initial fixation
- Less interference with the ACL graft and hardware
- Tendency to decrease tibial slope

Unfortunately, there are several significant disadvantages of a closing wedge osteotomy that must be considered especially for surgeons unfamiliar with this technique. These include:

- Greater soft tissue dissection
- Converging dual osteotomies
- Difficulty achieving and changing the desired correction
- Risk for peroneal nerve injury
- Risk for fibular osteotomy nonunion
- Risk for proximal tibiofibular joint instability secondary to ligamentous disruption
- Potential increase in patellar height

### Surgical Technique

In the setting of a combined closing wedge osteotomy and revision ACL reconstruction, the calculated correction of alignment, surgical set-up, and arthroscopic portion of the procedure are identical to the opening wedge technique. A reverse L-shaped incision is made from the fibular head to the tibial tubercle and curved distally to expose the fascia of the anterior compartment

**Fig. 13.25** L-shaped incision for closing wedge HTO

(Fig. 13.25). Though some authors advocate for alternative incisions and approaches, a parapatellar approach allows for easier exposure in the setting of an ACL reconstruction and for subsequent arthroplasty, if necessary [49]. Once the fascia is identified, the anterior compartment is incised parallel with the patellar tendon with electrocautery leaving a 1 cm strip of fascia to be used for later closure. The anterior compartment muscle is elevated off the tibia subperiosteally proximally to Gerdy's tubercle and laterally to the fibular head. Z-retractors are placed around the posterior aspect of the tibia to protect the popliteal neurovascular structures. The patellar tendon insertion is identified and protected.

There are three options to deal with the fibula when performing a closing wedge HTO. The proximal tibiofibular joint can be disrupted with a curved ½-inch osteotome to allow the fibula to slide proximally as the osteotomy is compressed. This is our choice for smaller corrections and in patients without PLC instability. A second alternative is an osteotomy of the fibular neck. This is especially useful for larger corrections but risks injury to the peroneal nerve and may compromise the fibular tunnel used for a lateral collateral ligament reconstruction. A third alternative is an oblique osteotomy of the fibula at the junction of the mid- and distal third. This option requires a secondary incision and is complicated by the potential risk for nonunion and injury to the superficial peroneal nerve [50].

Following division of the proximal tibiofibular joint, a guidewire is placed parallel to the joint line (approximately 2 cm distal to the articular surface) and advanced to the far medial cortex. A second guidewire is placed distal to the first wire, at a distance dictated by the preoperative planning, and drilled in a manner convergent with the first wire ending 1 cm from the medial tibial cortex. The second pin should be at or above the patellar tendon insertion. A commercially available guide can be used to ensure correct angulation of the second pin. The placement of these guidewires is confirmed with fluoroscopy, ensuring the planned osteotomy preserves a medial hinge. A cutting jig may be utilized to assist in the creation of the desired osteotomy to avoid complications while making two separate bone cuts [51]. With the knee in 30° of flexion to reduce tension on the popliteal neurovascular bundle and maximize distance between the bundle and the posterior tibia, the proximal osteotomy is made parallel to the tibial plateau 2 cm from the joint line. It is started with an oscillating saw with a posterior soft tissue protector in place. The second osteotomy is made parallel to the distal guide pin proximal to the patellar tendon insertion. Care is taken to maintain the medial tibial cortex which may be perforated with a Kirschner wire to allow closure without causing an acute fracture with loss of cortical contact. The bone wedge is removed as one triangular segment or in a piece-meal fashion (Fig. 13.26). Careful visualization of the posterior tibial cortex will help identify all remaining bone that may inhibit closure.

The osteotomy is closed either with a gentle valgus force or with a commercially available compression clamp. If a compression clamp is used, two proximal 6.5-mm-long (60 mm) cancellous screws are inserted through either an L- or T-shaped plate. Using shorter screws may cause them to cut out of the metaphyseal bone with compression. If the fibula was adequately released or osteotomized, there should be complete closure of the tibial osteotomy. Apposition of the bone fragments should be confirmed fluoroscopically and directly visualized. It is imperative that lateral closure does not result in medial cortical opening that may occur if the medial cortex cracks. If this occurs, a two-pronged staple or plate can be used to stabilize the medial cortex. Alignment is checked fluoroscopically to confirm that the desired mechanical axis was achieved.

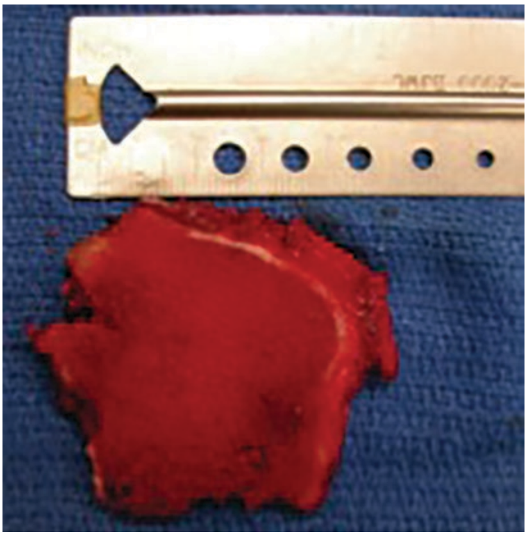

**Fig. 13.26** Triangular wedge of bone removed during a closing wedge HTO

Distal plate fixation is achieved with 4.5 mm bi-cortical screws. The long proximal cancellous screws are removed, and shorter (approximately 35 mm) screws are inserted parallel to the tibial plateau to accommodate the ACL graft. The tibial ACL tunnel is drilled normally past the smaller proximal screws, and the revision graft is inserted and fixed in the usual fashion depending on graft type and surgeon preference (Fig. 13.27). The surgical site is thoroughly irrigated, and the anterior compartment fascia is reapproximated to the residual strip on the proximal tibia with absorbable suture. A prophylactic anterior compartment fasciotomy is routinely made to reduce the risk of a compartment syndrome. A layered closure is performed, and a soft dressing, compressive ACE bandage, and hinged knee brace locked in full extension are applied.

## Outcomes Following Revision ACL Reconstruction and High Tibial Osteotomy

Little information is available regarding the outcomes of combined revision ACL reconstruction and coronal plane realignment, as the majority of studies evaluate outcome following HTO combined with primary ACL reconstruction [21, 31,

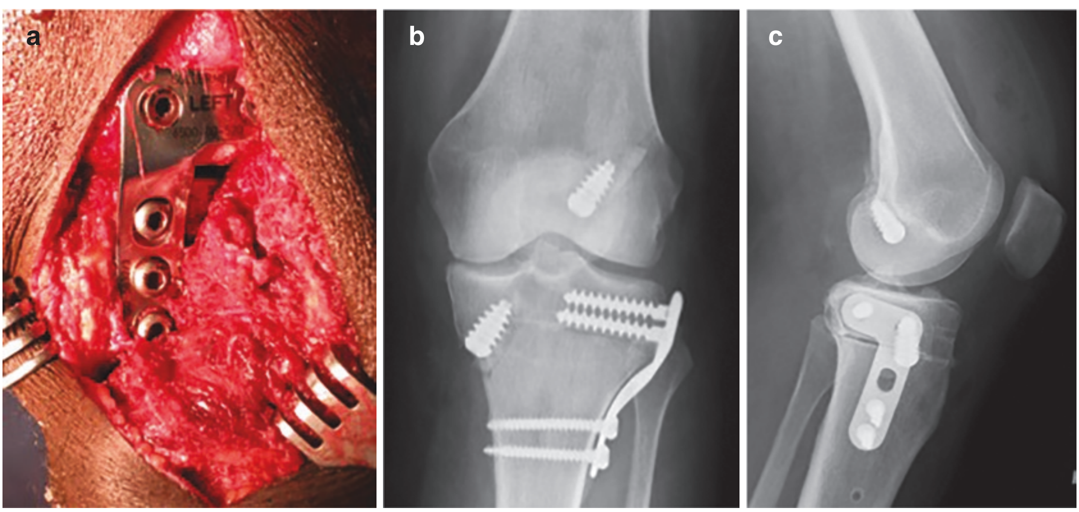


**Fig. 13.27** Closing wedge HTO and revision ACL reconstruction. (**a**) Closing wedge HTO with L-shaped plate. (**b**) AP x-ray showing final construct with hardware in place. (**c**) Lateral x-ray

52–59]. Additionally, the literature also varies in terms of surgical technique (opening versus closing wedge), ACL graft source, and length of procedure (single- versus two-stage). In the primary setting, a combination HTO and ACL reconstruction typically results in a significant improvement in functional knee outcome scores [52]. Li et al. [53] conducted a systematic review of 11 studies that reported simultaneous ACL reconstruction and HTO. All cases of varus malalignment were corrected an average of 7.1°. Overall, 85.7% of patients had normal or nearly normal knee stability with a mean KT-1000 side-to-side difference of 2.4 mm. All subjective knee scores improved, and most patients returned to recreational sports activities. The most prevalent complication in this review was deep venous thrombosis (7.7%). Zaffagnini [59] reported only 2 failures at a mean follow-up of 6.5 years in 32 patients who underwent closing wedge HTO and primary or revision ACL reconstruction. Severe medial compartment osteoarthritis was noted in 22%. Arun et al. [54] retrospectively analyzed 30 patients who underwent a combined ACL reconstruction and medial opening wedge osteotomy. They found that decreasing the posterior tibial slope >5° resulted in better functional scores (International Knee Documentation Committee [IKDC] and Lysholm) compared to patients who had <5° decrease, thus emphasizing the importance of the tibial slope and its effect on ACL graft strain. Noyes et al. [21] treated 41 young patients with combined ACL insufficiency and varus malalignment with HTO followed by ACL reconstruction 8 months later. Eighteen patients required PLC reconstruction. After a mean follow-up of 4.5 years, pain was eliminated in 71%, and instability was improved in 66%. Thirty-seven percent rated their knee as normal or very good. Correction of varus malalignment was maintained in 80%, and the adduction moment documented with gait analysis was decreased to below normal values.

## Lateral Opening Wedge Distal Femoral Osteotomy and Anterior Cruciate Ligament Reconstruction

Valgus malalignment is considerably less common than varus in the setting of a failed ACL reconstruction. In addition, fewer patients with uni-compartmental osteoarthritis have lateral compartment involvement than medial compartment involvement. Cooke et al. [60] reviewed the radiographs of 167 patients with osteoarthritis and noted valgus alignment in only 24% compared to 76% who were in varus. Normally, there is physiologic valgus of approximately 5°–7° due to 7°–9° of distal femoral valgus combined with 0°–3° of proximal tibial varus [61]. Despite this degree of physiologic valgus, the normal offset caused by the femoral neck results in the mechanical axis passing through the center of the knee. Pathologic valgus occurs when the distal femoral angle is elevated above normal causing the mechanical axis to pass through or lateral to the lateral compartment of the knee. This will lead to progressive wear of the lateral articular cartilage as well as contracture of the lateral capsule and ligamentous structures. Conversely, attenuation of the medial soft tissue restraints may develop over time.

The majority of patients with valgus malalignment have a deformity in the distal femur resulting in elevation in the distal femoral angle. Therefore, the correction of pathologic valgus is directed at realignment of the distal femur. Theoretically, correction of valgus malalignment could be accomplished at the proximal tibia, but this would likely cause joint line obliquity, increased sheer forces across the joint, and subsequent instability.

Surgical correction of valgus malalignment at the distal femur can be achieved with either a medial closing wedge or lateral opening wedge osteotomy similar to correction of varus malalignment at the tibia. Our preference, and that of most surgeons, is to perform a lateral opening wedge osteotomy due to the relative ease of exposure, need for a single osteotomy, ability to fine-tune the correction, and availability of less complicated fixation methods. However, many surgeons are still unfamiliar with this procedure because of its relative infrequency. Combining it with a revision ACL reconstruction increases the complexity and requires careful preoperative planning, accurate intraoperative imaging, and meticulous surgical technique to ensure a favorable outcome and avoid complications.

## Preoperative Planning

Full-length, weight-bearing radiographs of both lower extremities are obtained in order to define the extent of the valgus malalignment and to calculate the required degree of correction similar to the preoperative assessment of patients with varus malalignment. However, unlike correction of a varus deformity in which the mechanical axis is shifted to the lateral compartment at the 62% point of the tibial plateau, over-correction of pathologic valgus is contraindicated in order to avoid compressive overload of the medial compartment. Rather, correction of valgus malalignment in patients with symptomatic lateral compartment cartilage wear should be no further medially than to the medial tibial spine. Patients with physiologic genu valgum without lateral compartment wear should only be corrected to neutral (50% of the tibial plateau width) (Fig. 13.28). The degree of correction calculated by the femoral and tibial weight-bearing lines is calculated similar to the planned correction of varus malalignment. In general, each degree of correction of coronal plane alignment is equal to the number of millimeters the osteotomy must be opened. However, this must be confirmed through preoperative calculation of the location, length, and obliquity of the osteotomy (Fig. 13.29).

Deciding which graft to use for the ACL revision in the setting of a combined DFO should follow the same thought process used when performing an HTO in combination with an ACL revision. The primary technical issue associated with the combined procedure is femoral fixation. It is imperative that the femoral tunnel is drilled through an anteromedial portal or via an outside-in approach rather than through a trans-tibial tunnel in order to prevent a relatively vertical femoral tunnel that may interfere with the DFO hardware. Outside-in drilling has the advantage in that it can be done through the same incision as that for the DFO in order to avoid the femoral hardware. Our preference is to drill the femoral tunnel prior to performing the DFO so the hyperflexion of the knee that is required to drill the femoral tunnel does not destabilize the osteotomy fixation.


**Fig. 13.28** Full-length x-ray showing the degree of correction calculated by the femoral and tibial weight mechanical axis lines needed to achieve a new mechanical axis that is at a point 50% of the width of the tibial plateau

Suspensory cortical fixation may not be feasible due to the presence of the lateral plate and screws, but interference fixation can usually be accomplished given the obliquity of the distal cancellous DFO screws and the location of a properly drilled femoral tunnel.

## Surgical Technique

In the setting of a combined opening wedge DFO osteotomy and revision ACL reconstruction, patient positioning, arthroscopic meniscal/chondral procedures, and notch preparation are done


**Fig. 13.29** The angle of desired correction (α) is converted into millimeters of "opening" of the osteotomy. A line across the distal femur represents the anticipated site, angle, and length of the osteotomy (solid black line). The length of this line is superimposed on the femoral weight-bearing line, and the distance at this location between the femoral and tibial weight-bearing lines is the amount of opening, in millimeters, required to achieve the desired angular correction (dashed black line)

as in the HTO. If it is decided to proceed with the combined procedure, the revision graft is harvested and is made 1 mm larger in diameter than the primary graft, if known. The femoral tunnel is drilled through the anteromedial portal or with a two-incision outside-in method using the appropriate over-the-top guide and a shuttle suture is passed for later use. The tibial tunnel is created using compression drills with care taken to achieve anatomic placement. Confirmation of circumferential cancellous in the tibial tunnel

**Fig. 13.30** Incision of the distal lateral thigh used for a DFO

will aid graft fixation. This can be achieved with use of curettes and thermal ablation, while the tunnel is visualized from the intra-articular aperture with a 70° arthroscope.

A 10 cm incision is made along the lateral aspect of the distal thigh to 1 cm distal to the lateral epicondyle (Fig. 13.30). The iliotibial band is incised longitudinally, and the vastus lateralis is split in line with its fibers to the lateral intermuscular septum. A Cobb elevator is used to expose the anterior, lateral, and posterior surfaces of the distal femur. A Bennett retractor is used to facilitate exposure and protect the quadriceps muscle anteriorly (Fig. 13.31). A radiolucent or other curved retractor is used to protect the neurovascular structures posteriorly.

Under fluoroscopic visualization, a guide pin is drilled across the distal femur parallel to the joint line, and a second pin is drilled obliquely at a 15°–20° angle in the coronal plane to the level of the medial femoral cortex. It is imperative that the guide pin is placed *above* the level of the trochlear groove so that the patellofemoral joint is not breached with the osteotomy. A second guide pin is placed parallel with the first using a free-hand technique or the proprietary drill guide (Arthrex Inc., Naples, FL) (Fig. 13.32). Anteroposterior and lateral fluoroscopic images should confirm accurate pin placement to ensure a perpendicular osteotomy in relation to the femoral shaft in the sagittal plane. A flat cutting guide is inserted

**Fig. 13.31** Exposure of lateral femur following elevation of the vastus lateralis

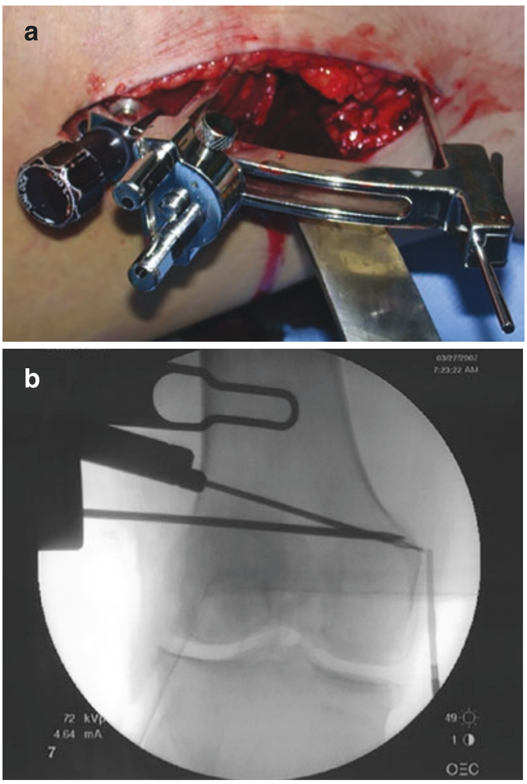


**Fig. 13.32** Osteotomy of the distal femur. (**a**) Guide used to place two Kirschner wires at the correct location and angle for the cutting guide. (**b**) Fluoroscopic image of Kirschner wires in place showing the intended angle of the osteotomy

over the guide pins, and a 1″ oscillating saw is used to cut the lateral, anterior, and posterior femoral cortices under fluoroscopic guidance with soft tissue protectors in place at all times (Fig. 13.33). A straight osteotome is used to complete the osteotomy to a distance 1 cm from the medial femoral cortex (Fig. 13.34). A Kirschner wire can be used to perforate the medial cortex several times to cause a "green-stick" effect and allow the cortex to bend with a gentle varus force applied to the osteotome. It is imperative that the osteotomy is performed perpendicular to the femoral shaft in the sagittal plane in order to avoid flexion or extension of the femoral condyle as the osteotomy is opened.

Once the osteotomy is mobile, a wedged osteotome with removable handle is gently impacted with a mallet taking multiple pauses to allow for stress relaxation of the intact medial cortex. The osteotome is inserted with the distance calculated preoperatively (Fig. 13.35). If a fracture of the medial femoral cortex occurs, it should be stabilized with a two-hole plate and screws as the curvature of the medial femoral metaphysis precludes fixation with a staple. Loss of medial cortical fixation will cause loss of the realignment and risk malunion and nonunion of the osteotomy. Once the osteotomy is completed, adequate correction is confirmed with a rigid alignment rod as discussed previously. The rod should ideally cross the joint between the tibial spines and no further medial than the medial tibial spine. If the correction is adequate, the handle is removed from the wedge osteotome, and a T-shaped osteotomy plate (Arthrex Inc., Naples, FL) with appropriate-sized tooth corresponding to the degree of opening in millimeters is inserted between the tines of the osteotome (Fig. 13.36). Four 4.5 mm bi-cortical screws are used for proximal fixation, and three converging 6.5 mm cancellous screws inserted parallel to the obliquity of the osteotomy are used for distal fixation. Placement of an arthroscopic shaver or drill into the previously drilled femoral tunnel while the distal screws are inserted can ensure free passage of the ACL graft.

Once osteotomy fixation is complete, the bone defect is filled anterior and posterior to the plate with autograft or allograft bone or synthetic bone graft substitute to both fill the cancellous defect and provide structural support to the lateral cor-

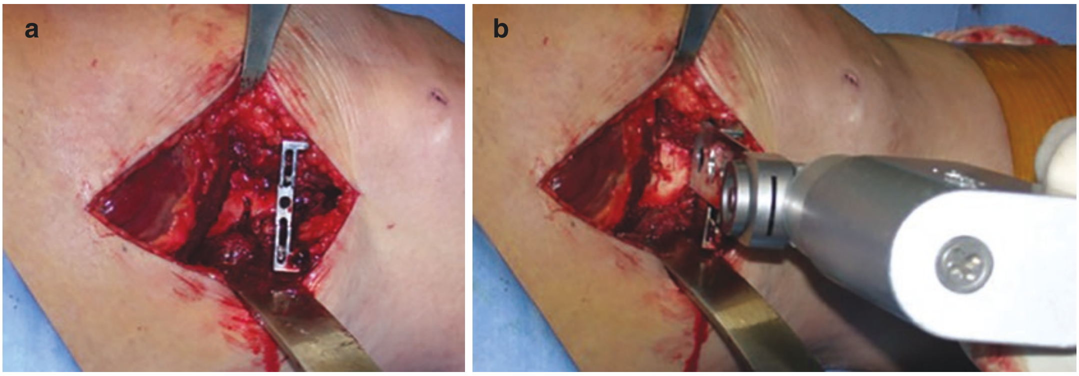


**Fig. 13.33** (**a**) Cutting guide secured by the Kirschner wires. (**b**) Osteotomy performed with an oscillating saw with neurovascular structures protected by Z-retractors

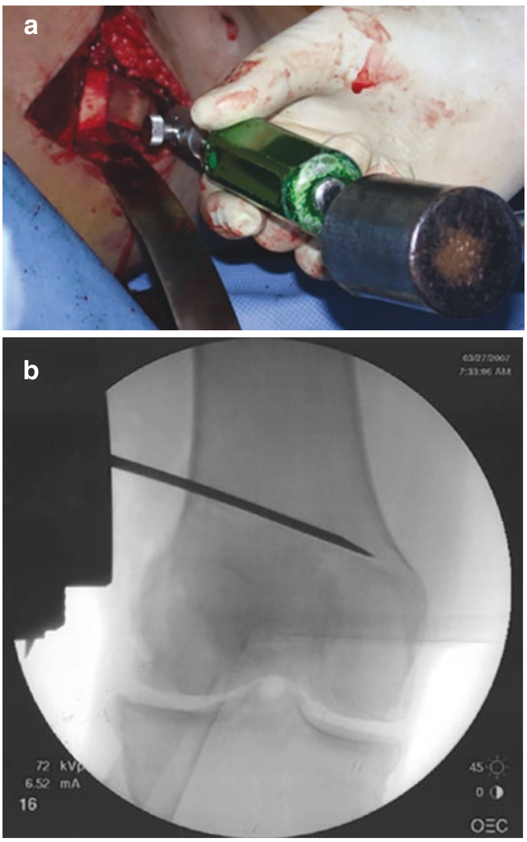


**Fig. 13.34** (**a**) Osteotome used to complete the osteotomy. (**b**) AP fluoroscopic image showing osteotome at correct angle and depth

**Fig. 13.35** Wedge osteotome used to progressively open the osteotomy to the desired degree in millimeters

**Fig. 13.36** T-shaped femoral Puddu plate (Arthrex Inc., Naples, FL) prior to insertion

tex (Fig. 13.37). The iliotibial band is closed with a running absorbable suture, and the skin is closed in layers.

The arthroscope is placed back in the joint, and the shuttle suture is used to pass the graft up the tibial tunnel and into the femoral tunnel. If a

**Fig. 13.37** Lateral x-ray showing femoral osteotomy plate in place with osteoinductive bone graft substitute filling the defect. Note the maintenance of normal femoral alignment

soft tissue graft is selected, suspensory cortical fixation may be feasible but must take the plate into consideration. The graft sutures may be tied around the distal cancellous screws to provide proximal fixation as an alternative option. If a graft with a femoral bone plug is used, interference fixation that is laterally oriented in the femoral tunnel should avoid the distal osteotomy screws. Adequate femoral fixation and graft isometricity are confirmed with 10 lbs. of tension applied to the distal graft sutures, while the knee is cycled multiple times from 0° to 90° of flexion. Two millimeters or less of graft migration within the tibial tunnel is acceptable with flexion and extension. Tibial fixation is accomplished with the knee in 10° of flexion and a posterior drawer applied. Choice of fixation is dependent on the graft chosen and surgeon preference (Fig. 13.38).

Once all wounds are closed, a well-padded dressing and an ACE wrap are applied to the entire lower extremity. A long-leg hinged knee brace is locked in full extension for 24 hours.

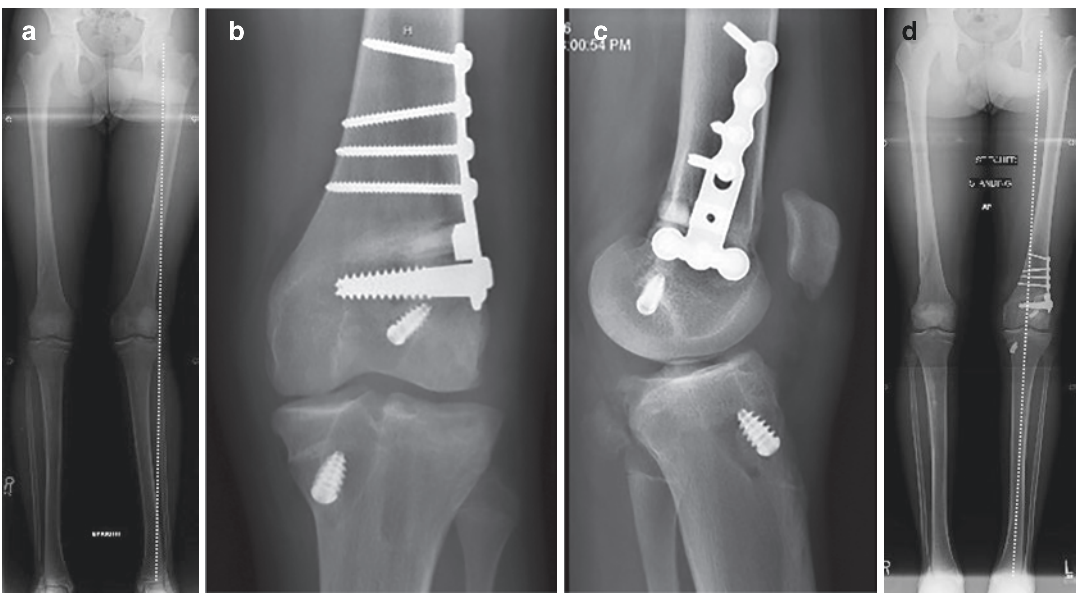


**Fig. 13.38** A 17-year-old male who underwent ACL "repair" several years prior with pain and recurrent instability. (**a**) Full-length x-ray showing mechanical axis indicative of significant genu valgum (dashed white line). (**b**) AP x-ray following DFO and ACL reconstruction. (**c**) Lateral x-ray. (**d**) Postoperative full-length x-ray of lower extremities showing new mechanical axis at the 50th percentile of the joint line following realignment (dashed white line)

## Postoperative Care Following Revision ACL Reconstruction and Osteotomy

The postoperative rehabilitation following an HTO or DFO combined with a revision ACL reconstruction is begun within the first week following surgery. Deep venous thrombosis (DVT) prophylaxis is recommended for 4 weeks given the magnitude of the procedure. Ankle pumps and elevation are helpful to facilitate venous blood flow. The rehabilitation regimen is generally less permissive than following an isolated ACL reconstruction due to the osteotomy that is solely dependent on the method of fixation for initial stability. Concurrent meniscal and/or cartilage restorative procedures may also necessitate limited weight-bearing. Patellar mobilization and isometric quadriceps contraction are performed as is aggressive use of cold therapy and compression to control swelling. Hamstring, gastrocnemius, and quadriceps stretching is performed throughout the rehabilitation period.

A long-leg hinged knee brace is worn for 8 weeks following surgery and is locked in full extension for the first 24 hours in order to reduce the risk of extension loss that may occur following a revision ACL reconstruction combined with an osteotomy. Range of motion is encouraged from 0° to 90° beginning on the day after surgery. Passive and active range of motion exercises are performed four times per day for 10 minutes per session with an emphasis on obtaining full, symmetrical extension. Patients should achieve 120° by 4 weeks and 135° by 8 weeks following surgery. Active range of motion is facilitated with a stationary cycle. Extension loss should be addressed immediately with an aggressive overpressure regimen, as necessary, to prevent arthrofibrosis.

The patient is allowed toe-touch weight-bearing for the first 4 weeks, after which plain radiographs are taken to assess healing and confirm satisfactory placement of all hardware. More permissive weight-bearing may be considered following a closing wedge HTO since there is immediate bone apposition. As healing progresses, patients are allowed to bear 25% of their body weight with emphasis on a normal heel-to-toe gait pattern. Full weight-bearing as tolerated is allowed when there is evidence of radiographic union and no tenderness at the osteotomy site, which usually occurs 8–10 weeks following surgery. Gait training is resumed with an emphasis on maintenance of a normalized gait pattern that was achieved preoperatively in those patients demonstrating pathologic gait patterns.

Quadriceps isometrics, straight leg raises, and ankle pumps are allowed within the first 2 weeks. Closed-chain exercises are started at 4 weeks. Hamstring curls and active open-chain knee extension from 90° to 30° are allowed at 8 weeks. Hip abduction, adduction, flexion, and extension are performed as tolerated. Balance and proprioceptive training are begun at 8 weeks if healing has occurred. Lower extremity conditioning, aquatherapy, treadmill ambulation, and walking for exercise are progressively allowed 3–4 months after surgery.

Patients who undergo an HTO or DFO are encouraged to return to low-impact, light activities (i.e., swimming, golf, cycling). Repetitive high-impact exercises such as running or jumping should be discouraged in those patients with meniscal or articular cartilage damage as they will potentially exacerbate preexisting cartilage damage. Sports that involve frequent cutting and pivoting should be avoided to reduce strain on the revision ACL graft. Light, recreational activity is typically allowed 6 months following surgery.

## Complications

A combined revision ACL reconstruction and coronal plane osteotomy offers the advantage of correcting both knee instability and malalignment in a single stage, thus avoiding two separate procedures and a lengthier rehabilitation. Unfortunately, both procedures have significant potential complications common to more complex operations. General complications common to both an HTO and DFO include under-correction and over-correction of the realignment. This can be prevented with careful preoperative planning, accurate use of the saw and osteotome to the correct depth, and fluoroscopic confirmation. Delayed union, malunion, and nonunion may occur secondary to noncompliance with postoperative weight-bearing restrictions, loss of fixation, or nicotine use. Loss of fixation of the tibial or femoral cortical hinge may occur postoperatively because either it was not noticed by the surgeon intraoperatively, the patient was non-compliant with weight-bearing restrictions, or there was preexisting decreased bone density. Intra-articular extension of the osteotomy may occur for three reasons: (1) if, during a DFO, the guide pins are inserted too far distally below the proximal edge of the trochlear groove causing violation of the patellofemoral joint; (2) if the osteotomy is angulated toward the joint, a fracture can extend into the lateral or medial compartment during an HTO and DFO, respectively; and (3) if the cortical hinge has not been adequately cut and perforated causing a fracture to propagate once a valgus (HTO) or varus (DFO) force is applied.

Flexion or extension of the distal femoral condylar fragment may occur during a DFO if the osteotomy is not perpendicular to the femoral shaft. This is analogous to inadvertently increasing the posterior tibial slope during an HTO. Malalignment of the distal femur in the sagittal plane will result in loss of knee extension or flexion and is difficult to correct postoperatively. Iliotibial band irritation from the underlying DFO plate and screws may occur and is more common in thinner individuals. Similar irritation can occur at the medial tibial plateau following an HTO. The hardware can be removed once adequate healing has occurred but, in general, should be delayed for at least 12 months.

Complications following an isolated HTO are considerably more likely compared to a DFO due, in part, due to the relative frequency of the two procedures. Spahn [62] noted deep infection rates following an HTO of 4.7%. Hardware failure due to plate or screw fracture following opening wedge osteotomies has been described in 16.6% [62], and intra-articular fractures have been described in 14.6% of patients [62]. Warden et al. [63] reported delayed union rates of 6.6% with nonunion occurring in 1.6%. Fortunately, the patients considered for these complex combined procedures are relatively healthy. Despite this, patient compliance with weight-bearing and activity restrictions is crucial to the success of these complex procedures in order to avoid complications.

Complications following isolated revision ACL reconstruction are dependent on the presence of concurrent meniscal and/or chondral pathology, technical aspects to address prior tunnels and hardware, and choice of the revision graft. These variables limit the ability to generalize complication rates across all ACL revisions. In general, there is a three to four times higher failure rate following revision ACL reconstruction when compared to primary reconstructions [64]. Rates of deep infection [65] and DVT following ACL surgery are consistently less than 1% [66].

Prior literature has focused mainly on the surgical technique and complications of a *primary* ACL reconstruction combined with an osteotomy. There is no body of literature specifically evaluating the complication rates of *revision* ACL surgery combined with an osteotomy. Despite this, prior literature pertaining to complications is still informative. Willey et al. [67] found after a mean follow-up of 45 months, 37% of patients who underwent a primary ACL reconstruction, and either an HTO or DFO, experienced either a major (i.e., arthrofibrosis, over-correction, nonunion, infection, neurovascular injury) or minor (i.e., hardware pain, hematoma, delayed union, superficial infection) complication. A significant number of associated procedures were performed (i.e., chondral resurfacing, meniscal transplantation, extensor mechanism reconstruction) that may have contributed to the 20% rate of major complications and 25.7% incidence of minor complications. These authors concluded that a combined ACL reconstruction and coronal plane osteotomy was a relatively safe procedure with complication rates similar to an isolated osteotomy. Boss et al. [56] reported 5 patients who required arthroscopic debridement and manipulation for arthrofibrosis and 2 patients with sensory disturbances in 27 patients who underwent a combined ACL reconstruction and HTO. Dejour et al. [57] noted 3 major complications and 16 minor complications among 44 patients who underwent combined HTO and ACL reconstruction. As a result of the relatively low complication rates and favorable outcomes, these authors also favored a single-stage approach for this patient cohort. In contrast, Lattermann et al. [58] recommended a staged approach in patients under 40 with combined medial compartment osteoarthritis and ACL insufficiency. They recommended that the HTO be performed first followed by ACL reconstruction if instability persists. In their series of eight patients who underwent the combined procedure, six of eight sustained major complications including two ACL re-ruptures.

## Conclusion

Assessment of coronal plane alignment is an essential element in the preoperative evaluation of patients considered for revision ACL reconstruction. Unaddressed malalignment places the revision ACL graft at risk and can lead to elevated compressive loads in the medial or lateral compartment for varus or valgus malalignment, respectively. A thorough physical examination is mandatory to diagnose all ligamentous insufficiencies and potential sources of pain. Graft options in the revision setting must take into consideration prior graft(s) and hardware used, hardware placement for the realignment procedure, concurrent pathology, and activity goals. Accurate preoperative calculation of the degree of coronal plane correction, anatomic placement of the revision graft, and treatment of all associated meniscal and chondral damage are imperative. The rehabilitation following these complex procedures is typically less permissive than following a primary ACL reconstruction as bone consolidation is the initial rate-limiting factor of the rehabilitation regimen. Low-impact activities should be emphasized to prevent further articular cartilage degeneration.

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