One-Stage Revision: Danish Approach

Martin Lind

Contents

M. Lind, MD, PhD
Division of Sports Trauma,
University Hospital of Aarhus, Tage Hansens Gade 2,
DK 8000 Aarhus, Denmark
e-mail: martinlind@dadlnet.dk

35.1 Causes for ACL Reconstruction Failure

35.1.1 Incidence of Failure

The incidence of failure after anterior cruciate ligament reconstruction (ACLR) is highly dependent on the failure definition. Failure after ACL reconstruction can be defined as need for revision ACLR, unsatisfactory outcome scores in objective or subjective clinical outcome instruments like the Lysholm and International Knee Documentation Score, excessive knee laxity above a specific level (typically 5 mm side-to-side increased objective laxity), or continuous subjective knee instability. Since revision ACLR is not performed on all patients with insufficient knee stability or poor subjective outcome after ACLR, then the revision rates after ACLR underestimate the true failure rate. Recent ACL revision rates based on data from national registries have found a revision rate of 4 % after 5 years [31] (Fig. 35.1). Even though the revision rate after ACL reconstruction appears to be relatively low in the range of 4–5 % after 5 years, a higher proportion of ACL reconstruction procedures are presently revision procedures. Data from national registries have shown that approximately 10 % of all ACL procedures are revision procedures [20, 30].

35.1.2 Failure Mechanisms

The main causes for ACL reconstruction failure are new trauma, technical failure, concomitant
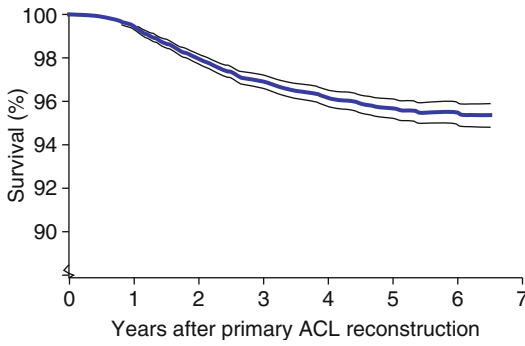
Fig. 35.1 Survival of ACL graft after primary ACL reconstruction. Kaplan-Meier survival profile for 14,878 patients from a national cohort followed for up to 6 years

Table 35.1 Causes for ACL reconstruction failure leading to revision ACL reconstruction as described in the literature

Cause for revision in %	Lind et al. (2012) [29]	MARS Group (2010) [57]	Trojani et al. (2011) [51]
New trauma	38	32	30
Femoral tunnel position	24	19	36
Tibial tunnel position	6	9	11
Tunnel widening	2		
Unknown cause	24	24 (biologic)	15
Fixation failure		5	5

ligament instability, and biological failure. The term biological failure is poorly defined and covers mainly unknown causes for failure (Table 35.1). A recent French multicenter study investigating descriptive data of ACL revision in 293 patients demonstrated that the main causes for ACL graft failure were femoral tunnel position (36 %), new trauma (30 %), and unknown cause (15 %) [52].

35.1.2.1 New Trauma
The main reason for failure of ACL reconstruction is a new trauma. New trauma has been estimated to be the cause for ACL graft failure in approximately 35 % of cases. [31, 59]

In 80 % of cases, the new trauma occurs during sports activities. In some pivoting sports like team handball, the risk for reinjury after ACL reconstruction is very high in the range of 25 % [37].

35.1.2.2 Technical Failure
Recent focus on the anatomy of the ACL insertions and the possibility to perform more anatomical correct ACL reconstructions have revealed that previous techniques resulted in suboptimal tunnel placement especially in the femur, where a tendency to a vertical tunnel placement was a standard until a decade ago (Fig. 35.2). Both too vertical and anterior placement of the tunnels in femur will result in impingement against the posterior cruciate ligament, which will over time result in graft tissue stretching and fretting, which

can lead to new instability. In the tibia a too anteriorly placed tunnel will result in impingement against the roof of the intercondylar notch, and this is another possible failure mechanism caused by graft impingement. Excessive graft tension exerted during surgery has been demonstrated to result in poor graft ligamentation and subsequent increased graft laxity [60]. The implants used for graft fixation in the bone tunnels can also be a cause for failure. Ligamentation and anchorage of the graft to the tunnel wall near the joint normally result in graft incorporation within 3–6 months, so insufficient implant fixation will normally result in early failure. Normal graft loading during rehabilitation can result in forces up to 500 N, so a fixation method needs to withstand forces of this magnitude [50].

35.1.2.3 Biological Failure
Biological failure is often defined as an exclusion diagnosis. If no obvious new trauma or surgical errors exist, a biological failure of some kind must be the reason for failure. However, the biological response of the grafted tissue is related to the mechanical and biochemical environment into which the graft is placed. Thus, the "biological failure" of the ACL graft is a complex pathological entity, and its nature is not insufficiently understood. Biological failure mechanisms can be early extensive graft necrosis, disturbances in

Fig. 35.2 Anterior-posterior radiograph of a patient with a vertical un-anatomical placement of the femoral tunnel. The metal interference screw is seen positioned at the 12 o'clock position

revascularization, and poor cell repopulation and proliferation that lead to late or insufficient ligamentization process [34]. When using allograft tendons for ACLR, an adverse immune reaction can play a role for graft disruption especially for irradiated graft that seems to be able to induce a more extensive immune response than nonirradiated allografts [9].

Tunnel widening following anterior cruciate ligament (ACL) reconstruction is a well-described phenomenon [6, 9, 55]. The basis of tunnel widening is multifactorial with several possible mechanical and biological contributing factors [22]. Suspensory graft fixation results in a more elastic graft construct and may contribute to the so-called bungee effect, which has been suggested to contribute to tunnel widening [11, 22, 38]. Tunnel widening is more frequent when using cortical fixation techniques, such as button fixations or fixation posts, compared to joint-near fixation methods [11]. Suspensory fixation methods in which there is excessive elasticity of the graft fixation implants can result in poor ligamentization in the bone tunnels. Continued adverse mechanical loading between graft and bone tunnel can subsequently lead to tunnel widening. Also resorbable implants can cause cystic bone resorption around the implants due to acidic degradation products that are released during implant degradation [9, 10, 36].

There is however no direction correlation between increased laxity after ACLR and tunnel widening.

35.1.2.4 Concomitant Lesions

Failure to identify and treat injuries to collateral ligaments and PCL can cause increased loads on the ACL graft after reconstruction. Posterolateral instability is the most commonly unrecognized concurrent ligament insufficiency and is seen in 10–15 % of chronically ACL-deficient knees [12].

35.2   Management of Patients with ACLR Failure: History, Clinical Symptoms, X-Ray, MRI, and CT

35.2.1 History

Careful patient evaluation is very important for proper planning and treatment of failed ACL reconstruction. Probably the most important step in the revision surgery is the preoperative planning. This is to avoid repetition of the failures related to the primary ACL reconstruction. Patient activity level and symptom characteristics after primary ACLR should be determined. Subjective complaints of failed ACLR may include instability sensation, pain, swelling, giving way, locking, noise, stiffness, or a limp. It is important to distinguish between pain and instability symptoms. All past operative records should be carefully reviewed for information about the previous intra-articular injuries and treatments. Regarding the previous ACLR it is important to know the type of graft, placement of graft, and graft fixation techniques and the

implants used. Physical examination should include assessment of knee effusion, range of motion, and detailed ligamentous laxity examination. Gait and alignment should be noted. Any valgus or varus deformity should be noted and possibly further evaluated by full extremity radiography. A varus or valgus thrust can indicate concomitant laxity of the medial or posterolateral corner. Such instabilities can be evaluated by valgus and varus stress tests and rotatory tests such as the dial test. Clinical finding of collateral instabilities can further be evaluated by stress radiographs where a side-to-side difference in joint space opening can indicate a significant collateral ligament insufficiency which should be addressed in a revision procedure [27]. Objective tests of ACL laxity include the anterior drawer and pivot-shift tests. Instrumented laxity examination is beneficial, and results can be compared with previous examinations. A side-to-side laxity difference of more than 5 mm has been defined as failure of ACLR [54].

35.2.2 Imaging

The primary investigation is radiographs in two or three planes. These are used to determine the presence and location of hardware. Secondly the radiographs reveal tunnel placements and tunnel widening. Tunnel widening can be measured as the diameter between the sclerotic margins of the bone tunnel [26] (Fig. 35.3). On lateral radiographs sagittal tibial tunnel position at the tibial plateau can be divided from anterior to posterior in four equal quadrants as described by Amis and Jakob [1]. The tibial tunnel should enter the joint in the posterior third of quadrant 2. For the femoral tunnel, Blumensaat line can be divided into four equal quadrants, and the tunnel should be in the most posterior quadrant [2]. On frontal radiographs the tibial tunnel should be in the center of the tibial plateau, and the femoral tunnel should be between 40° and 70° from central vertical axis.
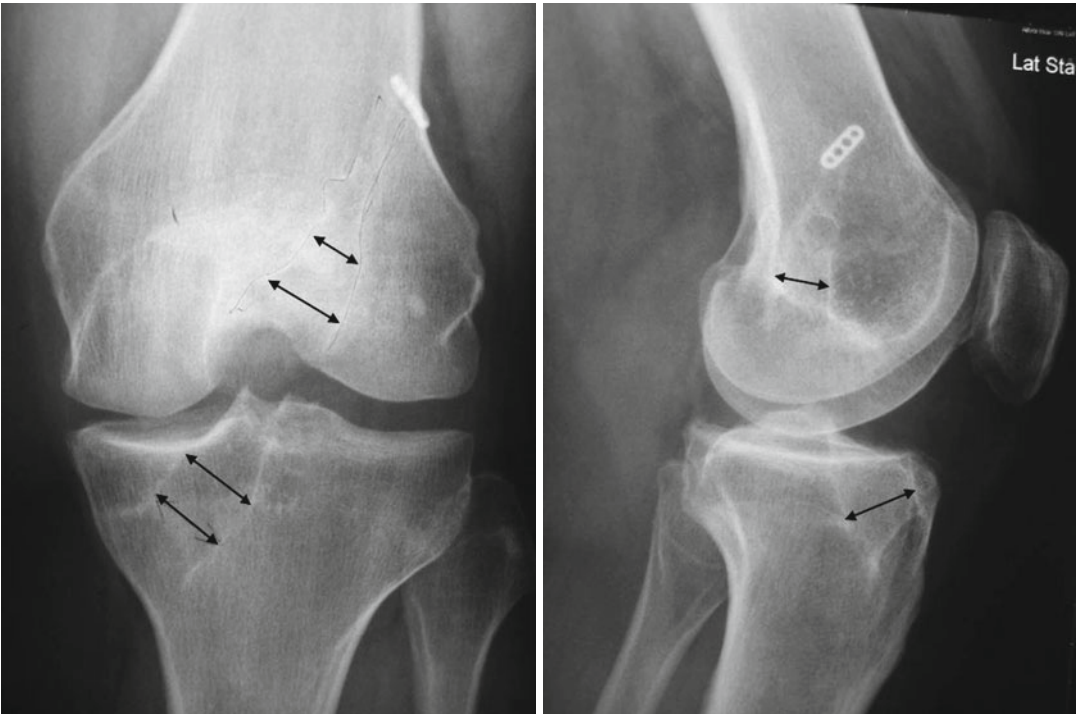

Fig. 35.3 Anterior-posterior and lateral knee radiographs of a patient with significant both femoral and tibial tunnel widening after hamstring ACL reconstruction. *Arrows* indicate the tunnel walls
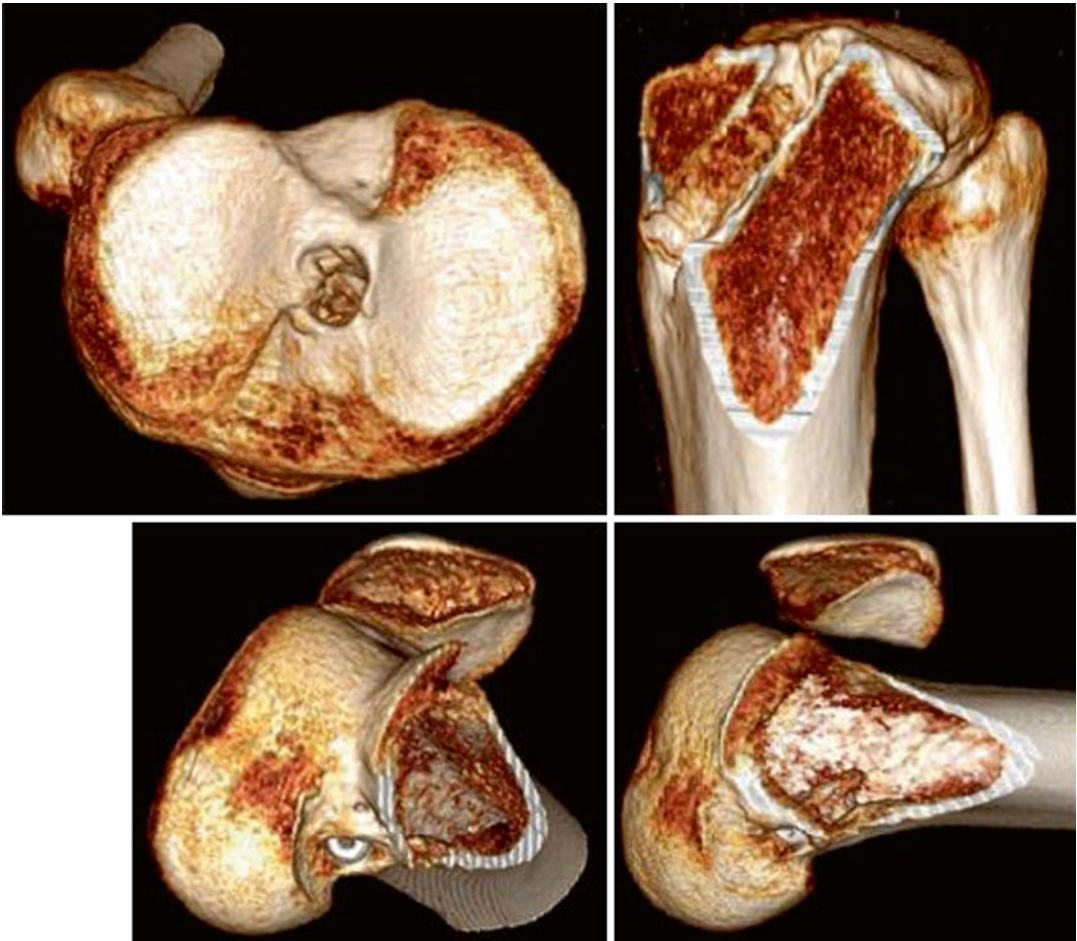
Fig. 35.4 3D reconstruction CT scanning is ideal to identify tunnel position and tunnel configurations prior to revision ACL reconstruction

Magnetic resonance imaging (MRI) is a useful adjunct to the radiological evaluation. MRI scanning can determine the integrity of the reconstructed ACL and evaluate the status of cartilage and menisci.

A CT scanning can supplement evaluation of bone tunnels and tunnel widening and gives more detailed information than the standard radiographs. It is recommended to use supplementary CT scanning if radiographs demonstrate potentially problematic tunnel positions or tunnel widening. 3D reconstructions may further add to the information retrieved from CT scannings especially to identify the tunnel entrances to the joint and to identify possible new tunnel placement (Fig. 35.4).

35.3 Surgical Tactics for Revision: Removal of Implants and Assessment of Bone Tunnels

When planning revision ACL reconstruction, the surgeon should have access to a variety of techniques to deal with malpositioned tunnels, bone loss, tunnel expansion, and implants needing removal. When all informations are available, decisions can be made with respect to timing, removal of old fixation devices (special removal instruments must be available), graft choice, tunnel placement, graft fixation, single- or two-stage technique. To avoid failure of the ACL revision, the patient must be carefully "educated" to prevent early return to sport or pivoting activities.

Thus, it is important that the operation is planned in a period where postoperative rehabilitation period suits the patient's social life and sports activities.

35.3.1 Timing

Before surgery it is mandatory that problems with lack of extension and flexion have been cleared. In some cases this is due to arthrofibrosis or infrapatellar contracture syndrome. In these cases arthroscopic release procedures and intensive rehabilitation must be done prior to revision ACLR.

35.3.2 Implant Removal

If the index tunnels and implants are correctly or nearly correctly placed, the screws have to be removed. Size and mark of screws used in previous surgery must be determined, and the appropriate screwdriver must be available for the surgeon. Care must be taken to remove any bone ingrowth from the inside and around the top of the screw, before the correct-sized screwdriver is engaged with the screw. The screwdriver has to be as parallel to the screw as possible. Stripping or damaging the threads of the screw during either insertion or removal may require a more extensive bone removal and subsequently a staged operation. In case of metallic screws placed in the proximal tibial or when there is complete bony overgrowth, fluoroscopy can be very helpful for identification of hidden screw position. A trick for screw identification is to use a K-wire and to drill the K-wire to the end of the screw using fluoroscopy. Subsequently it is possible to drill with standard reamers to expose the end of the screw, which then can be removed with minimal bone loss.

Changing the angle of drilling and thereby avoiding removal of the originally inserted screw can often facilitate tibial tunnel preparation when a new tibial tunnel is created [16]. Special attention should be given to the "absorbable interference screws," which, although radiolucent, may require removal even several years postoperatively. Poor quality bone tissue might exist around bone tunnels in which resorbable implants have been placed due to inflammatory possesses occurring during implant resorption. Cystic bone resorption has been documented as caused by resorbable implants [9, 10, 36]. Therefore, it is advisable always to remove such implants during revision ACLR procedures.

35.3.3 Tunnel Placement

Probably the most common technical failure of ACL reconstructions is nonanatomical femoral and tibial tunnel placement. Previous standard operative technique for ACLR has been to place the ACL graft in a near upright position in the femur to accommodate the use of femoral offset guides during transtibial ACLR techniques (Fig. 35.2). Only recently rediscovery of anatomical ACLR principles has changed tunnel placement to more correct anatomical positions especially in the femur. Regarding tunnel placement at primary ACLR, there are principally three situations to be considered.

35.3.3.1 Primary ACLR with Well-Placed Tunnels

Well-positioned tunnels with no enlargement can be reused, and routine fixation methods can normally be applied. In case of mild tunnel widening or osteolysis, a graft with a large bone plug may be used, which typically will be an allograft. For femoral tunnel widening a technique using a conical bone plug placed from outside-in has been described. With this technique only press-fit fixation is necessary. Another option in the femur is to use double interference screw fixation to fill up an oversized tunnel [39, 44]. On the tibia side, a large interference screw can be used to fill the tunnel or an allograft can be used with the bone plug sized to the enlarged tunnel diameter. If there is any doubt of the bone quality in the tibia, backup fixation with bicortical screw and washer is recommended. In cases with acceptable tunnel placement, old hardware is removed, and the drill hole is debrided and redrilled by stepwise increasing reamer diameter until a clean bone tunnel is achieved. Straight reamers may be preferred relative to acorn reamers to avoid possible drill migration or drifting. One method for insurance
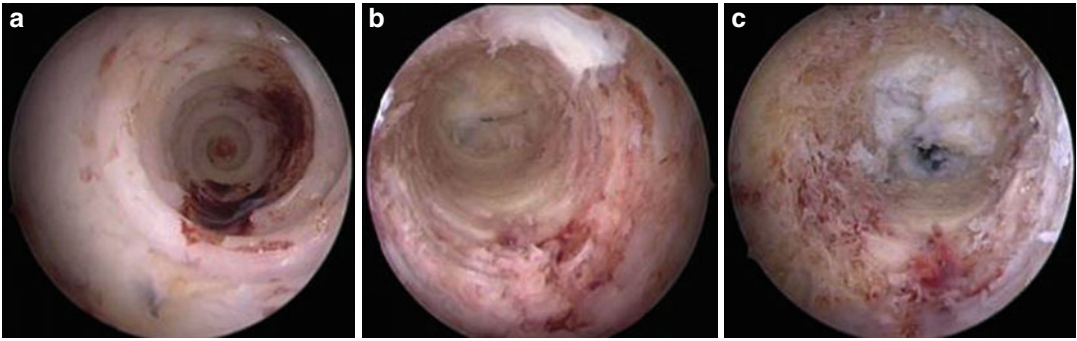
Fig. 35.5 Sequential drilling is essential for tunnel preparation in revision ACL reconstruction. In the (**a**) panel a metallic interference screw has been removed. In panel (**b**) reaming has been performed with an 8 mm reamer. In panel (**c**) reaming has been performed with a 10 mm reamer. The bone tunnel is now clean with fresh cancellous bone in tunnel wall. In the lower deep part of the tunnel, cortical remnants of the bone block from the patella bone autograft used at index surgery are visible

of drill direction is to drill the K-wire into the femoral notch roof during the sequential drilling. Another is to stabilize the tip of the K-wire with an instrument during drilling. Use the arthroscope to look up in the drill hole to make sure that old graft tissue, sutures, and implant remnant are removed and that sclerotic bone is removed from the tunnel walls (Fig. 35.5). In these cases it is normally necessary to increase the graft size from the first to the second operation.

35.3.3.2 Primary ACLR Operation with Malpositioned Tunnels

If a tunnel is clearly malpositioned, a new drill hole can be made through a different approach to obtain a tunnel with more correct anatomical position. In these cases old hardware can be left in situ to optimize the compactiveness of the surrounding bone for the revision fixation procedure. If new tunnels can be placed without confluence of malpositioned index tunnels, routine fixation can be used depending on graft choice and surgeon's experience. However, if the surgeon suspects weakened cancellous bone and thereby reduced fixation strength, extra cortical fixation may be considered. This extra fixation can in the femur be a hybrid fixation principle with cortical button and an interference screw if soft tissue graft is used. Combining a metal interference screw with a bicortical fixation post in the distal femur can enhance femoral fixation of grafts with a bone plug. In the tibia a backup fixation with a bicortical screw and washer can be combined with any intraosseous fixation implant.

35.3.3.3 Primary ACLR with Partly Malpositioned Tunnels

It is important to emphasize that a correct tunnel placement has little to do with the intraosseous placement or angulations. More important is the entry point of the tunnel in the joint. In cases of partially malpositioned tunnel placement, there are options to avoid staged procedures. It is however important to understand that increased tunnel obliquity results in increased tunnel ovularity and opening area.

In case of a partially posterior tibial tunnel, it is possible to correct this by shifting the tibial tunnel 2–3 mm anterior during the reaming and debridement of the primary tunnel. During graft fixation an interference screw is placed posterior to the graft and close to joint entry to ensure that the graft heals to the anterior aspects of the new tunnel. A similar principle can be used for partially anterior tibial tunnel, where the tunnel instead is shifted posteriorly and the screw is placed anterior to the graft. Care should be taken during screw placement in these cases since the anterior screw position can cause fracture to the anterior cortex. Also the tunnel length is short in the anterior aspects of an anteriorized tunnel so that the tip of the screw might enter the joint

space causing graft impingement or cartilage damage to femur joint surface. In the femur the typical problem with a partially malplaced tunnel is a tunnel that is moderately high in the notch but where preparation of a new tunnel might result in communication to the old tunnel during drilling. In such cases hardware in the old can be replaced by a composite bioresorbable screw or a PEEK screw. These screws can accept minimal damage during drilling of the new tunnel. It is advisable to use a composite resorbable screw containing hydroxyapatite calcium phosphate since these screws resorb very slowly and integrate well with surrounding bone, which will maintain bony integrity around the revision femoral bone tunnel [42].

Fluoroscopic imaging can be a valuable tool during revision ACLR procedures both for hardware removal and for optimization of tunnel positioning.

35.3.4 Revision After Double-Bundle ACLR

The recent focus on double-bundle ACLR will in the coming years lead to an increasing number of patients that need revision of failed double-bundle reconstructions. Revision in these cases exerts special challenges since we lack experience with the problems created of having four tunnels that need revision. The issue of having two tunnels in both the tibia and femur will make single-stage revisions more difficult. The safest option will be to choose a staged procedure with initial bone grafting of all four tunnels. An option for single-stage approach will be to perform a single-bundle revision of the anteromedial ACL bundle after filling the posterolateral tunnels with cortico-cancellous allograft plugs or allograft screws.

35.3.5 Concomitant Ligament Lesions

As previously mentioned, several cases of graft failures are caused by overload of the graft due to concomitant ligament lesion not detected at the time of the primary reconstruction. Isolated revision of the torn ACL graft without restoration of other ligament insufficiencies might lead to a new graft failure due to overtensioning, which can cause lack of graft incorporation in the bone tunnel and poor intra-articular tissue ingrowth and revascularization. Also concomitant ligament insufficiency can result in graft rupture due to new episodes of giving away when the patient returns to sports. Thus, it is advisable that concomitant ligament lesions with laxity of more than IKDC grade 3 and 4 should be reconstructed at the time of the ACL revision procedure. Standard collateral ligament reconstruction techniques should be used [28, 61]. Especially if rotatory instability is present in combination collateral ligament instability. Rotatory instability can be detected clinically by dial test and external and internal rotatory tests [32].

35.3.6 Rehabilitation

The postoperative rehabilitation protocol depends on a variety of factors. Important surgical factors to consider include the type of graft used, fixation stability, concomitant reconstruction of secondary stabilizers, and any meniscal or cartilage pathology. Patient considerations include age, activity level, size, compliance, and expectations of the patient. The rehabilitation can in most cases follow the principles for primary ACL reconstruction. However, if the graft fixation strength is not optimal, a more restrictive rehabilitation regimen must be used. The use of braces in ACL surgery is controversial and is still under debate with respect to primary ACL reconstruction [58]. Risberg et al. found in a randomized controlled trial (RCT) no difference between use and nonuse of braces in primary ACL reconstructions [3]. No RCT has been described in revision ACL surgery. However, biomechanical investigations indicate that braces can reduce load on the reconstructed ACL graft in both weight-bearing and non-weight-bearing situations. In the noncomplicated revision situations, brace usage is probably not indicated. In cases of poor bone quality and suboptimal graft fixation, a brace and reduced range of motion for 4–6 weeks

can be used to ensure reduced graft loading during the initial phases of graft healing. In cases where valgus or varus instability has been treated with collateral ligament reconstruction, the use of brace is needed in the period where the graft undergoes revascularization and incorporation to bone tunnel (6–10 weeks) [4, 53].

35.4 Indication for One- or Two-Stage Revision

The primary indication for considering revision ACLR is recurrent knee instability after previous ACLR. If the patient complains of reoccurrence of sudden knee failure and sensation of subluxation, then these symptoms are signs of graft failure, which potentially can be managed with a revision ACLR. Pain and problems with range of motions after ACLR are not necessarily corrected by a revision ACLR and should therefore be evaluated and treated independently. There is good evidence in the literature that a revision ACLR can restore knee stability to almost the same level as a primary reconstruction [29, 31]. However, symptoms and function and patient's subjective perception of knee functions are poorer than after primary ACLR [29, 31]. Indications for staged surgery should be reserved to cases where the quality of bone either at the joint entry points or in the fixation zones in the tibia or in the lateral femoral condyle is too poor to perform a one-stage revision ACLR with proper tunnel placement and secure graft fixation. Another indication is in cases with partly incorrectly placed bone tunnels, where the new graft position cannot be corrected by redrilling combined with graft bone block position or fixation implant positioning. In the first situation, insufficient graft fixation and potential poorer graft incorporation can lead to new mechanical failure. In the latter situations, a one-stage procedure probably would result in a repetition of the failure due to the same poor graft position that resulted in failure after the primary procedure. To avoid the above-mentioned problems, a staged procedure is necessary.

Staged revision ACLR involves in the first stage procedure removal of all hardware, debridement, and redrilling of the old tunnels with oversized drill diameter to remove sclerotic bone in the tunnel wall and subsequently autologous or allogenic bone transplantation in both femoral and tibial drill holes. Normally bone allograft is used as either milled bone chips or bone plugs drilled out from a femoral head. The bone graft tissue is subsequently compressed into the debrided tunnels. Autologous bone graft is normally harvested from the iliac crest. The second stage operation is performed 4–6 months later when the bone graft has been incorporated in the bone tunnel. A CT scanning is performed prior to the second stage procedure to ensure proper incorporation of the allograft bone in the tunnels (Fig. 35.6). A significant advantage at the second stage procedure of revision ACLR is that the construction typically can be performed like a primary reconstruction.

However, since studies have indicated that increased time to revision correlates with development of radiographic arthritis and meniscal and chondral lesions, the surgeon must use caution when deciding for a 2-stage procedure when a 1-stage procedure may be sufficient [40]. A 2-stage revision normally requires a 4- to 6-month window between procedures. This will subject patients to a prolonged period of continued knee instability, which may result in further cartilage and meniscal injury to the involved knee. Two-stage protocols also require a second anesthetic and further periods of activity modification. When possible, preference should be given to a 1-stage procedure in all situations in which adequate placement and fixation of the graft can be achieved.

35.5 Graft Choice and Surgical Technique (Table 35.2)

A major surgical strategy issue is which graft to choose for revision ACLR. In the literature there is very sparse evidence for which graft type provides the best outcome. The choice primarily stands between autografts and allograft. The choice of graft depends on which grafts have been used at the index surgery and on the placement of tunnels and tunnel size after debridement. Also the previous fixation method has to be taken into consideration during the planning along with the

Fig. 35.6 Standard radiographs of a patient with tibial (**a**) and femoral (**b**) tunnel widening. The patient was treated with a staged revision ACL reconstruction. After bone grafting a CT scanning was performed 5 months later to confirm proper bone tunnel filling and incorporation of the bone graft in the tibia (**c**) and femur (**d**)
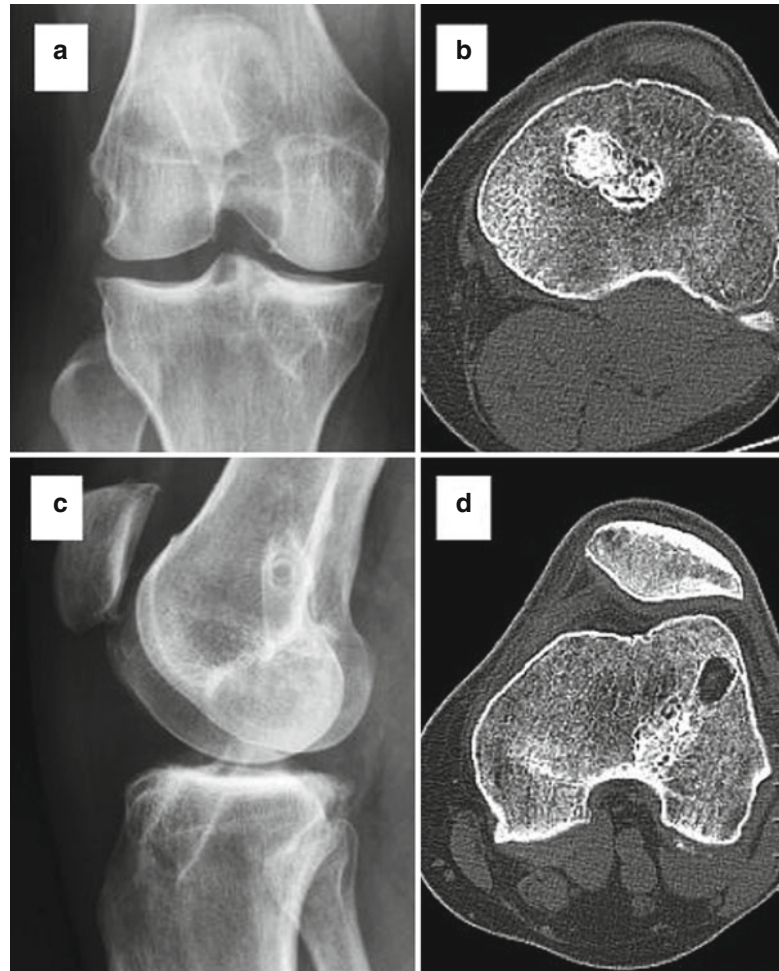

Table 35.2 Technical tricks and pearls

Removal of screws hidden in bone	Blindly drill K-wire to identify screw location. Then sequentially drill hole for removal of screw
Graft translation in partially malpositioned bone tunnels	Position graft fixation implant so that the graft is translated in the needed direction
Tunnel widening	Healthy bone tissue is typically found 1–2 mm earlier than the sclerotic bone margins seen on radiographs. Await staging decision until after bone debridement
Partially malpositioned tunnels	Reusage of partially malpositioned tunnel induces a risk for poor graft positioning and graft impingement. A low threshold for staged procedure is a good strategy in these cases

suspected reason for failure of the previous graft. Other factors of importance are patient's age, general health, activities of daily living, and specific sports demands postoperatively [44]. In the literature there is a tendency to favor autografts over allograft. This strategy is supported by a recent study based on a national cohort of revision ACLR patients demonstrating a twofold increase in failure rate for revisions performed with allografts compared to autografts [31].

If the primary surgery was performed with a hamstring graft and the tunnels are placed acceptable, the preferable graft choice would be to use ipsilateral patella-tendon-bone or a quadriceps tendon graft with dimensions of the bone plugs cut to match the size of the bone tunnels. After hamstring graft primary surgery, the typical

tunnel issues are moderate tibial tunnel widening (up to 12 mm) and posterior tibial tunnel placement due to transtibial technique at primary surgery. A graft with bone plugs can be fitted into tunnels with moderate tunnel widening or misplacement. A moderately posteriorly placed tibial tunnel can be corrected by ensuring that the tunnel is redrilled 2–3 mm anteriorly. With a bone plug in the new tibial tunnel, the graft can be shifted anteriorly by placing the tibial interference screw posterior to the bone plug. In cases where the index surgery was with patella tendon bone graft and the tunnels are placed acceptable, the use of hamstring grafts from either the ipsilateral or contralateral side depends on the diameter of the tunnels and/or the position of the tunnels. In cases of previous patella-tendon-bone graft usage, there is typically no tunnel widening as the patella-tendon graft bone plugs have been integrated into the tunnels. If tunnel widening has developed, a 7–9 mm hamstring graft can be too small for proper filling of the debrided tunnels. In these cases an allograft or a staged procedure with initial bone grafting is advocated. After bone grafting a problem-free usage of hamstring autograft for the second stage procedure can be performed. Another typical tunnel placement problem due to transtibial technique is a too vertical femoral tunnel placement. Often it is possible to drill a new femoral tunnel at the correct anatomical femoral ACL attachment position using drilling through the anteromedial portal.

Thus, it might be difficult to go from patella tendon graft to hamstring graft at revision procedures due to smaller graft diameter of the hamstring tendons, but more feasible to go from hamstring graft to patella-tendon-bone graft.

When an autologous tendon graft is planned for revision ACLR, the graft must be harvested as the last surgical step after determining if all the technical steps of the revision can be implemented [7].

When using allografts for revision ACL surgery, donor site morbidity issues are eliminated, but allograft usage adds concerns for bacterial or viral contamination from the graft, even though these risks are very minimal [35]. Allografts should be used as fresh frozen, because grafts treated with irradiation have shown significant worse results in recent studies [41, 45]. Allografts should not be obtained from too old donors as the tendon-to-bone interface weakens with increasing patient's age [56]. The preferred allografts for revision ACL surgery are patella tendon bone grafts, quadriceps tendon grafts, and Achilles tendon grafts, but also soft tissue graft such as tibialis tendon grafts can be used. Both deep frozen and cryopreserved allografts have been shown to repopulate with host cells and to reinnervate with nerve fibers (A fibers, afferent, and efferent C fibers) [19, 48]. Both allografts and autografts provide a fibrous framework for new ligamentous healing. Maximal tensile strength of allografts is less than that of autografts, but stronger than the native ACL if the diameter of allograft is sufficient [46, 47]. Due to these biomechanical issues, it is advisable to use allografts with a diameter of 10–11 mm. When using allografts, it is imperative that the surgeon is knowledgeable with graft processing techniques and the Tissue Banks certification. In the setting of multi-ligament reconstructions, in which also revision ACLR is performed, allograft tissue can diminish surgical time and associated surgical site morbidity. Also allografts might be the only options since potential autografts might have been used at the primary ACLR.

Use of the contralateral knee graft is an option, especially in situations where allograft tissue is unavailable. In some European countries, legal issues prevent the use of allograft tissue. A major issue with contralateral graft usage is the potential introduction of donor site morbidity to a healthy knee. Patella tendon harvest is associated with more donor site morbidity than hamstring harvest with a higher incidence of anterior knee pain and kneeling problems [24, 25]. If contralateral graft harvest is necessary, it is advocated to harvest hamstring grafts instead of patella tendon graft.

Presently there is no documentation for a place for synthetic grafts in revision ACLR [17]. Recently a new synthetic graft type, the Ligament Advanced Reinforcement System (LARS), has gained some popularity in selected countries. This synthetic graft has advantageous mechanical properties and could therefore be an option

for revision ACLR for athletes with high demands for knee function. However, the literature is still limited regarding outcome and complications [33]. The poor history of previous synthetic ACL grafts should lead to caution about usage of synthetic grafts for revision ACLR.

Graft choice in revision ACLR surgery is therefore based on detailed knowledge of the history of the previous surgery, tunnel placement, bone quality, and the availability of grafts and on the surgeon's experience and preferences. An algorithm for management strategy can be seen in Fig. 35.7.

35.6 Pitfalls and Complications

35.6.1 Technical Pitfalls (Table 35.3)

Numerous potential technical pitfalls exist when performing revision ACLR.

In cases of anteriorly placed tibial tunnels where revision is performed without staging, there is a potential risk for fracture of the anterior tibial cortex if the new tibial fixation screw is placed between the graft and the anterior tibial cortex wall. This technique can be used to correct the graft position into a more posterior direction, but care must be taken when placing the fixation implant to avoid cortical fracture which can result in long-term pain problems and fixation failure. In the similar situation where a screw is used to correct graft position in an anteriorly positioned tunnel, there is a risk for screw protrusion into the joint since the anterior aspects of the tibial tunnel are shorter than the average tunnel length. Thereby a screw length and tunnel length mismatch can occur. Recently there has been a trend to drill more horizontal tibial tunnels for transtibial single-bundle ACL reconstruction in order to be able to reach the anatomical insertion area when drilling the femur tunnel. Care should be taken to
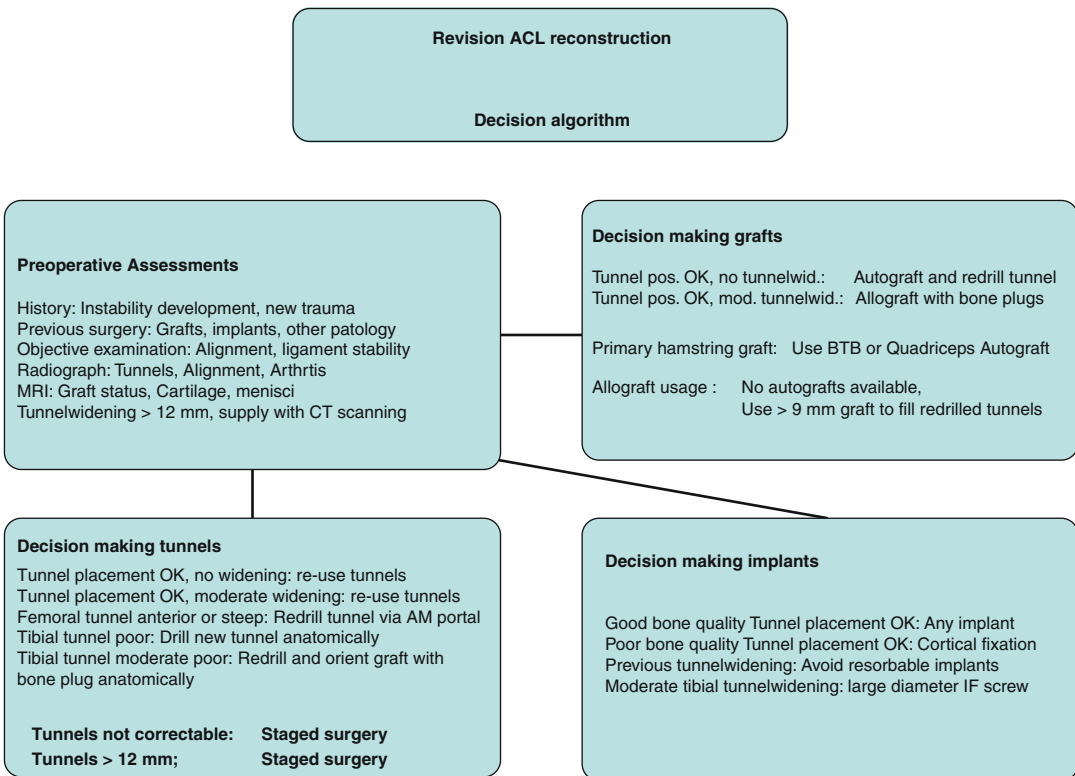

Fig. 35.7 Algorithm for revision ACL surgery

Table 35.3 Technical pitfalls

Implant protrusion	Reuse of partially misplaced bone tunnels increases the risk of implant protrusions
Tibial plateau collapse	Horizontal tibial tunnels established when trying to attempt anatomical femoral drill hole position can undermine tibial plateau when debrided further for revision reconstruction. Consider staged procedure
Anterior tibial cortex fracture	Insert implants with care when placed anteriorly to the graft in the tibia
Associated ligament insufficiency	Be prepared to reconstruct collateral ligament if found to be insufficient during the procedure

reuse such tunnels during ACL revision procedures. Redrilling of a tunnel just below the medial tibial plateau might result in too extensive removal of subchondral bone with subsequent medial tibial cartilage collapse as a complication.

When performing tunnel bone transplantation in staged procedures, an easy solution is just to remove the screw and then only transplant the screw cavity. This typically results in poor bone quality in the proximal and joint-near part of the tibial tunnel. It is therefore advisable to debride and transplant the entire tunnel during staged procedures.

35.6.2 Complications and Failure After Revision ACLR

Only two studies have studied large enough cohorts of revision ACL patients to determine reliable failure rates. In a national cohort re-revision occurred in 5.4 % of cases within 5 years. In a case series of 126 patients, 6 % were re-revised after average 6 years [29]. Lack of improvement of knee stability was seen in 15 % of patients, and this failure definition was not different from after primary ACLR where 12 % demonstrated lack of stability improvement. Another important type of failure after revision ACLR is chronic pain problems, which can result in significant disability. As chronic pain normally does not result in re-revision ACLR, the incidence

of this complication is poorly described in the literature. It is thought that the most likely cause for chronic pain is the accumulated injuries to cartilage and menisci combined with scar tissue formation due to multiple surgeries [52, 57].

35.7 Literature Results

35.7.1 Results After Anterior Cruciate Ligament Revision Surgery

Most of the literature on revision ACL reconstruction is related to technical aspects of performing revision procedures such as different fixation methods and graft types. The studies evaluating the outcome of revision ACL reconstruction have typically involved small case series and therefore have low level of evidence. Recently national registries and multicenter study collaborations like the Multi-center ACL Revision Study group (MARS group) have generated study populations that more reliably present epidemiology and outcome in relation to revision ACLR [30, 59] (Table 35.4). Weiler et al. compared the subjective and objective results after revision ACL minimum of 2 years postoperatively to a matched group of patients who had primary hamstring ACL reconstruction. They demonstrated 6.5 % in the revision group who experienced graft failure, compared to 5.6 % in the primary reconstruction group. The manual maximum KT-1000 arthrometer side-to-side difference was 2.1 ± 1.6 mm for the revision group and 2.2 ± 1.1 mm for the primary reconstruction group. The Lysholm score was significantly better in the primary reconstruction group. The incidence of postoperative positive pivot-shift test results was not significantly different [54].

Recent data from the Danish register for ACL reconstruction have demonstrated results after revision ACLR for a national prospective cohort. Tegner and KOOS scores increased significantly from preoperatively to postoperatively (Tegner score from 3 to 4, KOOS symptoms 50–57, KOOS pain 66–77, activity of daily living 73–83, KOOS sports 32–51, KOOS

Table 35.4 Clinical outcome after revision anterior cruciate ligament reconstruction in different previous studies

Author, year, reference	Study design	Number of patients	Follow-up (years)	Outcome measure	Results at follow-up
Noyes et al. (2001) [39]	Cohort	54	2.7	Cincinnati	87
Taggart et al. (2004) [49]	Case series	26	1–5	Lysholm	85
				Tegner	4.8
Fules et al. (2003) [14]	Case series	26	4.2	Lysholm	87
				Obj. IKDC	B 22/26
Grossman et al. (2005) [21]	Case series	27	3–9	Lysholm	87
				Tegner	5.2
Lind et al. (2012) [29]	Case series	128	2–9	KOOS	Symp 72
				Tegner	Pain 76
					ADL 82
					Sports 50
					QoL 52
					Tegner 4
Wright et al. (2011) [59]	MOON cohort	39	2		IKDC score 76
					Re-revision 4 %
Lind et al. (2009) [30]	National registry	222	2	KOOS	Symp 75
				Tegner	Pain 77
					ADL 83
					Sports 51
					QoL 47
					Tegner 3.9
Lind et al. (2012) [31]	National registry	1,099	1–6	KOOS (1 year)	Symp 73
				Tegner	Pain 78
					ADL 84
					Sports 52
					QoL 48
					Tegner 4

quality of life 32–47) [30]. The 1-year follow-up outcome after RACLR was poorer than after primary ACLR by 5–13 points for the different KOOS subscales with the quality of life subscore being the most different compared to primary ACLR.

In cases of new instability due to failure of the primary ACL reconstruction, revision surgery can result in regained stability to a level similar to after primary ACLR [23, 29, 31]. No high-evidence studies have been published, but several case–control studies demonstrate improved stability and function after revision surgery [5, 8, 21]. Eberhardt et al. showed that 67 % were able to return to sports activity, but 63 % had pain at activity, and 63 % showed signs of osteoarthritis 37 months after revision surgery compared to pre-op radiographs [8]. The risk of osteoarthritis

was significantly higher if the athlete continued sports activity [8].

Comparing revision surgery to primary ACLR, Carson et al. found significantly lower Hospital for Special Surgery knee ligament evaluation score 2 years after surgery (case–control study design) [5]. In a similar retrospective study, Grossmann et al. reported follow-up Lysholm score and subjective IKDC score minimum of 6 years after revision to be 87 and 86, respectively [21]. Furthermore the authors reported marked higher side-to-side knee laxity difference based on KT-1000 measurements when using allograft compared to autograft [21]. Similar findings of inferior outcome after revision ACL reconstruction were found in two national cohort studies with lower scores in knee-specific outcome score and function scores [18, 31]. One of the two

national cohort studies also demonstrated more osteoarthritis development in revision patients compared to primary ACLR patients. The 2- to 11-year follow-up results after revision ACL utilizing a nonirradiated patellar tendon allograft were less favorable than in patients who had a primary anterior cruciate ligament reconstruction, with a lower subjective satisfaction level and a higher percentage of patients with grade 1+ or higher pivot-shift results [13]. Similar finding was done in a national cohort of 1,099 patient, with a doubled re-revision rate for allograft revisions [31].

Using the quadriceps tendon for revision surgery, good results were reported mean 26 months after surgery with 97 % showing max-manual KT-1000 side-to-side translation <5 mm [15].

Any concomitant injuries to the knee will affect the results after revision surgery. Rollier et al. demonstrated inferior functional outcome if initial ACLR was done with a synthetic ligament and the knee presented meniscal or cartilage damage [43].

A recent study demonstrated a cumulative meniscus lesion incidence of 70 % after 2.5 years follow-up after ACL revision. They demonstrated that meniscectomy negatively influenced both functional outcome and knee stability. This accumulated incidence of meniscus and cartilage injuries in ACL revision patients is a likely contributing cause for case of chronic pain after ACL revision [51].

Data from the American MARS cohort demonstrated current or previously treated meniscal injury in 74 % of patients. Articular cartilage damage grade 2 or worse was noted in 73 %. Both meniscal and articular cartilage damage was seen in 57 % [57].

In conclusion, secondary instability after primary ACL surgery can be treated with revision surgery, resulting in improved stability and function. However, the results are poorer after revision ACLR than after primary ACLR. Use of allograft results in similar knee function compared to autograft but inferior stability and a higher risk of failure due to re-revision. Concomitant lesion will negatively influence the

pain and knee scores. Return to sports activity can be expected in approximately 60 %, but with significantly higher risk of osteoarthritis.

Memory

Failure mechanisms of ACLR are numerous, and new trauma and poor anatomical placement of the tunnels for ACL graft fixation seem to be the most important failure mechanisms. The surgical technique for ACL revision reconstruction needs to correct failure causes and address concomitant ligament lesions. It is often necessary to use allograft tendons as the new ACL graft and fixation methods should be suited for the graft choices and bone quality. The outcome of ACL revision surgery has previously been poorly described in small case series, but recent data from national registries and larger cohort studies provide more reliable results. Outcome after revision ACLR is poorer than after primary ACLR, and patients need to be informed about these results in order to have realistic expectations to the clinical outcome after revision ACLR.

References

1. Amis AA, Jakob RP (1998) Anterior cruciate ligament graft positioning, tensioning and twisting. Knee Surg Sports Traumatol Arthrosc 6(Suppl 1):S2–S12
2. Bernard M, Hertel P, Hornung H, Cierpinski T (1997) Femoral insertion of the ACL. Radiographic quadrant method. Am J Knee Surg 10(1):14–21; discussion 21–12
3. Beynnon BD, Good L, Risberg MA (2002) The effect of bracing on proprioception of knees with anterior cruciate ligament injury. J Orthop Sports Phys Ther 32(1):11–15
4. Beynnon BD, Uh BS, Johnson RJ, Fleming BC, Renstrom PA, Nichols CE (2001) The elongation behavior of the anterior cruciate ligament graft in vivo. A long-term follow-up study. Am J Sports Med 29(2):161–166
5. Carson EW, Anisko EM, Restrepo C, Panariello RA, O'Brien SJ, Warren RF (2004) Revision anterior

cruciate ligament reconstruction: etiology of failures and clinical results. J Knee Surg 17(3):127–132

6. Clatworthy MG, Annear P, Bulow JU, Bartlett RJ (1999) Tunnel widening in anterior cruciate ligament reconstruction: a prospective evaluation of hamstring and patella tendon grafts. Knee Surg Sports Traumatol Arthrosc 7(3):138–145

7. Denti M, Lo Vetere D, Bait C, Schonhuber H, Melegati G, Volpi P (2008) Revision anterior cruciate ligament reconstruction: causes of failure, surgical technique, and clinical results. Am J Sports Med 36(10):1896–1902

8. Eberhardt C, Kurth AH, Hailer N, Jager A (2000) Revision ACL reconstruction using autogenous patellar tendon graft. Knee Surg Sports Traumatol Arthrosc 8(5):290–295

9. Fahey M, Indelicato PA (1994) Bone tunnel enlargement after anterior cruciate ligament replacement. Am J Sports Med 22(3):410–414

10. Fauno P, Christiansen SE, Lund B, Lind M (2010) Cyst formation 4 years after ACL reconstruction caused by biodegradable femoral transfixation: a case report. Knee Surg Sports Traumatol Arthrosc 18(11):1573–1575

11. Fauno P, Kaalund S (2005) Tunnel widening after hamstring anterior cruciate ligament reconstruction is influenced by the type of graft fixation used: a prospective randomized study. Arthroscopy 21(11):1337–1341

12. Ferretti A, Monaco E, Labianca L, De Carli A, Conteduca F (2008) Double bundle or single bundle plus extra-articular tenodesis in ACL reconstruction? A CAOS study. Knee Surg Sports Traumatol Arthrosc 16(1):98

13. Fox JA, Pierce M, Bojchuk J, Hayden J, Bush-Joseph CA, Bach BR Jr (2004) Revision anterior cruciate ligament reconstruction with nonirradiated fresh-frozen patellar tendon allograft. Arthroscopy 20(8):787–794

14. Fules PJ, Madhav RT, Goddard RK, Mowbray MA (2003) Revision anterior cruciate ligament reconstruction using autografts with a polyester fixation device. Knee 10(4):335–340

15. Garofalo R, Djahangiri A, Siegrist O (2006) Revision anterior cruciate ligament reconstruction with quadriceps tendon-patellar bone autograft. Arthroscopy 22(2):205–214

16. George MS, Dunn WR, Spindler KP (2006) Current concepts review: revision anterior cruciate ligament reconstruction. Am J Sports Med 34(12):2026–2037

17. Getelman MH, Friedman MJ (1999) Revision anterior cruciate ligament reconstruction surgery. J Am Acad Orthop Surg 7(3):189–198

18. Gifstad T, Drogset JO, Viset A, Grontvedt T, Hortemo GS (2013) Inferior results after revision ACL reconstructions: a comparison with primary ACL reconstructions. Knee Surg Sports Traumatol Arthrosc 21(9):2011–2018

19. Goertzen MJ, Buitkamp J, Clahsen H, Mollmann M (1998) Cell survival following bone-anterior cruciate ligament-bone allograft transplantation: DNA fingerprints, segregation, and collagen morphological

analysis of multiple markers in the canine model. Arch Orthop Trauma Surg 117(4–5):208–214

20. Granan LP, Forssblad M, Lind M, Engebretsen L (2009) The Scandinavian ACL registries 2004–2007: baseline epidemiology. Acta Orthop 80(5):563–567

21. Grossman MG, ElAttrache NS, Shields CL, Glousman RE (2005) Revision anterior cruciate ligament reconstruction: three- to nine-year follow-up. Arthroscopy 21(4):418–423

22. Hoher J, Moller HD, Fu FH (1998) Bone tunnel enlargement after anterior cruciate ligament reconstruction: fact or fiction? Knee Surg Sports Traumatol Arthrosc 6(4):231–240

23. Johnson DL, Swenson TM, Irrgang JJ, Fu FH, Harner CD (1996) Revision anterior cruciate ligament surgery: experience from Pittsburgh. Clin Orthop Relat Res 325:100–109

24. Kartus J, Movin T, Karlsson J (2001) Donor-site morbidity and anterior knee problems after anterior cruciate ligament reconstruction using autografts. Arthroscopy 17(9):971–980

25. Kjaergaard J, Fauno LZ, Fauno P (2008) Sensibility loss after ACL reconstruction with hamstring graft. Int J Sports Med 29(6):507–511

26. L'Insalata JC, Klatt B, Fu FH, Harner CD (1997) Tunnel expansion following anterior cruciate ligament reconstruction: a comparison of hamstring and patellar tendon autografts. Knee Surg Sports Traumatol Arthrosc 5(4):234–238

27. Laprade RF, Bernhardson AS, Griffith CJ, Macalena JA, Wijdicks CA (2010) Correlation of valgus stress radiographs with medial knee ligament injuries: an in vitro biomechanical study. Am J Sports Med 38(2):330–338

28. Lind M, Lund B, Fauno P, Christiansen S (2009) Revision anterior cruciate ligament reconstruction. Challenges and approaches. Min Orthop Traumatol 60:341–351

29. Lind M, Lund B, Fauno P, Said S, Miller LL, Christiansen SE (2012) Medium to long-term follow-up after ACL revision. Knee Surg Sports Traumatol Arthrosc 20(1):166–172

30. Lind M, Menhert F, Pedersen AB (2009) The first results from the Danish ACL reconstruction registry: epidemiologic and 2 year follow-up results from 5,818 knee ligament reconstructions. Knee Surg Sports Traumatol Arthrosc 17(2):117–124

31. Lind M, Menhert F, Pedersen AB (2012) Incidence and outcome after revision anterior cruciate ligament reconstruction: results from the Danish registry for knee ligament reconstructions. Am J Sports Med 40(7):1551–1557

32. Lubowitz JH, Bernardini BJ, Reid JB 3rd (2008) Current concepts review: comprehensive physical examination for instability of the knee. Am J Sports Med 36(3):577–594

33. Machotka Z, Scarborough I, Duncan W, Kumar S, Perraton L (2010) Anterior cruciate ligament repair with LARS (ligament advanced reinforcement system): a systematic review. Sports Med Arthrosc Rehabil Ther Technol 2:29

34. Malinin TI, Levitt RL, Bashore C, Temple HT, Mnaymneh W (2002) A study of retrieved allografts used to replace anterior cruciate ligaments. Arthroscopy 18(2):163–170

35. Marrale J, Morrissey MC, Haddad FS (2007) A literature review of autograft and allograft anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 15(6):690–704

36. Martinek V, Friederich NF (1999) Tibial and pretibial cyst formation after anterior cruciate ligament reconstruction with bioabsorbable interference screw fixation. Arthroscopy 15(3):317–320

37. Myklebust G, Steffen K (2009) Prevention of ACL injuries: how, when and who? Knee Surg Sports Traumatol Arthrosc 17(8):857–858

38. Nebelung W, Becker R, Merkel M, Ropke M (1998) Bone tunnel enlargement after anterior cruciate ligament reconstruction with semitendinosus tendon using Endobutton fixation on the femoral side. Arthroscopy 14(8):810–815

39. Noyes FR, Barber-Westin SD, Roberts CS (1994) Use of allografts after failed treatment of rupture of the anterior cruciate ligament. J Bone Joint Surg Am 76(7):1019–1031

40. Ohly NE, Murray IR, Keating JF (2007) Revision anterior cruciate ligament reconstruction: timing of surgery and the incidence of meniscal tears and degenerative change. J Bone Joint Surg Br 89(8):1051–1054

41. Rappe M, Horodyski M, Meister K, Indelicato PA (2007) Nonirradiated versus irradiated Achilles allograft: in vivo failure comparison. Am J Sports Med 35(10):1653–1658

42. Robinson J, Huber C, Jaraj P, Colombet P, Allard M, Meyer P (2006) Reduced bone tunnel enlargement post hamstring ACL reconstruction with poly-L-lactic acid/hydroxyapatite bioabsorbable screws. Knee 13(2):127–131

43. Rollier JC, Besse JL, Lerat JL, Moyen B (2007) Anterior cruciate ligament revision: analysis and results from a series of 74 cases. Rev Chir Orthop Reparatrice Appar Mot 93(4):344–350

44. Safran MR, Harner CD (1996) Technical considerations of revision anterior cruciate ligament surgery. Clin Orthop Relat Res 325:50–64

45. Schwartz HE, Matava MJ, Proch FS et al (2006) The effect of gamma irradiation on anterior cruciate ligament allograft biomechanical and biochemical properties in the caprine model at time zero and at 6 months after surgery. Am J Sports Med 34(11):1747–1755

46. Shino K, Inoue M, Horibe S, Nagano J, Ono K (1988) Maturation of allograft tendons transplanted into the knee. An arthroscopic and histological study. J Bone Joint Surg Br 70(4):556–560

47. Shino K, Kawasaki T, Hirose H, Gotoh I, Inoue M, Ono K (1984) Replacement of the anterior cruciate ligament by an allogeneic tendon graft. An experimental study in the dog. J Bone Joint Surg Br 66(5):672–681

48. Shino K, Oakes BW, Horibe S, Nakata K, Nakamura N (1995) Collagen fibril populations in human anterior cruciate ligament allografts. Electron microscopic analysis. Am J Sports Med 23(2):203–208; discussion 209

49. Taggart TF, Kumar A, Bickerstaff DR (2004) Revision anterior cruciate ligament reconstruction: a midterm patient assessment. Knee 11(1):29–36

50. Tohyama H, Beynnon BD, Johnson RJ, Renstrom PA, Arms SW (1996) The effect of anterior cruciate ligament graft elongation at the time of implantation on the biomechanical behavior of the graft and knee. Am J Sports Med 24(5):608–614

51. Trojani C, Beaufils P, Burdin G et al (2012) Revision ACL reconstruction: influence of a lateral tenodesis. Knee Surg Sports Traumatol Arthrosc 20(8):1565–1570

52. Trojani C, Sbihi A, Djian P et al (2011) Causes for failure of ACL reconstruction and influence of meniscectomies after revision. Knee Surg Sports Traumatol Arthrosc 19(2):196–201

53. Uchio Y, Ochi M, Adachi N, Kawasaki K, Kuriwaka M (2003) Determination of time of biologic fixation after anterior cruciate ligament reconstruction with hamstring tendons. Am J Sports Med 31(3):345–352

54. Weiler A, Schmeling A, Stohr I, Kaab MJ, Wagner M (2007) Primary versus single-stage revision anterior cruciate ligament reconstruction using autologous hamstring tendon grafts: a prospective matched-group analysis. Am J Sports Med 35(10):1643–1652

55. Wilson TC, Kantaras A, Atay A, Johnson DL (2004) Tunnel enlargement after anterior cruciate ligament surgery. Am J Sports Med 32(2):543–549

56. Woo SL, Hollis JM, Adams DJ, Lyon RM, Takai S (1991) Tensile properties of the human femur-anterior cruciate ligament-tibia complex. The effects of specimen age and orientation. Am J Sports Med 19(3):217–225

57. Wright RW, Huston LJ, Spindler KP et al (2010) Descriptive epidemiology of the Multicenter ACL Revision Study (MARS) cohort. Am J Sports Med 38(10):1979–1986

58. Wright RW, Preston E, Fleming BC et al (2008) A systematic review of anterior cruciate ligament reconstruction rehabilitation: part II: open versus closed kinetic chain exercises, neuromuscular electrical stimulation, accelerated rehabilitation, and miscellaneous topics. J Knee Surg 21(3):225–234

59. Wright R, Spindler K, Huston L et al (2011) Revision ACL reconstruction outcomes: MOON cohort. J Knee Surg 24(4):289–294

60. Yoshiya S, Kurosaka M, Ouchi K, Kuroda R, Mizuno K (2002) Graft tension and knee stability after anterior cruciate ligament reconstruction. Clin Orthop Relat Res 394:154–160

61. Zantop T, Schumacher T, Diermann N, Schanz S, Raschke MJ, Petersen W (2007) Anterolateral rotational knee instability: role of posterolateral structures. Winner of the AGA-DonJoy Award 2006. Arch Orthop Trauma Surg 127(9):743–752