4 Graft Options in the Revision ACL Setting

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Introduction

Revision anterior cruciate ligament (ACL) reconstruction is indicated for management of failed primary reconstruction in an active patient population, as this can restore stability and facilitate reliable rates of return to sport between 56% and 100% in a recent systematic review [1–3]. Graft selection in revision ACL reconstruction can be complex, as previous surgery and concomitant pathology can have significant repercussions on surgical decision-making and subsequent outcomes [4]. Graft availability may be limited in the revision setting and frequently depends on previous graft use, retained implants or hardware, and relative tunnel placement. It is important to consider each patient's functional goals as well as their demographics (i.e., age, sex, and activity level) and anatomic variables (i.e., patella height, sagittal and coronal alignment, muscle strength and coordination). An awareness of the merits and disadvantages of each respective graft option is important for ultimate revision graft selection.

Patellar Bone-Tendon-Bone Graft

Patellar bone-tendon-bone (BTB) autograft has long been considered the traditional gold standard in ACL reconstruction surgery, and the advantages have been well documented including a strong graft, direct osseous healing, and faster incorporation times. Accordingly, young competitive athletes remain the ideal candidates for BTB in the revision scenario. In patients with a previous hamstring tendon (HT) or free quadriceps tendon (QT) autograft harvest, utilization of an ipsilateral BTB may serve as a reasonable option, especially among the younger athletic population. During revision ACL reconstruction, the tibial bone harvest can also be customized to a larger size in order to address osteolysis or widened tunnels while also obtaining rigid aperture screw fixation. The disadvantages to using BTB in ACL revision are similar to that seen with its use during primary reconstruction, primarily rates of anterior knee pain or crepitation, osteoarthritis of the knee, and patella fracture [5, 6]. In patients with previous QT autograft harvest and persistent extensor weakness, consideration of an ipsilateral BTB may cause a "second hit" phenomenon to the extensor mechanism.

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M. J. Alaia, K. J. Jones (eds.), *Revision Anterior Cruciate Ligament Reconstruction*,
https://doi.org/10.1007/978-3-030-96996-7_4

Initially popularized by Shelbourne for primary ACL reconstruction, contralateral BTB grafts have been used to facilitate greater parity in side-to-side strength without significant complications [7]. One must consider the potential harvest site morbidity to the contralateral extremity and take this into consideration during rehabilitation and recovery times for high-level athletes. Given the comparatively decreased rates of re-rupture in the young athletic population, the benefits of harvesting a contralateral BTB graft, including early bone-to-bone healing, customizable graft size, and low rates of soft tissue creep, may outweigh the disadvantages with bilateral lower extremity rehabilitation.

While repeated ipsilateral BTB harvesting after primary autologous BTB reconstruction has been reported, the data supporting its use is scarce. Prior advanced imaging studies have shown reconstitution of the central third of the BTB donor site, but the histologic composition at the tendon-bone interface largely reflects scar tissue rather than a traditional enthesis with four distinct zones of transition. There are limited reports from Europe detailing successful re-harvesting of BTB 4 years after primary reconstruction [8], but ipsilateral re-harvest of the BTB for ACL revision has been associated with inferior short- and long-term patient-reported outcomes [9, 10]. Based on these findings, this graft often is not recommended for ACL revision reconstruction.

Case 1

A 14-year-old male sustained a non-contact injury while playing football. He noted immediate pain and inability to bear weight and presented with a large effusion and positive 2B Lachman and grade I pivot shift exam. Radiographs revealed skeletal immaturity with open physes and ill-defined tibial tubercle apophysis. MRI was consistent with a right ACL intra-substance tear. He underwent a five-strand, HT autograft ACL reconstruction using a hybrid “physeal kind” technique with physeal-sparing, outside-in drilling of the femur, and central transphyseal tibial drilling. Suspensory fixation was utilized on the femoral side, and bio-composite screw fixation was employed on the tibial side with backup staple fixation (Fig. 4.1). Rehabilitation was successful, and the patient was

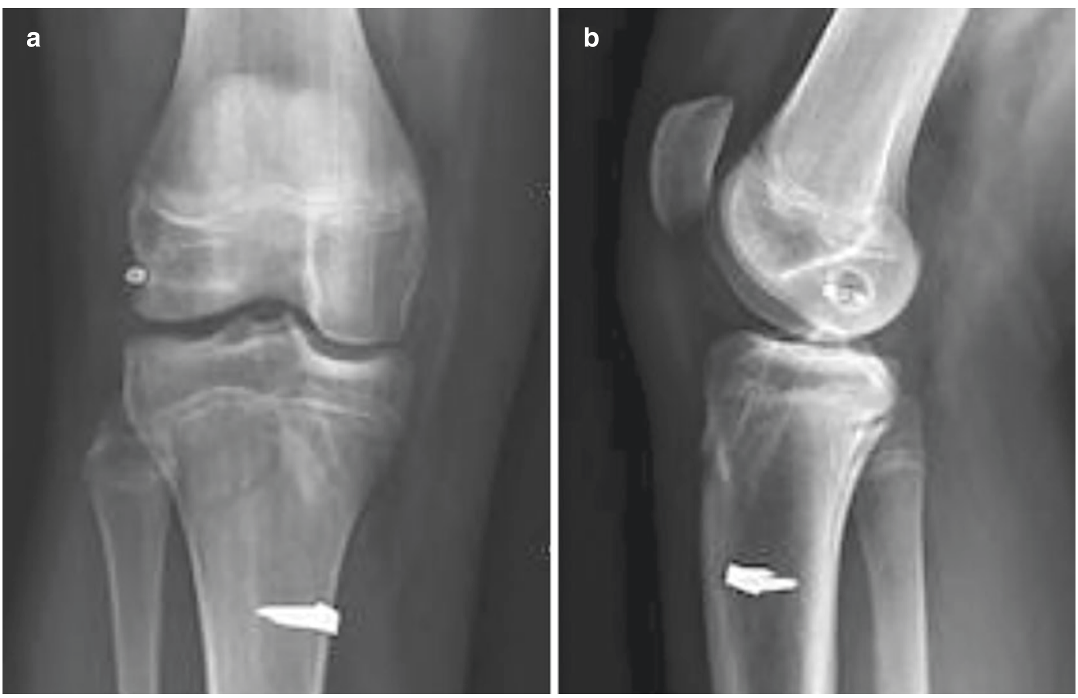

Fig. 4.1 (**a**) AP view (**b**) Lateral view status post primary HT ACL reconstruction

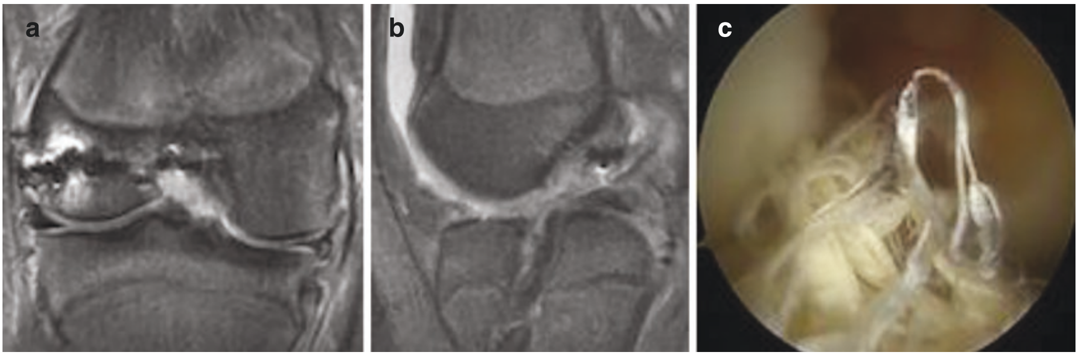

Fig. 4.2 (**a**) Coronal MRI (**b**) Sagittal MRI (**c**) Arthroscopic imaging of ACL graft failure

able to return to sport after comprehensive functional testing by physical therapy.

At approximately 10 months postoperatively, he sustained a twisting injury playing basketball and sustained a complete mid-substance graft tear (Fig. 4.2). Given his young age and multi-sport involvement, revision ACL reconstruction was recommended.

When considering graft selection for this patient, several factors were considered including his young age, involvement in competitive level 1 cutting and pivoting sports, and recent physeal closure. Given these risk factors, autograft was selected given the higher failure rates with allograft, with discussion between ipsilateral BTB or QT. Previous tunnel location and assessment for minimal widening were also considered.

Given the previous physeal-sparing-femoral tunnel, we elected for use of ipsilateral BTB graft with new divergent femoral tunnel across the physeal scar (so-called funnel technique), while the primary tibial tunnel was drilled until encountering healthy metaphyseal bone with punctate bleeding, with the use of a larger diameter bone block for optimal fill. The tunnel walls were found to be competent, and the BTB autograft was deployed and subsequently fixated with metallic interference screws on both sides (Fig. 4.3). Given his high-grade pivot shift and prior autograft failure, an extra-articular iliotibial band (ITB) tenodesis was also performed using the modified Lemaire technique. He successfully completed rehabilitation with objective return to sport testing and was able to return to football at 10 months after his revision BTB ACL reconstruction. He has remained stable without re-injury at approximately 3 years follow-up.

Hamstring Tendon Graft

HT autograft is commonly used in primary ACL reconstruction with favorable results [11], although there can be wide variability in preparation techniques and fixation constructs. In patients with previous BTB or QT autograft, harvesting an ipsilateral or contralateral HT remains a potential option. The advantages are similar to primary reconstruction including smaller incisions and less perioperative donor site morbidity, specifically less kneeling pain as compared to BTB. Fixation strength may be less than BTB, and caution is advised in females due to concerns about compromise of the posterior kinetic chain, residual hamstring weakness with loss of secondary stabilizers, and slightly higher risk of re-rupture. Traditionally, surgeons have also exercised caution to avoid HT autografts in athletes who compete in high-flexion (e.g., wrestling, hurdling) or hamstring-dominant sports such as skiing or soccer, although there is little evidence to support this theory. In contradistinction to primary ACL reconstruction, similar out-

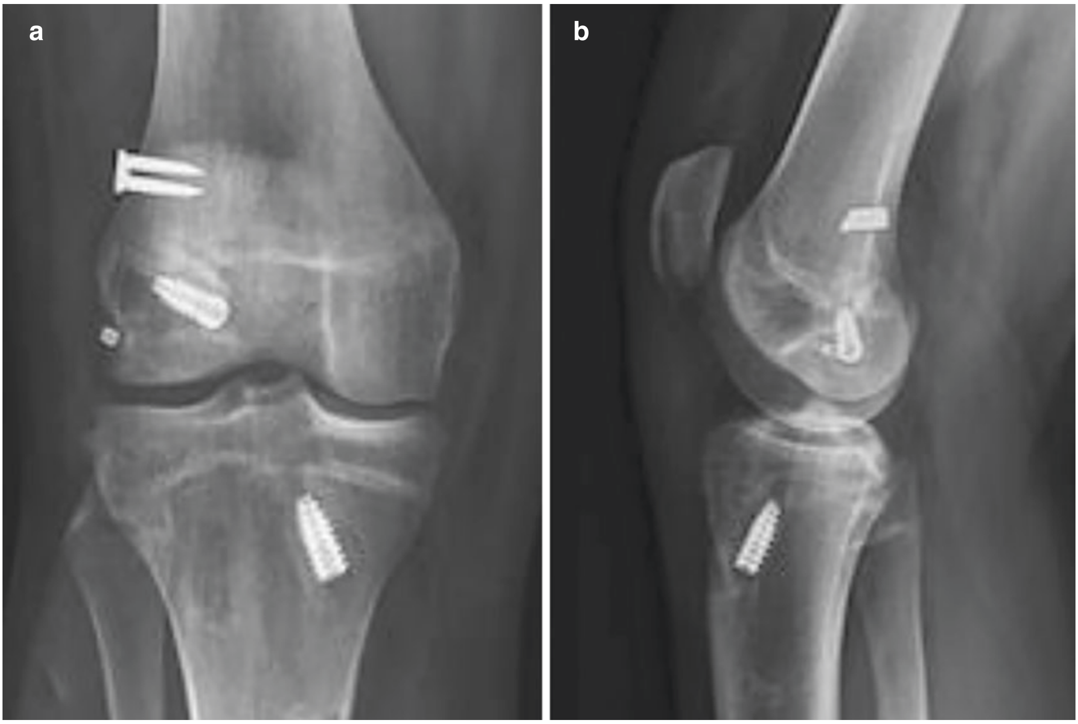

Fig. 4.3 (**a**) AP view (**b**) Lateral view status post ACL revision reconstruction with BTB autograft

comes and graft rupture rates between HT and BTB autograft in the revision setting have been shown across numerous large-scale database studies [2]. A recent meta-analysis showed patients treated with BTB autograft had inferior objective IKDC grades compared with HT autograft and non-irradiated allografts presumably from increased donor site morbidity in the BTB group [12].

Studies on contralateral HT harvest for ACL revision report this as a feasible option with similar clinical and patient-reported outcomes compared with ipsilateral HT harvest and allograft [13, 14]. While a valid option, caution should be taken in young females due to elevated risk of a contralateral ACL rupture secondary to hamstring weakness at index ACL surgery [15]. The ideal candidates for HT autograft are active patients without evidence of hyperlaxity, those seeking to avoid donor site morbidity associated with other graft options, and those objecting to allograft use.

Case 2

An 18-year-old male NCAA Division 1 offensive lineman sustained a non-contact twisting injury to his right knee. He presented with a large effusion and positive 2B Lachman and grade 1 pivot shift exam. Plain film radiographs of his right knee were unremarkable, and MRI was consistent with complete mid-substance ACL tear. He underwent a right ACL reconstruction with BTB autograft using suspensory fixation on the femur and a metal interference screw on the tibia (Fig. 4.4).

He was able to return to Division 1 football activity; however, 2 years after his primary reconstruction, he sustained a second non-contact twisting injury during a game. His exam was consistent with re-rupture of the BTB graft, which was confirmed with MRI (Fig. 4.5). Given his young age and goals to return to Division 1 football, revision ACL reconstruction was recommended.

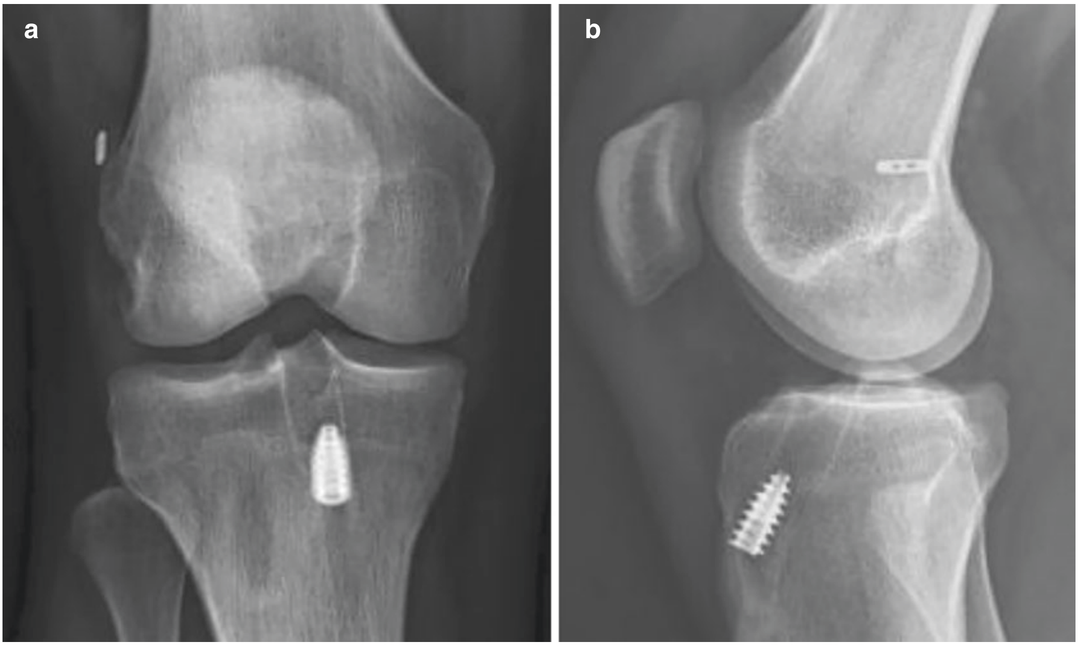

Fig. 4.4 (**a**) AP view (**b**) Lateral view status post primary BTB ACL reconstruction

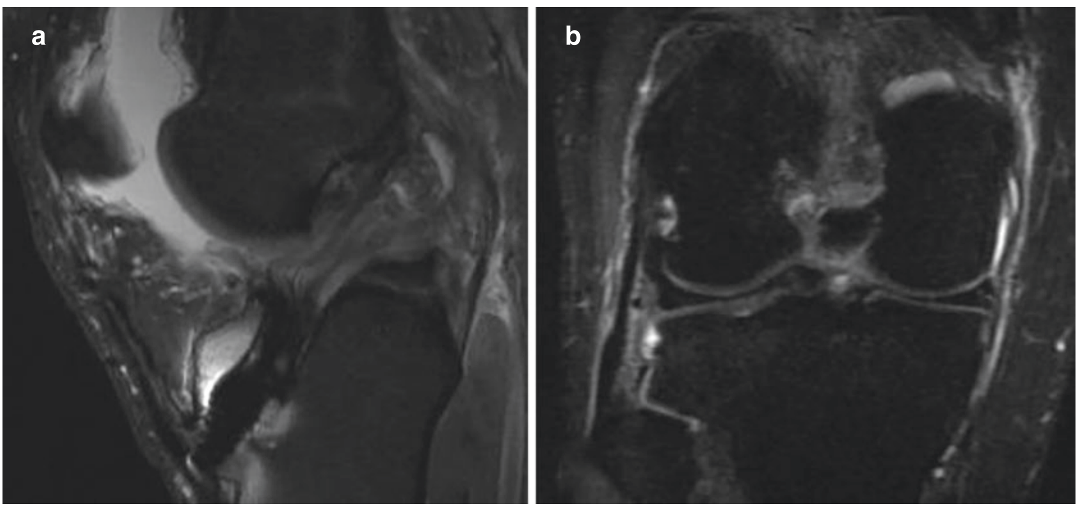

Fig. 4.5 (**a**) Sagittal MRI (**b**) Coronal MRI cuts of ACL graft failure

When considering graft selection for this patient, several factors were considered including his young age and involvement in high-level intercollegiate cutting and pivoting athletics. In view of these variables, autograft was selected, with deliberation between ipsilateral HT or QT. Contralateral BTB was also discussed with the athlete; however, he wished to avoid donor site morbidity to his healthy, unaffected extremity. Given the previous non-anatomic femoral tunnel location and minimal widening, HT autograft was selected for the revision reconstruction.

At the time of revision, an all-inside technique was utilized. The semitendinosus and gracilis grafts were harvested from the ipsilateral knee and fashioned to a four-strand 10-mm diameter. The femoral and tibial tunnels were reamed with an outside-in technique. The previous bone plugs from the primary reconstruction were completely consolidated with no tunnel widening. The tibial metal interference screw was removed to ream the tibial tunnel to healthy metaphyseal bone. The tunnel walls were found to be competent, and the HT autograft was deployed and subsequently secured with suspensory fixation on both sides (Fig. 4.6). He successfully completed rehabilitation with objective return to sport testing and was able to return to football 10 months after his revision HT ACL reconstruction.

Quadriceps Tendon Graft

The quadriceps tendon (QT) has gained increasing attention as an option for both primary and revision ACL reconstruction. Given its larger average graft thickness, the QT can be harvested with or without a bone block and either using two or three layers of the QT. The thickness of the QT has been measured to be an average of 18 mm in males and 16 mm in females [16, 17]. This thickness is compared with a thickness of less than 6 mm for normal BTB grafts [16–18]. The intra-articular volume of harvested QT has also been found to be 87.5% greater than harvested BTB,

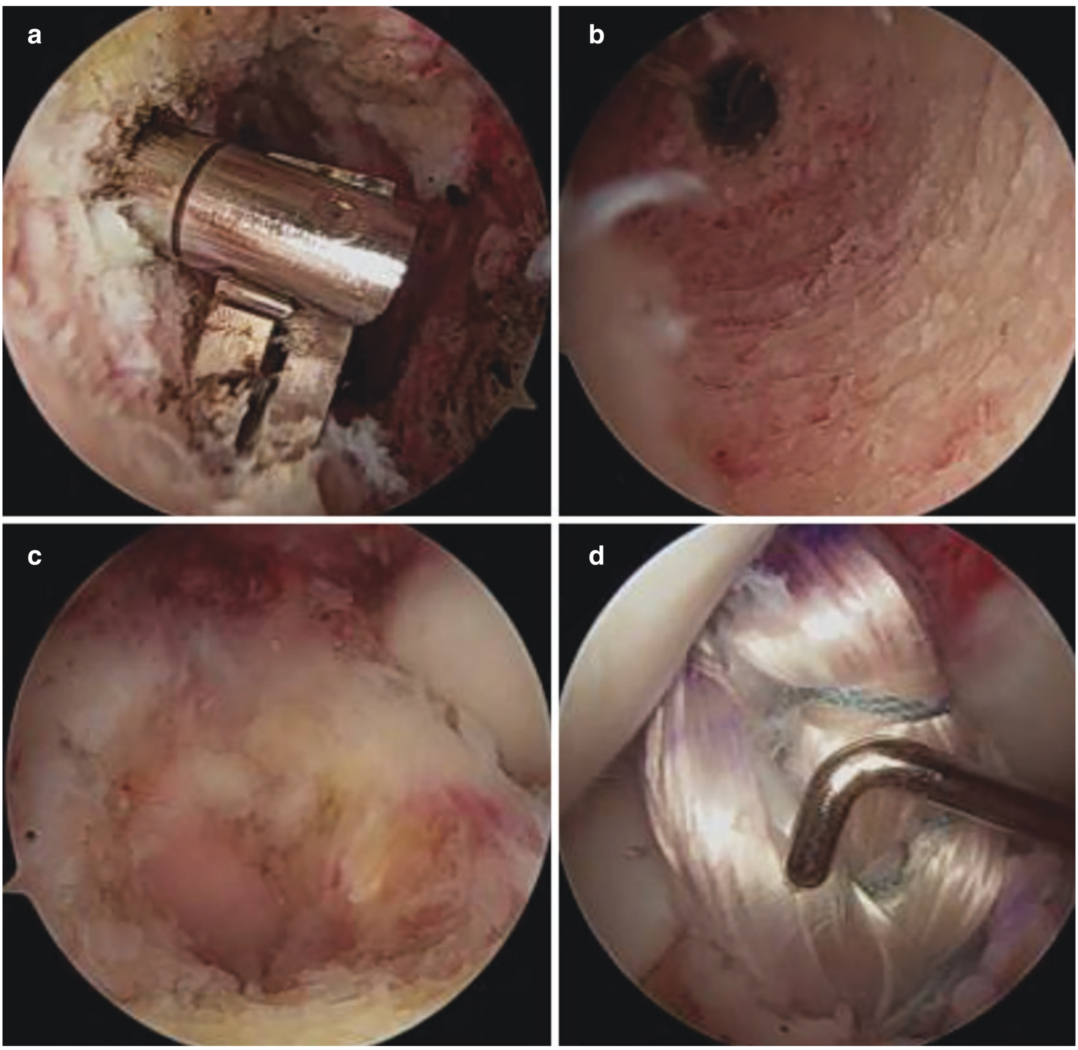

Fig. 4.6 (**a**) Arthroscopic imaging of retrograde reamer (femur) (**b**) Femoral tunnel (**c**) Tibial tunnel (**d**) HT autograft

and after the harvest, there was significantly more QT remaining than BTB [18]. Similar to the BTB bone plug, a quadriceps bone block can also be used to augment bone loss from widened tunnels with the possibility of less donor site morbidity. In addition to robust tissue volume, the QT has lower donor site morbidity and equivalent outcomes to other autograft types [19–21].

A recent study compared ipsilateral QT with contralateral HT autograft for ACL revision and found no differences in revision rates, postoperative knee joint stability, or patient-reported outcomes [22]. Utilizing a contralateral QT autograft is also an option; however, there is little literature regarding this option. As with any contralateral autograft, the primary reservations often center around the potential donor site morbidity to the uninvolved extremity. Younger athletic patients, particularly those with open physes, patella alta, or pre-existing anterior knee pain or patellar tendinopathy, are among the ideal candidates for QT autografts.

Case 3

A 17-year-old male with previous history of left HT autograft ACL reconstruction sustained a non-contact twisting injury during a high school football game. He felt immediate pain and swelling. Pivot shit and Lachman examination were positive, and MRI confirmed re-rupture of the HT autograft with prior anatomic tunnel position. Given his young age and wish to continue competitive high-demand sports, revision ACL reconstruction was recommended.

Interestingly the patient also had evidence of patella alta with a large patellar tendon enthesophyte at the inferior pole of the patella (Fig. 4.7). Given his age and commitment to play collegiate football, QT autograft was recommended in order to prevent concerns related to graft tunnel mismatch or pre-existing tendinopathy. His previous surgery was performed with suspensory fixation on both the femur and tibia. A QT autograft with patellar bone block was considered for modest tunnel widening due to the previous soft tissue graft. Alternatively, QT could also be harvested without the bone block if one was more comfortable with soft tissue fixation and tunnel lysis was not a concern. Relative contraindications to BTB in this case included pre-existing enthesopathy with large accessory ossicle and patella alta (Insall-Salvati index 1.5).

At the time of surgery, the central third 10 × 70 mm of the QT was harvested taking a 10 × 20 mm bone block (Fig. 4.8). An over-the-top femoral footprint guide and tibial guide were used to create a 10-mm and 10.5-mm tunnel, respectively, after sequential tunnel dilation.

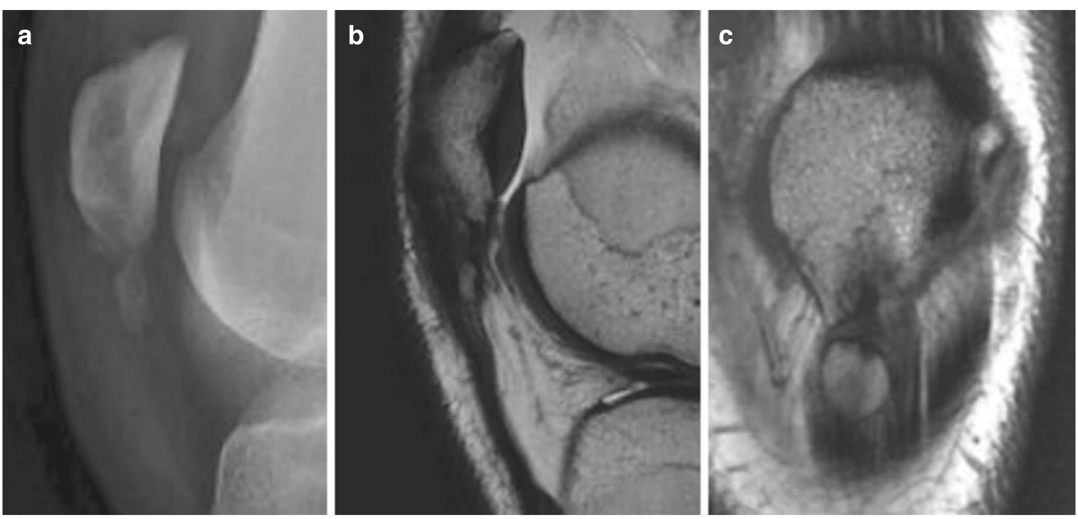

Fig. 4.7 (**a**) Lateral X-ray (**b**) Sagittal MRI (**c**) Coronal MRI showing enthesophyte at inferior pole of patella

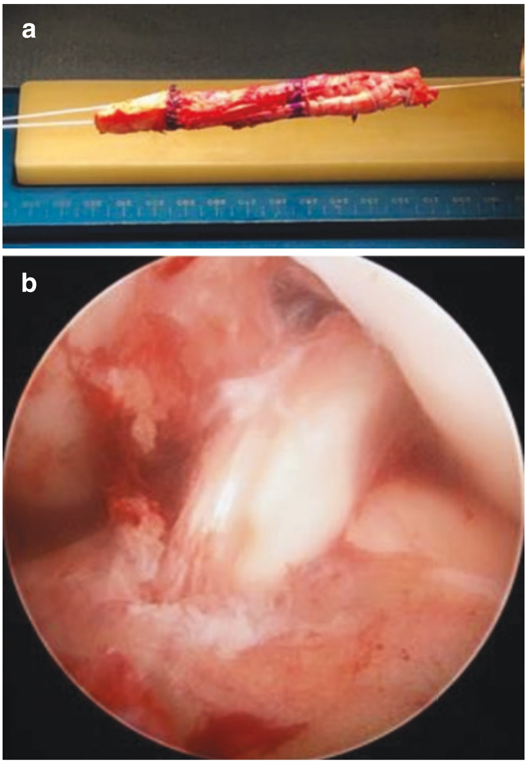

Fig. 4.8 (a) QT autograft after harvest (b) QT autograft after fixation

Careful scrutiny and direct "tunneloscopy" revealed a competent back wall with surrounding healthy reamed bone devoid of prior graft tissue. The QT graft was then deployed with the bone plug on the femoral side and soft tissue end towards the tibia (Fig. 4.9). After tapping, two PEEK interference screws were then placed in the femur and tibia, with sizes 7 mm and 10 mm utilized, respectively (Fig. 4.9).

By nearly 10 months postoperatively, the patient had a successful rehabilitation with no donor site morbidity, residual strength deficits, or limitations in terminal range of motion, and he has been able to return to competitive sport.

Allograft

Unlike primary ACL reconstruction, graft choice during revision cases can be limited by prior autograft use. Among these, numerous allograft options exist for revision ACL reconstruction and may offer the advantages of shorter operative times, smaller incisions, single- or two-staged reconstruction, and ability to obviate

Fig. 4.9 (a) AP view (b) Lateral view status post revision QT ACL reconstruction

donor site morbidity. BTB, HT, posterior tibialis (PT), and Achilles allografts are commonly used in the revision setting. Use of a larger allograft, such as an Achilles allograft and hemi-patellar (or whole tendon) allograft, can allow for customization of bone block sizing to accommodate larger tunnel diameters seen with prior interference screw fixation, tunnel osteolysis, or subtle tunnel malposition. However, the disadvantages need to be dually considered, including longer incorporation times, potential disease transmission, and higher cost. It has been well documented that younger patients experience disproportionally higher re-rupture rates during revision surgery with allograft use [4, 12]. Several large-scale studies have also reported up to four times higher failure rates for primary [23] and two times higher in the revision setting [24]. Conversely, patients of increased age (i.e., >40 years) and/or lower physical demands are more appropriate candidates for allograft, and their use should be used with caution in young competitive athletes.

Furthermore, tissue processing and sterilization of allografts also must be taken into consideration. Several studies have demonstrated that non-irradiated and fresh allografts have similar failure rates to autograft. Conversely, there is a corresponding higher rate of failure in irradiated allografts, even at lower doses [4, 12, 25]. A systematic review compared autograft to non-chemically treated and non-irradiated allograft tissue during primary ACL reconstruction. The authors noted no differences between the two groups in terms of Lysholm scores, IKDC scores, Lachman examinations, pivot shift testing, KT-1000 measurements, or failure rates [25]. In addition, another group evaluated 5986 primary ACL reconstruction cases and found the use of BioCleanse and graft irradiation of >1.8 Mrad were associated with a higher risk of revision when compared with all other methods of processing [26]. A recent meta-analysis including 32 studies looked at outcomes of revision ACL reconstruction, comparing the use of autograft and irradiated (2.5 mRad; 2 studies) and non-irradiated allograft (7 studies) [12]. Autografts exhibited better outcomes than allografts, with lower postoperative laxity and rates of complication and reoperations. However, outcomes were similar between autografts and allografts after exclusion of irradiated allografts.

One of the goals of the Multicenter ACL Revision Study (MARS) cohort was to determine if revision ACL graft choice predicts outcomes related to sports function, activity level, OA symptoms, graft re-rupture, and reoperation at 2 years following revision [4]. In this study, 1205 patients underwent revision ACL reconstruction at a mean age of 26 years old, and the distribution of graft selection was 48% autograft, 49% allograft, and 3% hybrid autograft/allograft. The use of autograft predicted improved score on the IKDC, KOOS subscale Sports and Recreation, and KOOS subscale Quality of Life. Importantly, the use of an autograft resulted in patients 2.8 times less likely to sustain a subsequent graft rupture than if an allograft was utilized. No differences were noted in re-rupture or patient-reported outcomes between soft tissue and BTB autografts.

Case 4

A 42-year-old male sustained a twisting injury at work and felt immediate pain and swelling. His exam was consistent with a left ACL tear which was confirmed with MRI. He underwent soft tissue allograft ACL reconstruction via a trans-tibial technique by an outside surgeon with suspensory fixation on the femur and bioabsorbable screw on the tibia (Fig. 4.10). He was able to rehabilitate his knee and return to recreational sports; however, while playing basketball he sustained a twisting injury and was diagnosed with a re-tear of his allograft ACL reconstruction.

Given his age and activity goals, it was recommended he undergo revision ACL reconstruction. His goals were to return to recreational sports including basketball and running. Preoperative imaging was obtained including MRI and CT scan to evaluate for tunnel widening (Fig. 4.11). The MRI revealed complete rupture of the allograft, and CT scan revealed tunnel widening of approximately 14 mm on the tibial side and 12 mm on the femoral side. Given this information it was determined the revision would be

Fig. 4.10 (**a**) AP view (**b**) Lateral view status post primary allograft HT ACL reconstruction

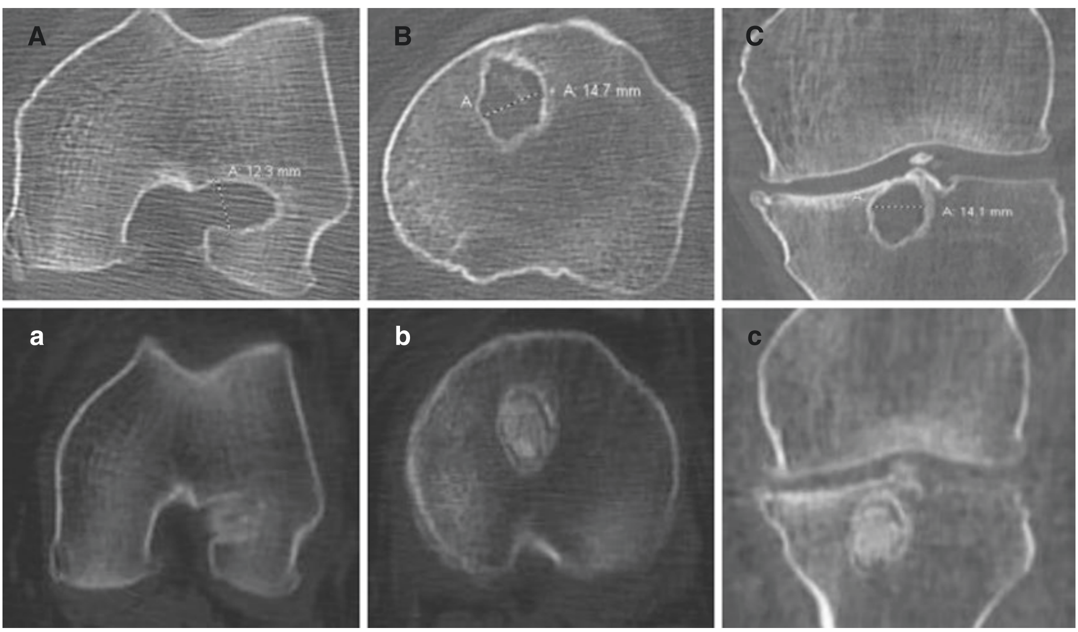

Fig. 4.11 (**A**) Axial CT (femur) (**B**) Axial CT (tibia) (**C**) Coronal CT pre-bone grafting. (**a**) Axial CT (femur) (**b**) Axial CT (tibia) (**c**) Coronal CT post-bone grafting

staged with bone grafting of the defects followed by revision ACL reconstruction.

Taking into consideration the patient's age, activity goals, and previous surgical confounders including tunnel widening, allograft was selected for the revision reconstruction. In choosing between the multiple allograft options, BTB was selected to allow for the possibility of utilizing the bone block to fill any residual tunnel widening and obtain secure fixation with screws.

At the time of surgery, both the femoral and tibial bone grafts had consolidated. With an anteromedial portal technique, an over-the-top footprint guide was utilized for the femur, and a 10 mm socket was reamed. The tibial guide was then used to ream a tunnel in anatomic position. A BTB allograft was then deployed into the tunnels with good fit, and metal screws were then placed with excellent purchase (Figs. 4.12 and 4.13). His postoperative course including reha-

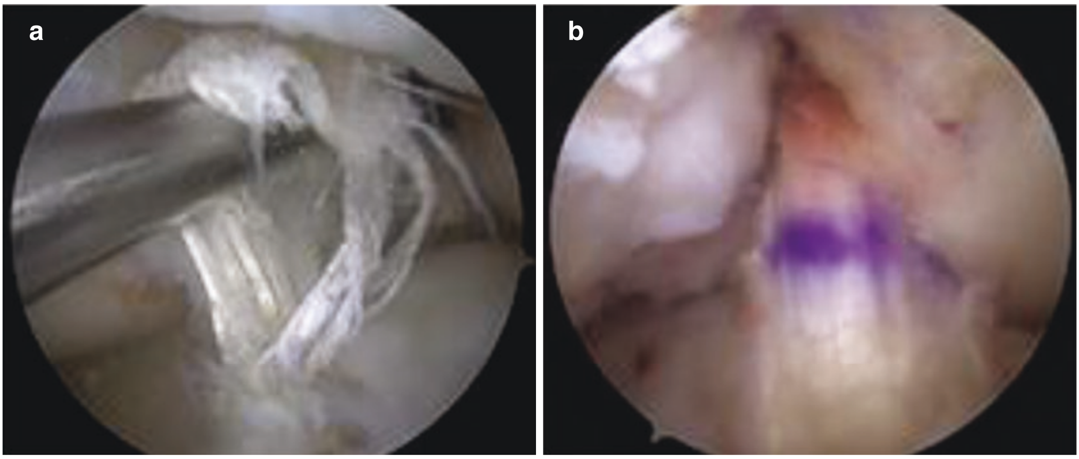

Fig. 4.12 (**a**) Arthroscopic image of failed primary ACL reconstruction (**b**) Revision BTB allograft reconstruction

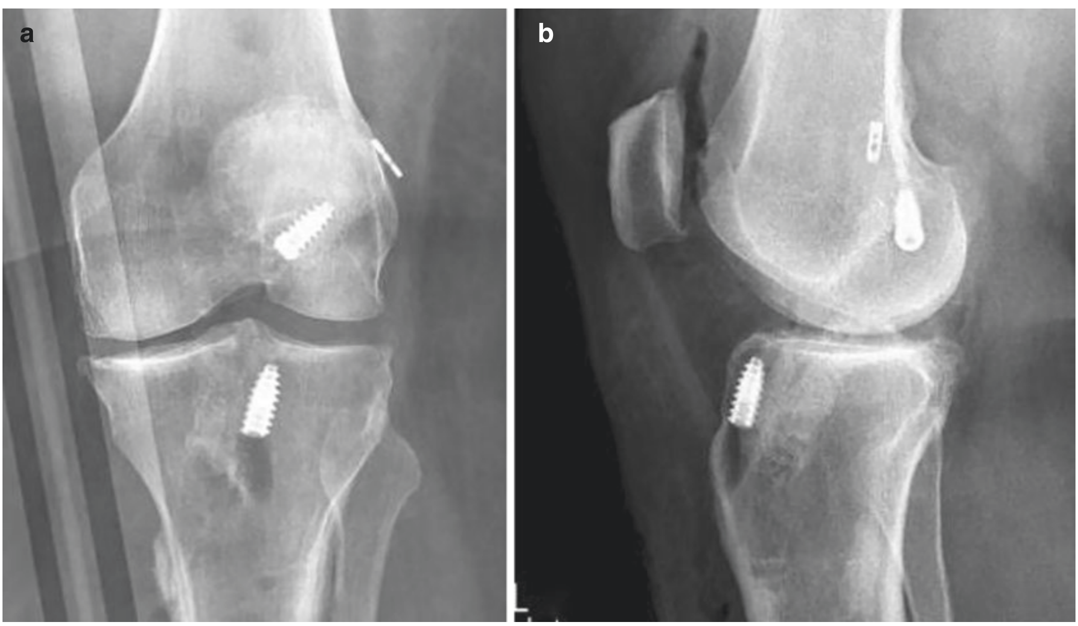

Fig. 4.13 (**a**) AP view (**b**) Lateral view status post BTB allograft revision reconstruction

bilitation was successful, and he has been able to return to activities of daily living and recreational athletics without further instability.

Conclusion

In summary, there are multiple options for graft selection during revision ACL reconstruction, with numerous relative advantages and limitations. In planning for revision ACL surgery, consideration of technical aspects of primary reconstruction, risk factors for failure, and unique patient-specific variables is critical during this decision-making process to ensure an optimal outcome. In addition to patient demographics, one must also evaluate factors such as prior surgical procedures, prior graft use, presence of tunnel widening, previous fixation methods, and patient goals with anticipated future level of activity. Ultimately, a technically well-performed ACL reconstruction is critical for early graft remodeling, function, and longer-term survivorship, regardless of graft selection. However, in many cases, graft selection can impact patient-reported outcomes and surgical success rates, and preoperative planning is essential for appropriate graft selection.

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