First anterior cruciate ligament revision in adults: the ESSKA formal consensus recommendations

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First anterior cruciate ligament revision in adults: the ESSKA formal consensus recommendations

I. Introduction

Anterior cruciate ligament (ACL) tears are one of the most common sports injuries and anterior cruciate ligament reconstruction (ACLR) is one of the most commonly performed surgery, with ACL repairs getting recently some attention. However, these procedures can fail in a number of ways, requiring ACL revision (ACL Rev), which is technically more demanding than primary reconstruction. Many variables including tibial slope, anterolateral stabilization, the role of the meniscus for stability, hidden meniscus lesions/root lesions, treatment of associated ligament injuries, and cartilage lesions in conjunction with increasing patient expectations and activity have made the topic even more significant in recent years. Also, psychological readiness to return to sport after ACL revision is an important issue. Due to the complex nature of revision surgery, an in-depth preoperative examination using history, clinical examinations, advanced imaging and other methods as appropriate is of the utmost importance.

The aim of this ESSKA Consensus is to provide a combination of evidence-based and expert opinions about the diagnosis, preoperative assessment and management of patients with failed ACL reconstructions, regardless of the time from initial surgery. However, this consensus is not focused on specific surgical techniques.

Goal of treatment and expected clinical outcome of ACL revision surgery:

The goal of ACL revision surgery is to achieve a stable, pain-free knee, close to full range of motion, allowing sport and unrestricted daily activities while slowing down the long-term progression of osteoarthritis (OA). However, several studies have shown that the outcomes of revision ACL reconstruction are less predictable compared to primary reconstructions. Although stability can be restored with revision ACL reconstruction, patient-reported outcome measures are worse and the rate of return to sport is lower compared with patients after primary ACLR. Furthermore, the rate of recurrent instability/re-rupture has been reported to be higher after revision procedures.

Definitions

Definition of ACL revision: inclusion and exclusion criteria

"All surgical procedures involving replacement of the ACL graft with a new graft."

On this basis, partial meniscectomy after ACLR is not defined as ACL revision; nor is a cyclops resection, nor are isolated peripheral ligamentous reconstructions. Associated additional procedures such as osteotomy, meniscus repair or replacement, peripheral ligament reconstruction and cartilage surgery are included, providing a revision ACL reconstruction has been performed.

Exclusion criteria (for consensus):

- Patients with open growth plates at time of revision
- Multiligament injuries involving ACL and PCL
- Any concomitant prosthesis
- Second or more ACL revision

Definition of knee instability and laxity:

Pathological laxity is a sign defined as "increased passive response of a joint to an externally applied force or torque in biomechanical terms. Thus, laxity tests for evaluating knee injury evaluate the passive limits of motion in a particular direction or plane".

Instability is defined as a functional symptom: "an abnormal dynamic joint motion that can occur in response to the complex, high-magnitude loads encountered during activities of daily living and sport activities."

The terms stable or unstable knees have created ambiguity. A patient may sustain functional instability without laxity and vice versa. In the following discussion, instability will only refer to a functional symptom (such as giving way) and laxity will refer to an objective clinical sign. Subtle laxity is difficult to define. The IKDC (1995/2000) has defined normal laxity as -1 to 2 mm (compared to the healthy side), nearly normal laxity as 3 to 5mm, abnormal laxity as 6 to

10mm and severely abnormal laxity as over 10mm during Lachman, anterior/posterior drawer, medial and lateral joint opening.

IKDC 1995/2000 definitions of knee laxity

Instrumented measurements or stress x-ray, examined with Lachman's test (ACL/PCL), drawer test anterior-posterior(ACL/PCL), medial(MCL/POL) or lateral(LCL/Popliteus) opening.

Laxity measurements	Side to side difference Compared to the normal knee
-1 - 2 mm	**Normal laxity**
3 - 5 mm	**Nearly normal laxity**
5 - 10 mm	**Abnormal laxity**
> 10 mm	**Severely abnormal laxity**

Definition of partial meniscectomy:

The definition of partial meniscectomy includes a wide range in terms of size and location of the tissue resection. While the amount of removed meniscus is not sufficient to define this, newer biomechanical studies have evaluated the influence of the type of meniscus tear on articular pressure distribution (Lau et al. JBJS Rev 2018). Partial meniscectomy with less than 50% removed has no significant increased contact pressure, whereas complete meniscectomy more than doubles the contact pressures. From biomechanical studies the impact of radial tears is still debated. Root tears are comparable to total meniscectomy.

For the purpose of our consensus we define partial meniscectomy as resection of up to 50% of the meniscus depth but not more, and the presence of intact roots with no meniscus extrusion. This leaves three groups that are relevant for decision making and surgical strategy:

- Intact meniscus or partial meniscectomy (without compromised meniscus function)
- Repairable meniscus lesion (e.g. bucket handle tear, root tear, ramp lesion)
- Nonrepairable tear (greater than around 50%), subtotal meniscectomy or nonfunctional meniscus (extrusion >3mm) (compromised meniscus function)

The exact cutoff values are seen as a rough estimate and can vary somewhat.

Definition of Hyperextension/Hyperlaxity:

Hyperextension of the knee can be posttraumatic or congenital, which can be differentiated by side-to-side difference (increased in traumatic hyperextension vs. bilateral in hyperlaxity (hypermobility)). The MARS group found knee hyperextension of more than 5° to be a risk factor for ACL injury (MARS Group; Daniel E. Cooper, Am J Sports Med, 2018).

General hyperlaxity is defined by a Beighton score >5 (Beighton, J Bone Joint Surg Br. 1969).

Methodology:

It is the aim of the ESSKA consensus to assist surgeons in the treatment of patients after failure of an ACL reconstruction. Our goal is to propose a "framework" rather than strict guidelines. We have set up the "Formal Consensus Project" (derived from a Delphi methodology) for diagnosis and preoperative planning and surgical strategy as well as a "RAND/UCLA Appropriateness Method" (RAM) process for indication of the first ACL graft revision. To define treatment indications, the RAM combines the best available scientific evidence with the collective judgment of a panel of experts, guided by a core panel and multidisciplinary discussers. Since ACL revision is highly specific, a "multidisciplinary" discussion was not performed. A list of specific clinical scenarios was produced regarding ACL graft re-rupture with increased laxity in an aligned knee in adults. Each scenario underwent discussion and a two-round vote on a nine-point Likert-scale, and scores were pooled to generate expert patient-specific recommendations on the appropriateness of revision ACL reconstruction. Scenarios not pertaining to this definition were considered in a Delphi indications section. For the Delphi process the core group comprised a steering group of 14 experts assisted by a literature group of three additional experts. Based on the diagnostic and therapeutic workup for ACL revision, they proposed a series of relevant questions, their respective answers, and applied a scientific grade based upon existing literature (screened from 2005 - 2020) and their expert opinion.

Grade A: high scientific level

Grade B: scientific presumption

Grade C: low scientific level

Grade D: expert opinion

A first draft was reviewed and amended twice by another independent panel of 19 experienced orthopaedic surgeons (rating group). The final text underwent a second review process by an additional peer review group comprising 51 clinicians and clinical scientists from different European countries. This long and complex process has two main advantages. It limits any individual or organizational bias or conflict of interest and it may have a better chance of general acceptance due to the involvement of a large number of participants from different countries (88 people from 27 European countries were involved). For indications we used the RAM methodology. This reflected the large diversity of clinical presentations in our daily practice. Just like the large amount of individual anatomical variations, the orthopaedic clinician needs to approach each individual patient bearing in mind his or her unique medical history, individual physiology, gender, activity level, weight and a number of other variables that do not fit into a single statistical picture. This "consensus investigation" has attempted to shed some light on these important clinical entities. In addition, the recommendations are presented free from economic constraints.

We hope the following recommendations will take into account these messages, avoid any conflicting or political statements, and provide a well-balanced treatment algorithm with a place for both non-operative and arthroscopic treatment in the orthopaedic armamentarium. Our findings will hopefully assist every orthopaedic clinician in their decision making when confronted with patients with ACL graft tears.

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II. Diagnosis and preoperative planning (formal consensus)

D1) How is a failed ACL Reconstruction (ACLR) defined?

Consensus answer:

Failure of ACLR is defined by abnormal knee function associated with a previous primary reconstruction. This could be due to graft failure itself with abnormal laxity (IKDC C/D) or failure to recreate a functional knee according to the expected outcome. Reasons for failure could be a new trauma with graft rupture, repeated microtrauma, surgical technical errors, biological failure, unaddressed associated lesions, or complications associated with the primary procedure.

Agreement: 8.6/9

Grade of recommendation: B

Literature review:

ACL reconstruction is considered a successful procedure with satisfactory outcomes ranging from 75% to 97% of cases[1-4,18].

No precise and universal definition of failure after ACL reconstruction has been produced, as it is due to a combination of technical errors, biological causes and/or new trauma[5]. Biau et al.[6] reported in their meta-analysis that 34% of patients treated for an ACL reconstruction with autograft had positive results on a Lachman test and 24% on the pivot-shift test. These results suggest that residual laxity may exist in a large number of patients after reconstruction, in spite of satisfactory subjective outcomes. However, the causes of ACL reconstruction failure can be grouped into one or a combination of different problems such as recurrent instability, graft failure, loss of motion, extensor mechanism dysfunction, OA, infection and comorbidities related to concomitant pathological abnormalities[7]. As we reported, failure has a multifactorial nature, generated by objective and subjective factors. The causes of recurrent instability are multiple, but they can be divided into early and late failure: an exact cut-off point does not exist.

Early failure is usually related to poor operative technique, failure of graft incorporation, premature return to high-demand activities, aggressive rehabilitation or a new trauma[1,7]. Late failures may also depend on technical errors, repeated trauma to the graft and/or associated pathology (e.g. lower limb malalignment, collateral ligament injury and ligamentous laxity).

Technical errors

Technical errors include tunnel malposition, insufficient or excessive graft tensioning, fixation problems, concomitant untreated laxity and additional pathologies being inappropriately addressed (meniscal and cartilage injuries).

Tunnel malposition may lead to an excessive change in length of the graft during knee movement. Such changes can lead to graft stress with consequent elongation or rupture. A tunnel malposition may lead to graft impingement with soft tissue (e.g. posterior cruciate ligament) or bone (e.g. intercondylar notch).

The tension that should be applied to a graft during an ACL reconstruction has not been defined as it depends on several factors, such as the type and size of graft material, the type of fixation, and the degree of knee flexion at the time of graft tensioning[8]. However, it has been demonstrated that over-tensioning the graft can be associated with over-constraint of the joint, with loss of joint motion and increased joint contact pressures.

Concomitant untreated laxity and intraarticular deficiency have an important role in predicting ACL reconstruction failure (see also D4 and S10); indeed, knee hyperlaxity is correlated with non-contact ACL injuries and may lead to an increased risk of ACL injury[9]. The medial and lateral collateral ligaments provide secondary stability in the ACL-deficient knee and must also be carefully assessed for injury. Bonanzinga et al.[10] reported that isolated ACL reconstruction is able to control antero-posterior knee laxity with a combined complete lesion of the postero-lateral corner (PLC) at 30° of knee flexion, but not at a higher angle of knee flexion. Moreover, Zhu et al.[11] suggest that in the case of a combined ACL and severe superficial medial collateral ligament (sMCL) injury, both ligaments should be reconstructed, as single-bundle ACL reconstruction alone is not able to restore anterior tibial translation, valgus rotation, and external rotation in the case of combined ACL and sMCL injuries.

In the existing literature it is estimated that more than 15% of ACL reconstruction failures are a result of missed diagnosis of an associated ligament, meniscus or cartilage lesion at the time of surgery[12].

Meniscal deficiency

Meniscal deficiency is an important factor in predicting graft failure. The medial meniscus contributes to protecting the anterior tibial translation, and the lateral meniscus is an important restraint to anterior tibial translation during internal tibial rotation[13,14]. Seon et al.[1] found, in a cadaveric study, that a subtotal medial meniscectomy and an ACL reconstruction was unable to completely restore normal anterior stability with a residual laxity of 2.6 to 5.5 mm.

Early return to activity

Premature return to high-demand activities or aggressive rehabilitation can alter neuromuscular control patterns during landing. However improved postural stability and control of the center of mass may help minimize subsequent ACL injury[16].

Traumatic reinjury

Traumatic reinjury is responsible for 24% to 32% of graft failures, compared to surgical error with tunnel malposition, which causes graft failures in 24% to 63.5% of cases[2,17].

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D2) Which aspect(s) of the patient's status and surgical history should be documented in the setting of a known or suspected failed ACL Reconstruction?

Consensus answer: The following aspects of the patient's history should be documented in the setting of a known or suspected failed ACL Reconstruction: (1) demographics, including gender/age/BMI; (2) date of previous ACL replacement; (3) previous treatment (including surgical report, imaging and associated lesions); (4) surgical technique (previous errors); (5) graft used; (6) graft fixation; (7) timepoint of return to activity/sports; (8) current ADLs/sporting activities before reinjury; (9) duration of symptoms; (10) pain; (11) swelling; (12) giving way; (13) history of trauma; (14) mechanism of injury; (15) status of opposite side; (16) patient expectations.

Agreement: 8.3/9

Grade of recommendation: D

Literature review:

No level I-II studies exist in order to identify which aspects of patient history should be documented in the setting of known or suspected failed ACL reconstruction. Based on the available low-level evidence, history is fundamental to diagnosis of the ACL failure, identification of its etiology and optimization of management planning.

Failures of ACL reconstruction are multifactorial and influenced partly by surgeon-dependent technical issues [1], and by patient-related factors. Basic non-modifiable demographics characteristics have been reported to affect the failure rate of ACL reconstruction, such as young age (usually under 25 years [2]. Some authors found up to 19% failure rates in patients younger than 18 years [3]) and in male patients [4].

Other patient-specific modifiable characteristics have been considered to affect ACL failure, in particular related to the type of sport and the timing of return to sport after ACL reconstruction. Especially young female athletes are at increased risk [17]. Noyes and Barber-Westin, in a systematic review, reported that 90% of ACL failures occurred in high-risk sports (pivoting, jumping, landing, cutting) [5], while Beischer et al. reported a 7-fold risk of a second ACL injury in those returning to sport before 9 months [6]. Similarly, Dekker et al. identified the time to return to sport as the only predictor of second ACL injuries [3]. In this regard, Nagelli and Hewett suggested delaying the return to sport for up to 2 years following reconstruction, particularly in high-risk young athletes [7]. On the other hand, other authors reported good outcomes and limited failure rates with early return to sport [8,9], before 6 months, even if the biomechanical properties of the graft 6 months after ACL reconstruction remained unclear. If sport practice itself does not represent a cause of ACL failure, it can be responsible for a higher chance of traumatic events and knee sprains. Sport practice and level are thus considered important factors to take into account in the diagnosis and management of many sport-related injuries and probably should be approached more individually.

The interval between failure or re-rupture after ACL reconstruction is another important variable and has been investigated, particularly after primary reconstruction. Larger intervals between ACL rupture and treatment affect the outcomes because of the incidence of meniscal injuries and overall knee laxity [10-11].

Finally, considering the multiple pathologies associated with multiple ACL failures and reconstructions, such as meniscal injuries [12], cartilage lesions [13], other ligament ruptures

[14] and OA [15], it is considered important to pay attention to every symptom, including those not strictly specific to ACL insufficiency, such as multi-planar instabilities, pain, swelling and locking, in order to tailor adequate treatment for each patient based on possible co-morbidities.

Most of these aspects were included in the 1995 version of the International Knee Documentation Committee (IKDC) evaluation form, specifically designed by ESSKA and AOSSM to document ligament diseases. With regard to patient history, the form included demographic information, occupation and sport, date and cause of injury, level of activity, previous surgeries, self-reported knee function and symptoms such as pain, swelling and giving way, based on the intensity of activity [16]

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D3) Which aspect(s) of the physical examination should be performed/documented in the setting of a known or suspected failed ACL Reconstruction?

Consensus answer: The following aspects of the physical examination should be performed/documented in the setting of a known or suspected failed ACL reconstruction, in comparison with the non-injured leg: (1) assessment of AP and rotatory laxity (e.g. Lachman, anterior drawer, pivot-shift); (2) assessment of other laxities (e.g. Varus-Valgus, Dial Test, Posterior Drawer); (3) range of motion; (4) alignment (varus/valgus) including dynamic thrust; (5) tenderness and meniscus tests; (6) donor site morbidity or other specific pain locations; (7) swelling; (8) hyperextension (>5°) and generalized hyperlaxity; (9) muscle status (atrophy); and (10) neurovascular status

Agreement: 8.5/9

Grade of recommendation: D

Literature review:

No high-level studies exist aimed at identifying which aspects of physical examination should be performed in the setting of known or suspected failed ACL reconstruction. Based on the available low-level evidence and expert opinion, all the aspects which contribute – together with patient's history – to the definition of "failure" and the establishment of an adequate surgical planning should be assessed.

The mainstay of ligament assessment is manual evaluation through the anterior drawer and Lachman tests to evaluate antero-posterior laxity. However, the rotatory laxity evaluated with the pivot-shift is considered fundamental since it better correlates with patient's clinical symptoms and subjective instability but is often difficult to perform in the awake patient [1]. It plays a crucial role in the revision ACL setting, especially considering the relevant percentage of patients with residual pivot-shift after primary ACL reconstruction [2] (usually due to technical issues). However, significant differences in the grading of the pivot shift test have been reported between awake and anesthetized patients, regardless of the use of quantitative instruments during the evaluation, with lower values of both tibial acceleration and lateral compartment translation in awake patients compared to those under anesthesia [3]. Moreover, the pivot-shift is the most widely used test to identify antero-lateral laxity, which has been suggested as a risk factor for Primary and Revision ACL failure [4].

Assessment of varus-valgus laxity and signs of rotatory laxity could identify undiagnosed concomitant ligament injuries, especially MCL and PLC, which have been proved to contribute to the failure of primary ACL reconstructions. In fact, Akoto et al. identified medial instability as a predictor of ACL revision failure, and medial stabilization as a protective factor against failure [4]. Similarly, Noyes et al. reported the necessity to perform a PLC reconstruction in 29% of ACL revision procedures due to persistent postero-lateral laxity imputed to be responsible for primary ACL failure [5]. The recognition of such complex laxities is considered the basis of correct treatment planning.

Considering the multifactorial nature of ACL failures and the broad spectrum of possible symptoms also due to multiple injuries or previous surgeries, aspects such as possible range of motion limitations, pain or impairment due to donor site morbidity should be assessed. Kraeutler et al. reported that it is essential to look for signs and symptoms of indolent infections, even if this occurs without defining them in detail [6].

Finally, patient-inherent features such as hyperextension or lower-limb malalignment have been reported to play a role: hyperextension has been proved to be associated with higher post-operative laxity and inferior patient-reported outcomes in a systematic review (especially when considering knee hyperextension) [7], while varus malalignment has been demonstrated to have a two-fold occurrence in a revision setting with respect to primary ACL reconstruction [8], even if no impact on failure rate has been reported in the case of primary varus with no medial OA [8]. In this regard, it was suggested to also assess the patient's gait and the possible presence of varus thrust [6].

Most of these aspects were included in the 1995 and 2000 versions of the International Knee Documentation Committee (IKDC) evaluation form. Thus, physical examination included the documentation of severity of swelling (especially the amount of effusion), passive motion deficit, ligament examination (Lachman, AP translation, posterior drawer, medial and lateral joint opening, external rotation test, pivot shift and reverse pivot shift), crepitus and harvest site pathology [9]. The form also included the "One Leg Hop" test, which was, however, referred to as a functional assessment and was not included in the calculation of the final overall IKDC grading.

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D4) What is the role of hyperextension in ACL Revisions?

Consensus answer:

Knee hyperextension regardless the cause, is a risk factor for ACL reconstruction failure. The cut-off value is still under debate, but recent multicenter studies (MARS group) showed that more than 5° is a risk factor for failure. Patients' expectations should be managed accordingly. The surgical strategy may change according to further risk factors.

Agreement: 7.7/9

Grade of recommendation: C

Literature review:

Knee hyperextension can be found on both sides due to generalized hyperlaxity or on the index side due to ligamentous/capsular injuries or posttraumatic bone deformities.

Knee hyperlaxity can lead to an increased risk of failure in ACL reconstruction: it is correlated with noncontact ACL injuries[1-2] and excessive knee joint laxity after ACL reconstruction may increase the risk of another graft failure[3].

In patients with knee hyperextension, the graft suffers increased stress compared to grafts in patients with normal joint laxity. This may be due to the absence of tautly stretched ligaments and tendons, which stabilize the knee, absorbing the ground reaction forces[2].

Moreover, in patients with excessive hyperextension, the reconstructed graft can create an impingement against the intercondylar roof, which may lead to a deterioration of the graft or re-rupture.

Therefore, an ACL reconstruction in these patients should be undertaken with caution.

Patients with ligamentous hyperlaxity represent a known risk group for both primary ACL injury and failure after reconstruction.

The MARS study[4] showed that passive extension of more than 5° is an important predictor of failure of ACL revision surgery. Guimaraes et al., in a cohort study of patients who had primary ACL reconstruction with hamstring tendon autograft, reported that patients with more than 5° of hyperextension, compared to the contralateral knee, had a higher failure rate than patients with less than this value[5]. A case control study showed that passive anteroposterior tibiofemoral laxity and passive knee hyperextension may contribute to increased ACL injury risk[6]. Helito et al.[7] reported that patients with ligamentous hyperlaxity should receive both ACL and anterolateral ligament (ALL) reconstruction in order to reduce the likelihood of failure, due to the improved anteroposterior and rotation stability compared with isolated ACL reconstruction. A study by Larson et al.[8] showed a significant increase in the risk of failure after ACL reconstruction in patients with generalized hyperlaxity. More than one-third (34.1%) of the patients categorized as hyperlax sustained an ACL graft injury or developed excessive graft laxity in comparison with 12.0% of those without hypermobility at a mean 6-year follow-up. In this study graft failure rates were higher and inferior subjective outcomes were observed after ACL reconstruction in patients with hypermobility.

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D5) Are instrumental devices helpful to evaluate knee laxity in the setting of a known or suspected failed ACL Reconstruction?

Consensus answer:

The use of devices does not replace careful manual evaluation and clinical history taking. However, arthrometers, Rolimeters, accelerometers, image-based and electromagnetic systems are helpful to quantify laxity, especially in unclear cases or research settings.

Agreement: 8.2/9

Grade of recommendation: C

Literature review:

The degree of laxity that defines graft failure is not universally recognized, according to the International Knee Documentation Committee (IKDC) evaluation form. The anterior drawer test, Lachman test, and pivot shift test laxity can be graded as normal, nearly normal, abnormal, and severely abnormal, although the limitation of these tests is their subjective nature. Usually IKDC "B" is considered "nearly normal" and an acceptable outcome for patients treated for ALCR[1].

The assessment of knee laxity is a crucial step in ACL reconstruction and physical exam maneuvers depend on a variety of factors, including clinical experience, patient relaxation and patient hyperlaxity. In addition, MRI is a fundamental examination but while it can diagnose a graft rupture it can only evaluate knee instability by indirect signs. Arthrometers are devices designed to apply reproducible force to the joint, allowing measurement and quantification of the resulting anterior translation.

According to the literature these devices are easy to use, allowing a rapid and reproducible measurement, and guaranteeing greater objectivity when compared with simple manual testing.

Multiple devices have been developed, with testing techniques that differ somewhat for each device.

The most commonly used arthrometers was the KT-1000 Knee Ligament Arthrometer (MEDmetric Corp, San Diego, CA, USA), which was introduced in 1982 and first reported in

1985; the KT-2000, which adds a two-dimensional display that can produce a force-displacement curve; the GNRB (Genourob, Laval, France), first documented in 2009 and frequently cited in the arthrometry literature, especially in the past 3 years; the Rolimeter (Aircast Europa, Neubeuern, Germany); the Genucom Knee Analysis System (FARO Medical Technologies Inc, Montreal, Canada); the Stryker Knee Laxity Tester (Stryker, Kalamazoo, MI, USA); and the Vermont Knee Laxity Device (VKLD) [2,3].

The KT-1000 was the most commonly used arthrometer worldwide; it quantifies the degree of antero-posterior (AP) tibial-femoral displacement. A side-to-side (STS) distance greater of than 5 mm[6-9] is considered to represent graft failure; however, others believe an STS difference of 3 mm[4,5] classifies as graft failure. As reported by Wiertsema et al., over the past two decades some authors believe that STS distance should not be over 3 mm. While clinical tests are easier to perform (Lachman test, drawer tests), the KT-1000 arthrometer is reported to more precisely quantify the amount of AP laxity.

Kamath et al.[10], in a systematic review of STS difference in KT 1000 measurements, reported 1.0 to 2.5mm displacement after ACL revision surgery using autografts, which is similar to the results after primary reconstruction. Roham et al.[2] reported that laximetry is a useful technique in clinical practice, but the validity measures of these methods vary, depending on the examiner. The KT series of devices is the current gold standard for quantifying AP laxity. However, Wiertsema et al.[4] reported that the reliability of the KT1000 measurements is inadequate, whereas the Lachman test was found to be reliable in diagnosing ACL ruptures, although it should be carried out by experienced examiners. Goodwillie et al.[11] noted that a postoperative laxity greater than 5 mm STS difference as measured using a KT-1000 arthrometer did not show worse clinical outcome scores at long-term follow-up in a group of 171 consecutive patients who had undergone a transtibial bone–patellar tendon–bone ACL reconstruction. 50 out of 53 arthroscopically verified complete ACL tears were preoperatively diagnosed with KT1000.[12]

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D6) Which radiographic/imaging studies should be used to evaluate a known or suspected failed ACL Reconstruction?

Consensus answer: Weight-bearing anteroposterior (AP) and lateral x-rays (superimposed posterior condyles, preferably in monopodal stance), with at least 15cm of proximal tibia visible, as well as MRI (without contrast agent) should be used in every case of suspected ACL reconstruction failure. Parameters assessed on x-ray include joint narrowing, patellar height, tibial slope, static anterior tibial translation, tunnel placement and widening, and retained hardware. For CT scans, see D7. For MRI parameters, see D8.

Agreement: 8.7/9

Grade of recommendation: D

Literature review:

The literature review of D6 has been performed in common with D7 since both questions look for evidence from radiographic/imaging studies to evaluate known or suspected failed ACL Reconstruction.

D7) Which additional radiographic/imaging studies can be used to evaluate a known or suspected failed ACL Reconstruction?

Consensus answer: Based on patient history, symptoms, physical evaluation and results of initial radiological assessment, further studies can be used:

- **Long weight bearing radiographs** can be used to measure lower limb axes in the case of suspected knee malalignment and/or unicompartimental OA.
- **Lateral long leg radiographs** can be used when there is suspicion of extraarticular tibial deformity (tibial bowing), to accurately measure the tibial slope.
- **CT scan** is the most reliable method to assess tunnel widening and osteolysis, but due to costs and radiation exposure, should be used only if there is concern about tunnel widening and osteolysis, or if it is not possible to properly identify tunnel placement. 3D CT might be of additional value.
- **Flexed knee postero-anterior weight bearing radiographs** (Schuss or Rosenberg) can be used to increase the sensitivity of standard x-rays in order to document joint space narrowing
- **Axial view radiographs** can be used to document the amount PF OA and its progression
- **Stress radiographs** (bilateral) can be used to quantify the amount of laxity, or in cases of chronic multidirectional laxity, to quantify the main directions of laxity.

Detailed explanation of when and how to use radiological studies is provided in the following dedicated questions.

Agreement: 8.5/9

Grade of recommendation: D

Literature review:

Based on the available evidence, a variety of radiographic exams have been suggested to be useful in the diagnosis and management of known or suspected failure ACL reconstruction. Kraeuteler et al. [1], in a recent (2017) review, reported that initial radiographic series should include standing anteroposterior radiographs at 0°, lateral radiographs in full extension, Rosenberg views, and patellofemoral axial views. Long weight-bearing radiographs of both lower extremities to include the femoral heads and ankle joints should be obtained if malalignment is a concern. They also reported that varus-valgus and/or lateral stress views (in 20-30° flexion) can objectively evaluate the integrity of the ligamentous structures about the knee, but without specifying the indications [2]. MRI was considered important to provide critical information about the primary graft, location, orientation, and diameter of the existing bone tunnels, as well as information about the integrity of the other ligamentous structures, cartilage surfaces, menisci and the possible existence of pathognomonic traumatic bone edema. They considered the CT scan as a second-level exam to be conducted if there is concern about tunnel widening and osteolysis on radiographic or MR imaging [1, 2]. However, each imaging serves a specific purpose.

Criteria for correct AP and lateral x-rays:

For multiple parameter assessment with the purpose of diagnosis and pre-operative planning, standard antero-posterior radiographs should be performed with the patient in a monopodal stance, with an extended knee and the radiography directed perpendicularly to the coronal plane; the femoral and tibial condyles should be symmetrical, the head of the fibula slightly superimposed to the lateral tibial condyle and showing the femorotibial joint space correctly. The lateral radiograph should be performed with patient in a monopodal stance, with superimposed femoral condyles and including at least 15 cm of proximal tibia, especially if slope assessment is required. Lateral radiographs can be made in extension, which has the advantage of evaluating the relationship of the extension angle of the knee and the roof angle (Blumensaat line), which is helpful in evaluating "unforgiving knees" at risk of graft impingement, as is the case in hyperextension. In these cases the tibial tunnel must be slightly more posterior [3-5]. Lateral radiographs in 20-30° of flexion allow the measurement of static anterior tibial translation. The position of the tibia in respect to the femoral condyles under axial compression during monopodal stance has been considered a useful parameter for pre- and post-operative assessment.

Dejour et al. reported a higher static anterior translation in patients with increased posterior tibial slope and partial medial meniscectomy [6-7], while other authors also reported a correlation with longer time from ACL injury to reconstruction [8-9]. Higher lateral tibial plateau subluxation has been reported in multifailure ACLR when compared with first ACL revision according to MRI [10] and weight-bearing radiographs [11]. Usually, studies that assessed the anterior tibial subluxation on lateral radiographs reported performing the exam on weightbearing monopodal stance; if from one side the single or double leg weightbearing have been reported to increase the varus deformity on the coronal plane [12], there is however no clinical evidence of altering the anterior subluxation on sagittal plane. Thus, the monopodal stance during lateral radiographs is recommended, if possible, but not mandatory. A particular mention is reserved for lateral radiographs, due to the role of posterior tibial slope. In the literature it is not possible to find a clear indication of when to perform long-leg lateral radiographs. Independently from different measurement reliabilities (which will be discussed in the question dedicated to slope assessment), in the two available studies on ACL revision and slope-correcting deflexion osteotomy, long-leg lateral radiographs were obtained only by Sonnery-Cottet et al. [13], while Dejour et al. [14] relied on knee true lateral radiographs obtained under fluoroscopic control.

Long weightbearing radiographs

Regarding the use of long weightbearing radiographs, Borphy et al. reported that among 1200 patients included in the Multicenter Revision ACL Study (MARS) only 246 (20.5%) had bilateral weightbearing long-leg alignment films taken just before their revision surgery. They reported that although these films had been recommended for all patients enrolled in the MARS study, they were not required and were only collected if surgeons used them as a standard of care [15]. Considering the higher chance of meeting the general indications of HTO in patients with failed ACL reconstruction compared to patients undergoing primary ACL reconstruction [16], it is suggested to assess limb alignment through long weightbearing radiographs in the case of suspect knee malalignment and/or unicompartmental OA [**See D10 for specific literature search**].

CT scan

Kosy and Mandalia [17], in a recent systematic review, analyzed the different methods for tunnel placement assessment and reported that CT is advantageous when tunnel placement is planned for revision surgery (and if there are anticipated potential conflicts with existing tunnels) and in assessing the shape of the tunnel aperture created or tunnel widening, using serial scans [**See D12 and D13 for specific literature search**]. Marchant et al. [18] in a comparative study of different imaging methods, supported the use of CT scans for the evaluation of bone tunnels in patients with tunnel widening, regardless of plain radiograph quality. With regard to clinical practice, in a recent clinical study that aimed to correlate the outcomes of ACL revision with tunnel enlargement (<12 mm or >12 mm), Yoon et al. [19] performed only radiographic tunnel assessment. Franceschi et al. [20], evaluating the outcome of 2-stage ACL revision, used only radiographs and MRI pre-operatively, while CT scanning was reserved for the evaluation 3 months after tunnel grafting. In contrast, Mitchell et al. [21], comparing the outcome of 1-stage and 2-stage ACL revisions, reported that each patient underwent serial measurements of the previous reconstruction tunnel diameters in several sequences of plain radiographs, MRI and CT. A limit of these studies was that, considering the length of follow-up and year of publication, patients were treated 10 years ago or more.

Flexed knee postero-anterior weightbearing radiographs

With regard to the use of radiographs with a flexed knee (Schuss and Rosenberg view), these have been suggested in the preoperative planning stage in the Manual “Revision ACL Reconstruction” [2] and by Krautler et al. [1], because of their higher sensitivity in detecting joint space narrowing compared to standard AP radiographs with an extended knee [**see D15 for specific literature search**]. However, no studies were found regarding the clinical utility of such radiographs in the specific context of Revision ACL, rather than for detecting joint space narrowing.

Axial view radiographs

With regard to patello-femoral axial radiographs, the IKDC Evaluation Form dedicates an item to the assessment of radiographic PF OA [22], since PF OA is considered a common occurrence after ACL reconstruction, especially with BPTB autograft [23]. However, in the context of Revision ACL reconstruction, the role of PF axial radiographs has not been deeply investigated.

Stress radiographs

A 2013 systematic review reported that “the diagnostic accuracy of stress radiography including the sensitivity, specificity, and positive and negative predictive values varied considerably depending on the technique and choice of displacement or gapping threshold" but that "excellent reliability was reported for the diagnosis of anterior cruciate ligament, posterior cruciate ligament, varus, and valgus knee injuries". The authors were not able to make specific recommendations with regard to the best stress radiography technique for the diagnosis of knee ligament injury and stated that no gold standard for a specific stress radiographic technique or the magnitude of force applied during testing was established for assessing anterior, posterior, varus, and valgus knee stability. However, they recognized the utility of stress radiography in offering an objective, quantifiable, non-invasive, and retrievable record that can be used to augment the diagnosis of knee ligament injuries [**See D14 for specific literature search**] [24]

Considering the large variety of possible radiological exams for assessing patients with known or suspected failure of ACL reconstruction, a case-by-case approach is suggested based on the patient's history and physical evaluation, in order to minimize costs and radiation exposure.

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D8) Can MRI assess the ACL graft status in the setting of a known or suspected failed ACL Reconstruction?

Consensus answer: MRI for the diagnosis of an ACL graft tear is limited (sensitivity 60%, specificity 87%). However, graft functionality can be assessed by indirect signs, such as anterior tibial translation or angulation of the PCL and typical bone bruise patterns. Clinical evaluation is still mandatory to assess graft integrity and functionality.

Agreement: 8.2/9

Grade of recommendation: C

Literature review:

The evidence on the optimal method for assessing graft status in the setting of known or suspected ACL reconstruction is limited. MRI is universally accepted as the best non-invasive method to assess the graft after ACL reconstruction; however, different methods of measurement have been proposed and no gold standard exists; moreover, the clinical relevance is controversial [1-2].

For assessing graft integrity, the performance of MRI was tested in a series of 50 revision ACL reconstructions with a graft lesion confirmed by arthroscopy as diagnostic standard. The graft was reported to be intact on MRI evaluation in 24% of cases. The discordance between MRI and clinical evaluation, and between MRI and arthroscopic evaluation was 52% and 44% respectively, especially in the cases of an insidious-onset mechanism of injury [3]. With arthroscopic evaluation as the diagnostic standard, the sensitivity of MRI to diagnose an ACL graft tear was 60%, and specificity was 87%. The authors concluded that caution should be used when evaluating a failed ACL graft with MRI, especially in the absence of an acute mechanism of injury, as it may be unreliable and inconsistent [3].

Regarding graft signal, a recent systematic review of 34 studies assessing graft signal intensity with MRI concluded that the MRI protocols (including sequence type, acquisition parameters, coil design, and field strength) and methods used for evaluating the ACL graft signal intensity differed widely across the studies, and that the wide variety of scan protocols and image assessment techniques impedes comparison of signal intensity between successive scans and between independent studies [2]. MRI qualitative (scores) [4-6] and quantitative (signal-to-noise quotient; SNQ) [6] methods have been proposed to assess graft status [2,7]. However, the role of MRI in monitoring and predicting outcomes after ACL surgery remains uncertain. Only seven studies examined the correlation between MRI findings and clinical outcomes after ACL surgery [2]. Overall, the T2-weighted graft signal was not reliable and did not predict clinical or functional outcomes after ACL reconstruction at both early and long-term follow-up. Biercevicz et al. [8] found that only the combined parameters of graft volume and median graft SI derived from T1-weighted 3D Gradiant Recalled Echo (GRE)-MRI had the ability to predict clinical or in vivo outcomes in patients at 3- and 5-year follow-up after ACL reconstruction. Moreover, even if technical and biological aspects such as graft types, graft position, insertion-preserved vs detached hamstring graft, navigated vs manual surgery, and minimal debridement vs conventional clearance of the intercondylar notch exhibited differences in graft signal intensity at follow-up, similar final clinical outcomes were reported [2].

Indirect MRI signs for ACL insufficiency

Apart from graft structural integrity, MRI can be helpful to identify signs of ACL insufficiency.

Bone Bruise: The presence of bone bruises, especially on the lateral tibio-femoral compartment, has been considered a reliable radiological sign of traumatic ACL rupture; therefore, their presence has been considered useful in the diagnosis of ACL injury and the understanding of rupture mechanisms [9-11].

Anterior tibial translation (ATT): The ATT with respect to the posterior femoral condyles has been reported to be increased in patients with ACL injury compared to those with intact ACL; moreover, the maximum amount of translation has been reported in patients with failed ACL reconstruction or multiple failures [12].

PCL buckling: Finally, a hyper-buckled PCL (defined as a PCL with vertical straightening of the mid-distal fibers at MRI) is suggested to be present in ACL deficient knees: although Van Dyck et al. [13] reported its presence in only 4/97 (4%) patients with ACL injury, it was noted only in patients with complete ruptures.

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D9) What additional pathologies and specific features in the setting of known or suspected failed ACL reconstruction should be assessed by MRI?

Consensus answer: Important aspects to evaluate with MRI in the cases of known or suspected failed ACL reconstruction are: (1) meniscal status (defects, radial tears, root tears, ramp tears, longitudinal\bucket handle tears) (grade B); (2) other ligament status (PCL, MCL, LCL, popliteus) (grade C); (3) extensor apparatus (grade C); (4) cartilage and subchondral status (grade B); (5) location of bone bruises (grade B); (6) hardware position (depending on artefacts); (7) tunnel position (see D12/D13); and (8) posterior tibial slope.

Agreement: 8.5/9

Grade of recommendation: B

Literature review:

Menisci, cartilage and subchondral bone lesions are frequently found during an ACL revision: the rates of concomitant chondral damage at the time of revision reconstruction range from 10% to 70% in published studies[1-3]. Thomas et al.[4] found a much higher rate of meniscal and chondral lesions in a group of patients treated for ACL revision compared to a group of patients with primary ACL reconstruction. In addition, Chen et al.[5] encountered significantly more chondral injuries in the medial compartment during a second ACL revision compared with a primary reconstruction and first revision surgery. It can therefore be assumed that a direct effect of continued instability is to predispose the knee to further chondral and meniscal damage.

Meniscal status

The role of the menisci as secondary anterior stabilizers of the knee is known; however, there are few papers in the literature correlating meniscal status and graft failure in primary ACL reconstruction[6-7].

Biomechanical studies have underlined the roles of the menisci in knee stability. The medial meniscus contributes to resisting direct anterior tibial translation and the lateral meniscus is an important restraint to anterior tibial translation during internal tibial rotation. Parkinson et al.[8] demonstrated that meniscal deficiency is the most significant factor in predicting graft failure in single-bundle ACL reconstruction. The MARS Group reported[9] that patients with partial lateral meniscectomy and current grade III–IV articular cartilage damage to the trochlear groove at the time of the revision scored significantly lower on the IKDC, KOOS and WOMAC questionnaires at the 2-year follow-up than revision ACL reconstruction patients with other injuries. Anand et al.[10] reported that meniscal status at the time of revision did not affect the return to sport rates. Patients with lesions involving <50% of the thickness of the articular cartilage at the time of revision were more likely to have returned to their pre-injury level of sport and had significantly better Marx Activity Scale, Knee injury and Osteoarthritis Outcome Score-Quality of Life (KOOS-QOL) and International Knee Documentation Committee (IKDC) scores at the mean 5-year follow-up.

MRI seems to demonstrate moderate accuracy in the diagnosis of ramp lesions in patients with ACL tear (although considerable heterogeneity in study results) and the surgical repair of ramp lesions could improve knee laxity and thus possibly leading to better outcomes.[25] A posterior lateral meniscus root tear is a clinical relevant but most likely underrecognized concomitant injury in patients with a tear of the ACL.[26]

Other ligament status

There is a lack of literature on associated ligament tears in MRI imaging of an ACL revision. However, Temponi et al.[11] in their retrospective study demonstrated that nearly 20% of patients with an ACL rupture had some injury to the PLC when evaluated by MRI, and Medvecky et al.[12] reported that early MRI evaluation is important in the assessment of 3-degree superficial medial collateral ligament (sMCL) sprains and associated posterior oblique ligament (POL) injuries to rule out associated problematic injuries that may lead to surgical reconstruction. There is evidence of increased failure of ACL reconstruction with unaddressed MCL laxity [13].

Willinger et al. [14] reported that a truly 'isolated' ACL rupture is uncommon; 67% of them have a complex medial collateral ligament (MCL) injury, with 62% of these involving the sMCL and 31% the deep medial collateral ligament (dMCL), a higher incidence than reported in previous studies [15], probably due to a shorter time from injury to MRI assessment.

Extensor apparatus

Emerson et al.[16] underline the importance of being familiar with normal post-operative MRI changes as well as having an understanding of the appearance of each post-operative complication. Indeed, a rupture of the knee extensor mechanism is a rare complication [17] after harvesting either the quadriceps or patellar tendon. A quadriceps tendon tear is shown by a hematoma formation at the superior pole of the patella in the post-operative MRI in conjunction with patella infera.

Cartilage and subchondral status

The current literature shows that severe chondral damage and meniscal lesions at the time of ACL revision have a negative effect on the clinical outcome, activity levels and return to sport rates, despite good results in terms of clinical laxity[1,18].

Location of bone bruises

Bone bruises in the setting of known or suspected failed ACL reconstruction could suggest a traumatic type of failure if present in the posterior lateral tibial plateau and the anterior portion of the lateral femoral condyle. Posterior medial tibial plateau bone bruising could indicate possible medial meniscus ramp tear, while patellar and anteromedial tibial bone bruises could suggest severe trauma. Medial or lateral subchondral bone bruises with cartilage thinning could indicate a chronic overload or a chronic meniscal root tear. Although magnetic resonance imaging (MRI) of the injured knee provides critical information about the graft rupture as well as information about menisci, cartilage surfaces and subchondral bone[19], bone edema in the lateral compartment can indicate whether the rupture was traumatic in nature[20].

Hardware position

Fixation devices can lead to ACL reconstruction failure or be a cause for complications such as mal-positioning, mobilization and fracture. Unfortunately the hardware position can be an issue in an ACL MRI evaluation, because metallic devices can cause image artifacts. However, hardware mobilization, migration or rupture can easily be shown on MRI with specific software techniques[21]. Hardware failure in the early postoperative period may lead to the loss of graft fixation and cause instability; nevertheless, MRI findings of device mobilization should be correlated with clinical findings of joint instability or pain [22-23].

Once an ACL graft has healed and is firmly integrated, stability may not be compromised, but hardware mobilization or fractures of fixation hardware components can lead to intra-articular bodies[24].

ESSKA

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D10) What imaging is recommended to assess lower leg coronal alignment?

Consensus answer: The optimal method to assess lower limb alignment is the measurement of the mechanical axis either with mechanical femoro-tibial angle or weight bearing line, as well as mechanical medial proximal tibial angle (mMPTA), mechanical lateral distal femoral angle (mLDFA) and joint line convergence angle (JCLA), on long leg weightbearing radiographs (with centered patella).

Agreement: 8.7/9

Grade of recommendation: C

Literature review:

A limited number of studies investigated when and how to assess lower limb alignment in the setting of Revision ACL reconstruction, and which is the optimal method. Borphy et al. highlighted the role of lower limb alignment in patients from the Multicenter Revision ACL Study (MARS). The authors included only 246/1200 patients (20.5%) with bilateral weightbearing long-leg alignment films taken just before their revision surgery. They reported that although these films had been recommended for all patients enrolled in the MARS study, they were not required, and were only collected if surgeons used them as a standard of care. Measuring the distance from the medial border of the tibial plateau and the mechanical axis, the authors reported that for every 10% shift in the weightbearing line (WBL) lateral on the tibial plateau, the risk of medial compartment chondrosis decreased by 9.7%. In contrast, alignment was not associated with chondrosis in the lateral compartment [1].

In a Level III therapeutic study, Won et al. compared the mechanical tibio-femoral angle, the weight bearing line (%) and the Kellgren-Lawrence (KL) of 58 Asian patients undergoing Revision ACL with 116 undergoing primary ACL reconstruction. The authors found that the revision ACL reconstruction group had more frequent varus malalignment in terms of the proportion of knees with a mechanical tibiofemoral >5° of varus (19% versus 8%, p=0.029) and knees with a weightbearing line of less than 25% (22% versus 9%, p=0.011). This group also showed more frequent high-grade injury of the medial meniscus (34% versus 16%, p=0.007) and tended to more frequently have more advanced radiographic signs of OA at the medial tibiofemoral compartment (19% versus 9%, p=0.076). Moreover, the percentage of patients meeting potential indications for high tibial osteotomy was greater in this group (14% versus 2%, p=0.003), considering as HTO criteria (1) weight loading line less than 5% from the medial edge of the tibial plateau regardless of any other condition; (2) weight loading line less than 25% plus radiographic OA of KL Grade III or higher at the medial tibiofemoral joint regardless of meniscal condition; and (3) weight loading line less than 25% plus KL Grade II at the medial tibiofemoral compartment and after subtotal or total medial meniscectomy. HTO was not considered in the case of KL grade III or higher at the lateral compartment and/or subtotal or total lateral meniscectomy. The authors concluded that many patients undergoing revision ACL surgery may also be reasonable candidates for concurrent high tibial osteotomy to address concomitant alignment and OA issues in the medial compartment [2]. However, a meticulous differentiation during clinical examination between instability and medial joint line pain is crucial.

With regard to the importance of alignment in the context of ACL reconstruction, a biomechanical study by Van de Pol et al. aimed to assess ACL tension and lateral joint opening, after recreating a neutral axis, an axis passing through the midpoint of the medial compartment and an axis passing at the medial margin of the medial compartment. They reported that the ACL tension was significantly higher with the weightbearing line passing through the medial border of the medial compartment (53.9 N) compared with its midpoint (37.9 N) and neutral axis (31 N). Moreover, a significant lateral joint opening (thrust) was observed only in the most severe varus setting. They concluded that a slight varus alignment does not yield clinically relevant ACL tensions, while a severe varus alignment, especially with a varus thrust, can yield high ACL tensions that can be responsible for the failure of an ACL reconstruction. It is therefore important to rule out a varus thrust by carefully examining patients [3]. Varus thrust, which is defined as an abrupt worsening of existing varus during the weightbearing phase of gait, with a return to a reduced varus alignment during the non-weightbearing (swing) phase, is in fact considered a general indication for HTO even in the case of no medial OA [2-5].

To investigate the clinical consequences of varus malalignment and primary ACL reconstruction, Kim et al. (Ref.) retrospectively evaluated 201 primary single-bundle ACL reconstructions, stratifying them into 4 groups based on the deviation in mm of the mechanical axis from the center of the joint. With a minimum of 2 years of follow-up, no differences were reported for the Lachman-Test, Pivot-Shift, Lysholm, IKDC and KT-1000 between those with neutral alignment and varus alignment with the weightbearing line passing within the medial compartment. In fact, patients with varus thrust, subtotal meniscectomy and Chondrosis > grade II were excluded from the study. The authors concluded that if there is no OA in the medial compartment and no varus thrust, HTO is not indicated in varus knees undergoing ACL reconstruction [6].

Criteria for long weightbearing radiographs

Regarding the technical execution of long-leg weightbearing radiographs, the true AP view is defined with the knee in forward position with the patella centered on the femoral condyles, independent of the foot position. In the case of patella dislocation, the knee flexion-extension axis is used as a reference [7]. It is also suggested to use blocks in the case of limb discrepancies to adjust length and avoid compensatory knee flexion. A long cassette (130 cm) is also preferable due to lower magnification [7]. Despite these suggestions, studies with 3D models reported that the hip-knee-ankle angle in the cases of limb alignments from 9° of varus to 9° of valgus, does not substantially vary with internal rotation, external rotation or flexion up to 30° [Lukas jud 2019], and the measurement error rarely exceeds 3° [8]. In contrast, other authors suggested the assessment of fibular overlapping to determine the exact amount of rotation in order to avoid errors in axis measurements [9,10].

Legend: The Femoro-Tibial Angle (FTA) (green line) is the angle formed by the intersection of the line connecting the femoral head and the center of the knee, and the line connecting the center of the knee and the midpoint of the talus surface. The weightbearing line (red line) connects the center of the femoral head and the midpoint of the talus surface; the amount of malalignment is measured as the distance from the medial border of the tibial plateau to the mechanical axis, calculated as % of the whole tibial plateau.

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D11) How should Tibial Slope be assessed in the setting of a known or suspected failed ACL Reconstruction and what is the optimal method?

Consensus answer: In the setting of known or suspected failed ACL Reconstruction, Posterior Tibial Slope (PTS) should be assessed, but an optimal method has not been universally defined. It is suggested to measure the medial posterior tibial slope on a lateral view of the proximal tibia, measuring the angle between the tangent of the medial tibial plateau and the proximal anatomical tibial axis (normal value **9° ± 3°**). The normal value depends on measurement methods. An angle ≥12° should be considered critical using the described measurement method. MRI methods can independently measure lateral and medial soft tissue tibial slope, but should be used with caution for surgical planning due to the high variability of measurements and the lack of solid evidence.

Agreement: 8.1/9

Grade of recommendation: C

Literature review:
Posterior tibial slope (PTS) has received particular attention in recent years due to the increasing evidence of its role as risk factor for anterior cruciate ligament (ACL) injury [1], ACL reconstruction failure and ACL multiple failures [2-8]. The biomechanical rationale is that axial-loading tasks, such as walking, squatting, and jump landing, produce a vertical shear force through the tibiofemoral joint that is converted to a slope-related, anteriorly directed tibial translational force [4-9]. Moreover, a cadaveric model demonstrated that PTS strongly correlates directly with the amount of graft force experienced by an ACL graft in axially loaded knees with flexion between 0° and 60°. Thus, a flatter tibial slope has significantly less loading of ACL grafts, while steeper slopes increase ACL graft loading, supporting their role as risk factors for ACL graft failures demonstrated clinically [9-10]. Therefore, PTS should be taken into account when assessing failed ACL reconstruction, to optimize the treatment strategy. However, there is no consensus on how to measure the PTS and where the critical cutoff may lie.

Several case-controlled studies used MRI to measure the medial and lateral PTS, demonstrating higher values on failed ACL reconstructions compared to non-failed ACL reconstructions [2,4-6,11]. In a retrospective comparative trial of 232 patients with at least 10 years of follow-up, a higher failure rate was reported in patients with medial PTS>5.6° (16.1% vs 5.1%; p=0.01) and with lateral PTS>3.8° (14.5% vs 4.7%; p=0.01) [11]. However, MRI measurement is considered demanding, cut-off values varied significantly among studies, and reliability of measurements was lacking in absolute precision (ICC=0.4276) [12].

The radiographic method is most commonly used to also measure PTS in the assessment of ACL reconstruction outcomes, even if different measurement methods exist and PTS magnitude can be dependent on the measurement method [13]. Also in this case, comparative, prospective and retrospective studies of primary ACL and revision ACL reconstructions are available [6,7,13,14]. The results seem more homogenous than for MRI. In fact, Webb et al., in 200 consecutive patients, showed that the odds of further ACL injuries (either ipsilateral or contralateral) after reconstruction were increased by a factor of 5, to an incidence of 59%, in those with a posterior tibial slope of ≥12° [8]. The authors measured the PTS on lateral radiographs, as the angle between a line drawn tangentially to the medial tibial plateau and a perpendicular line to the proximal anatomical axis of the tibia, which was determined from a line connecting the mid-cortical diameters of the tibia at a point between 5 cm and 15 cm distal to the knee joint [8]. Using the same measurement method, Salmon et al. identified a PTS ≥12° as having an Odds Ratio=3 compared to patients with PTS <12°. Moreover, the ACL survival for adolescents with a PTS≥ 12° was 22% at the 20-year follow-up [7]. In addition, Ahmed et al. reported that among 11 patients with 3 or more ACL reconstructions, 64% had a PTS ≥12° [14]. Using the same measurement but a different study design, through Receiver Operating Characteristics (ROC) analysis, Lee at al. identified PTS ≥12° as the optimal cut-off to predict failure of ACL reconstruction, with a sensitivity of 0.703 and a specificity of 0.344 [15]. Grassi et al. identified the same PTS measurement as a predictor of contralateral ACL injury in patients aged under 18 years after ACL reconstruction and lateral plasty in the cases of values ≥12°, but not for failure of ipsilateral primary reconstruction [3]. Su et al. found no significant differences in radiographic PTS with different measurement methods between patients undergoing primary ACL reconstruction, Revision ACL and patients with intact ACL [16].

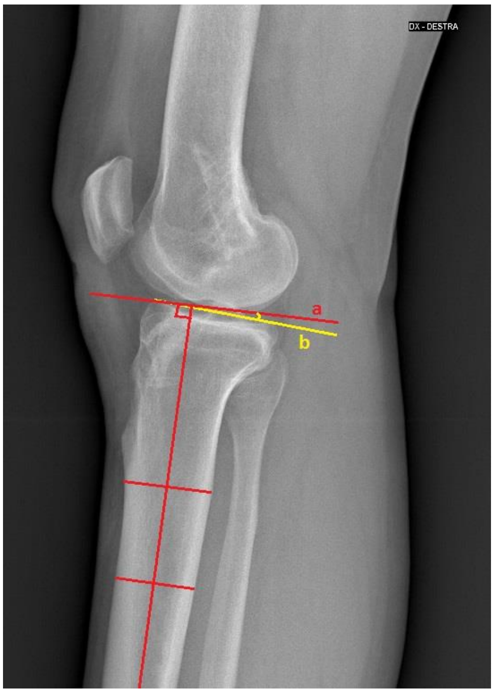
Finally, measurement methods have also been reported with CT [17], but their use in clinical and research settings in the context of Revision ACL Reconstruction is limited.

A recent study aimed to compare the reliability and variability of PTS according to radiographs, MRI and CT measurements. The authors reported good reliability (ICC between 0.80-0.90), but they found a mean difference of up to 5.4° ± 2.8° and 4.9° ± 2.6° between different measurement methods for the medial and lateral tibial slope, respectively. They concluded that PTS measurements have a high degree of variability and inaccuracy between imaging modalities and different measurement methods and that care must be taken when deciding on indications based on individual modality measurements [17]. Similarly, Dean et al. assessed the variability of different radiographic measurements. In 140 patients, the authors found that the measurement of PTS using the anatomic tibial axis was similar if measured on standard lateral radiographs or in long-leg lateral radiographs. However, a significant difference was present between the PTS measured using the anatomical axis and the mechanical axis in the lateral view, with an overestimation of the anatomical axis in respect to the mechanical axis of at least 2° in 55% of cases. The authors concluded that lateral knee radiographs are adequate to accurately obtain PTS measurements, and advocated for consistency in the technique for obtaining PTS measurement by using anatomic axis PTS measurements from both lateral knee and full-length lateral tibia radiographs in order to accurately and reliably compare PTS measurements [18]. Similarly, Faschinbauer et al. suggested using expanded lateral radiographs with more than 10 cm of proximal tibia, since long-leg lateral radiographs are not always feasible in everyday practice and short radiographs lead both to overestimation of PTS by nearly 3° and provide less reproducible results [19]. Other measurement methods have been suggested to have good reliability, such as those using the tibial cortex, but experimental and clinical evidence are still limited [20].

In clinical practice, only three studies applied a cut-off value of PTS to perform deflexion HTO in the setting of multiple failures of ACL reconstruction [21-24]. Sonnery-Cottet et al. used a cut-off of ≥12°, measuring the angle between the tangent to the medial tibial plateau and the mechanical axis of the leg on a true long-leg lateral radiograph obtained under fluoroscopic control [21]. Similarly, Dejour et al. also used a cut-off of ≥12°, but this was obtained from measurement of the angle between the anatomical proximal tibial diaphyseal axis and the tangent to the most superior points at the anterior and posterior edges of the medial tibial plateau, on true lateral knee radiographs, without mentioning (or illustrating) the use of long leg lateral radiographs [22]. Akoto et al. used the same measurement method (anatomical axis measured at 9 cm and 15 cm from the joint line) and cut-off (≥12°) to indicate 2-stage deflexion HTO and ACL revision+lateral plasty [23]. It should be noted that most of literature regarding PTS and its correction is based on studies on European patients. Considering that

PTS values >12° have been reported in Asian patients with no mention of ACL injury [25], caution should be used when generalizing the normal values and cut-offs [26].

Recommended method for assessing tibial slope on x-rays: The posterior tibial slope is measured by calculating the angle between the perpendicular to the tibial diaphysis, and the tangent to the anterior and posterior edges of the medial tibial plateau. The axis of the tibial diaphysis is obtained by creating a vertical line beginning at the midpoint between the anterior and posterior tibial cortex, 5 cm distal to the joint line, and ending at the midpoint between the anterior and posterior tibial cortex, 10-15 cm distal to the joint line.



Legend: The posterior tibial slope can be measured on 'true lateral view' radiographs, by calculating the angle between proximal anatomical axis (red "a" line) and the line tangent to the anterior and posterior edges of the medial tibial plateau (yellow "b" line). The proximal anatomical axis was obtained by connecting the midpoints between the anterior and posterior tibial cortex at 5- and 10-cm distance to the joint line.

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D12) When is a specific assessment of tunnel widening necessary and how should it be done?

Consensus answer: Radiographs (AP and lateral) should be considered an inexpensive first level method to assess tunnel position, osteolysis and enlargement (especially of the tibial tunnel). When the tunnel is not properly positioned, expanded or abnormally shaped, or cannot be safely evaluated on x-ray, a CT scan is required, including 3D reconstructions when available. Measurements should be performed in each plane, with a straight line from the tunnel side-to-side, in the portion of its more relevant enlargement.
High-quality MRI could also be used for tunnel diameter measurement, although it is less well evaluated.

Agreement: 8.5/9

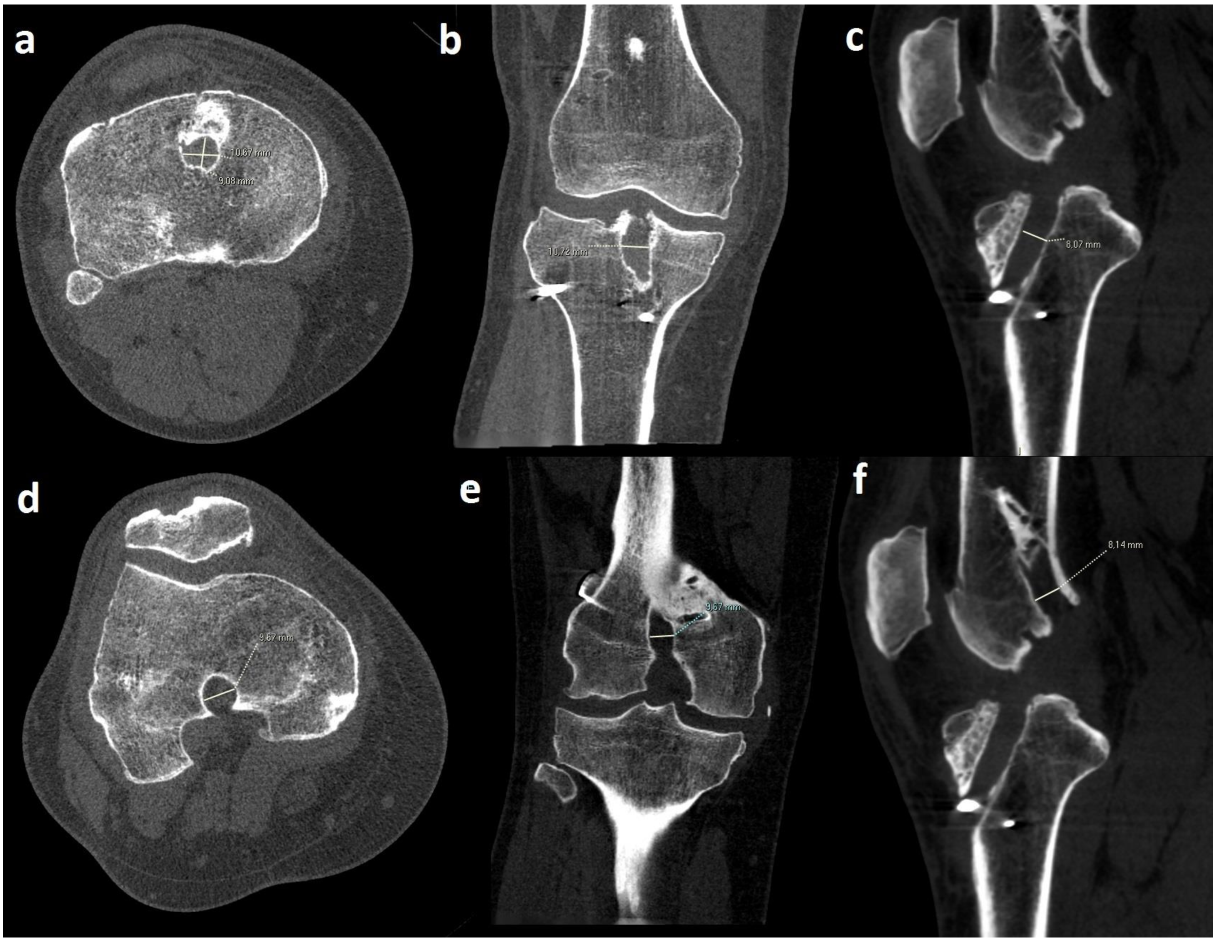
Grade of recommendation: B

Literature review:
Several studies assessed the reliability of tunnel measurement, with good-moderate quality due to sound statistical analysis and blinding of evaluators. Based on the current evidence, CT scanning is generally considered the optimal method for evaluating tunnel enlargement. This was confirmed in a recent review, which suggested performing a CT scan if there are concerns with tunnel widening or osteolysis [1].
Merchant et al. [2] tried to define the optimal method to evaluate tunnel diameter, comparing the reliability of plain radiographs, MRI and CT scans. Five observers measured the tunnel size in 12 patients using the different methods and reported that the CT scan was the only method that allowed tunnel identification in 100% of cases for both tibial and femoral tunnels in either the coronal or the sagittal plane. Moreover, CT had the highest inter- and intra-observer agreement for the measurement of tunnel diameter, with “substantial” (k=0.60-0.80) to “moderate” (k=0.40-0.60) agreement in most cases. However, CT was similar to MRI in coronal images and to radiographs in sagittal images in measuring tibial tunnel diameter. Finally, with regard to tunnel cross sectional area, CT scans were superior to both MRI and radiographs, with “substantial” intra- and inter-observer agreement.

Another systematic review of diagnostic modalities to assess tunnel enlargement, which included 103 studies and 6383 patients, reported that 44/103 studies used radiographs, 21/103 used MRI and 20/103 used CT scan, with radiographs considered the most used method at all time points of follow-up [3]. However, the authors reported that CT scanning was the most sensitive method for detecting tunnel widening. The authors thus concluded that “CT scans remain the optimal modality for diagnosis“. Factors such as costs, time, and radiation explain why plain radiographs are still commonly used for the assessment of tunnel widening. Plain radiographs are limited by their two-dimensional nature and, therefore, differences in knee position and distance from the film surface can affect results [3].

Another debated and less standardized issue is the method for concretely obtaining the measurement of the tunnel. Merchant et al., in a study on tunnel measurement reliability described the tunnel measurement as the distance between the tunnel’s sclerotic margins, perpendicular to the tunnel axis, at its widest point [2]. A similar method was employed by Yoon et al. [4] and Choi et al. [5] in clinical studies on revision ACL reconstruction. Mitchell et al. [6], in another clinical study on revision ACL performed in either a 1-stage or 2-stage fashion, performed the tunnel measurement “in any sequence that was in the desired anatomic tunnel location or would critically overlap with these tunnels“. Groves at al. [7], in a pictorial review of the use of CT in the management of revision ACL, reported that “tibial tunnels should be measured in the sagittal and coronal plane at their midpoint, and at their proximal and distal apertures, whereas femoral tunnels should be measured at their midpoint and at the notch aperture“.

Meuffels et al. [8] used a 3D approach to assess tunnels, reporting higher reliability compared to CT, MRI and radiographs; however, the authors studied only tunnel placement with no mention of diameters. Crespo et al. [9] also used 3D models, reporting a higher accuracy in comparison to 2D methods; however, it was used only in a controlled setting with no tunnel enlargement and dedicated software was necessary.



Legend: When the CT scan is used, the tibial tunnel enlargement is measured on axial (a), coronal (b) and sagittal (c) slices, with a straight line from the tunnel side-to-side, in the portion of its more relevant enlargement. The same is done for femoral tunnel (d, e, f)

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D13) How can the assessment of tunnel placement be performed and what is the definition of tunnel misplacement in the setting of a known or suspected failed ACL Reconstruction?

Consensus answer: Tunnel placement can be assessed with standard AP and lateral radiographs (grade B), but the definition of femoral tunnel misplacement is not universally accepted and remains controversial (Grade C).

However, as a general rule to help pre-operative management, a misplaced femoral tunnel may be considered when the center is outside an area within 19-29% of the proximo-distal dimension and within 22-53% of the antero-posterior dimension, according to Bernard and Hertel's grid method.

A misplaced tibial tunnel may be considered when it is outside the range of 30-50% of the antero-posterior distance, according to the method of Staubli and Raushning, or when the tunnel is anterior to the Blumensaat line in full knee extension.

In cases where it is impossible to detect either tunnel, their positions can be assessed with a CT scan, using the same references for a sagittal slide parallel to the notch for femoral tunnel and an axial slide parallel to the posterior border of the tibial plateau for the tibial tunnel. A surrogate for abnormal tunnel placement is an abnormal graft inclination on MRI, which can be considered when >60° on the sagittal MRI plane and >75° on the coronal MRI plane.

Considering the existing controversies relating to anatomy, measurement methods and individual characteristics, the ranges provided do not represent absolute values or standalone parameters to determine ACL failure or indication for revision. Rather, they should be interpreted critically and used in combination with clinical evaluation and other objective assessments to develop adequate pre-operative planning.

Agreement: 8.1/9

Grade of recommendation: B/C

Literature review:

The assessment of tunnel placement in a known or suspected failed ACL reconstruction is considered a mainstay in diagnosis and surgical planning [1]. However, there are controversies regarding the optimal methods and the cut-off do define placed graft [2], especially in the light of new science and evidence in the field of ACL anatomy [3].

A systematic review of the radiological methods used to assess tunnel placement was conducted in 2018 by Kosi and Mandalia [3]. They concluded that “plain radiographs are adequate for the surveillance of the ACL graft position with normal values defined for the commonest methods used”. The authors added that “despite continued debate about optimal positioning of the graft, plain radiograph measurements provide the surgeon with adequate information to monitor their performance in the majority of cases” and that “CT and MRI have been shown to provide additional information about the tunnels and graft that are of importance in comparative studies and in revision surgery”.

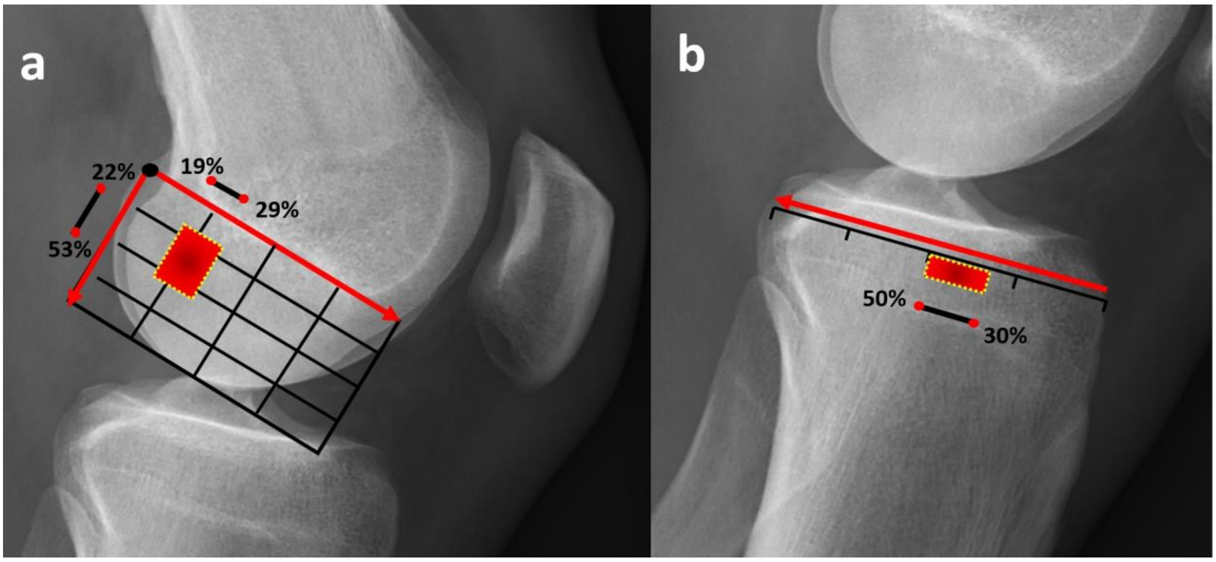
Femoral tunnel assessment:

Regarding the radiographic assessment of the femoral tunnel, its position is commonly assessed in the lateral view, using several different methods. The methods developed by Harner, Aglietti, and Amis, all use Blumensaat’s line as a reference, while the grid\quadrant method, described by Bernard and Hertel, uses Blumensaat’s line and the posterior aspect of the lateral femoral condyle to draw a 4 X 4 grid. Evidence exists that correlates clinical outcomes with tunnel placement according to the Harner, Aglietti or Amis methods [3], but the largest literature is for the grid method [3]. According to the Bernard and Hertel grid method, the center of ACL insertion has been reported to be at 24.8 ± 2.2% of the sagittal width of the femoral condyle and at 28.5 ± 2.5% of the height of the intercondylar fossa [4], therefore its center is located in the distal corner of the most supero-posterior quadrant. Zantop et al. investigated the position of the two ACL bundles according to the Bernard and Hertel method, describing the center of AM bundle at 18.5% of the lateral condyle height and 22.3% of the Blumensaat line, while the center of the PL bundle at 53.6% of lateral condyle height and at 29.3% of the Blumensaat line [5]. It can thus be deduced that an ACL tunnel can fall within a range of 18.5-29.3% of the Blumensaat line and 22.3-53.6% of the lateral condyle height. Moreover, a systematic review of 13 studies, that however used different measurement methods (radiographs, CT, MRI and direct anatomical measurements) reported the normal range of centers of ACL between 24-37% on the Blumensaat line and at 28-43% of lateral femoral condyle height [6].

Measurement of the femoral tunnel using AP radiographs has also been described; however, their reliability has been reported to be inferior compared to lateral radiographs, which have higher inter class correlation (ICC) values >0.80-0.90) [7].

Tibial tunnel assessment:

Tibial tunnels can be assessed radiographically in a lateral view using the method of Staubli and Raushning, which is the distance of the ACL from the anterior tibial margin, as a % of the whole tibial length [8,9]; based on this, the ACL tibial insertion has been defined at 43%. However, more recent studies analyzing the double-bundle structure of the ACL have reported the center of the AM bundle to be located at 30% of the antero-posterior tibial dimension, with the center of the PL bundle at 44% [2,5]. Moreover, according to this measurement method, studies had reported higher failures with this distance >50% and also with tunnels anterior with respect to the intersection between the tibial plateau line and the extension of the Blumensaat line [3]. Merchant et al. reported a high prevalence of tibial tunnels positioned more than 50% outside the anatomical insertion (43%) [10]. With regard to tunnel placement on antero-posterior radiographs, a midline position with respect to the tibial plateau width is suggested, with no relevant controversies [3]. If lateral radiographs are performed in extension, “unforgiving knees” can be evaluated, by measuring the relationship between the extension angle of the knee and the roof angle (Blumensaat line), suggesting the risk for graft impingement as is the case in hyperextention [11-12].



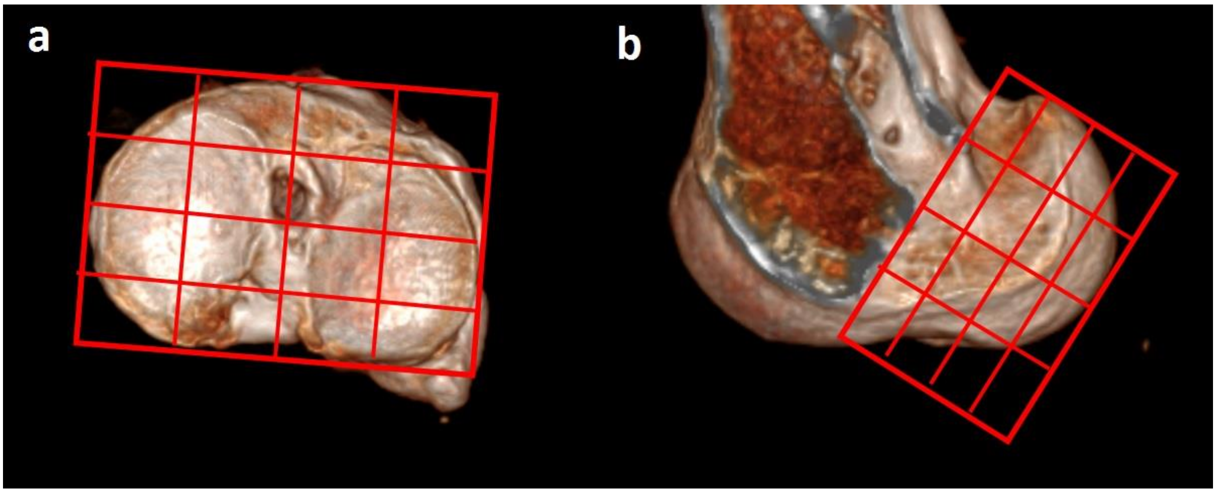
Legend: (a) Femoral tunnel placement can be assessed with the Bernard and Hertel's grid methods; correct placement is considered when the tunnel center falls within an area comprised between the 19% and 29% of the proximo-distal dimension and between the 22% and 53% of the antero-posterior dimension (red square).

(b) Tibial tunnel placement can be assessed according to the Staubli method; correct placement is considered when the tunnel center falls within the range between the 30% and 50% of the antero-posterior distance (red square)

CT assessment:

For the CT assessment of femoral tunnel placement, most methods adopted have similarities to the grid method used to interpret plain radiographs. 3D-CT allows the medial wall of the lateral femoral condyle to be viewed directly (with the medial condyle removed) and positioned with a "strictly lateral" orientation of the femur, rotating the reconstruction until the condyles are overlapping. Several methods with different references have been suggested [3]. However, no substantial changes have been made with respect to the CT-adaptation of the Bernard and Hertel method. This method has been used to assess failed ACL reconstruction: non-anatomic tunnel placement was defined by Parkinson et al. [13] if it was more than 2 standard deviations from the normal position based on the weighted mean in the literature (AMB=25%, PLB=34%, Central=29.3% on Blumensaat or Deep/Shallow position; AMB=22.4%, PLB=48.6%, Central=34.7% on lateral condyle height or High-Low position); by Jaecker et al. [14] as being outside the range of 19-29% for depth and 22-53% for height; by

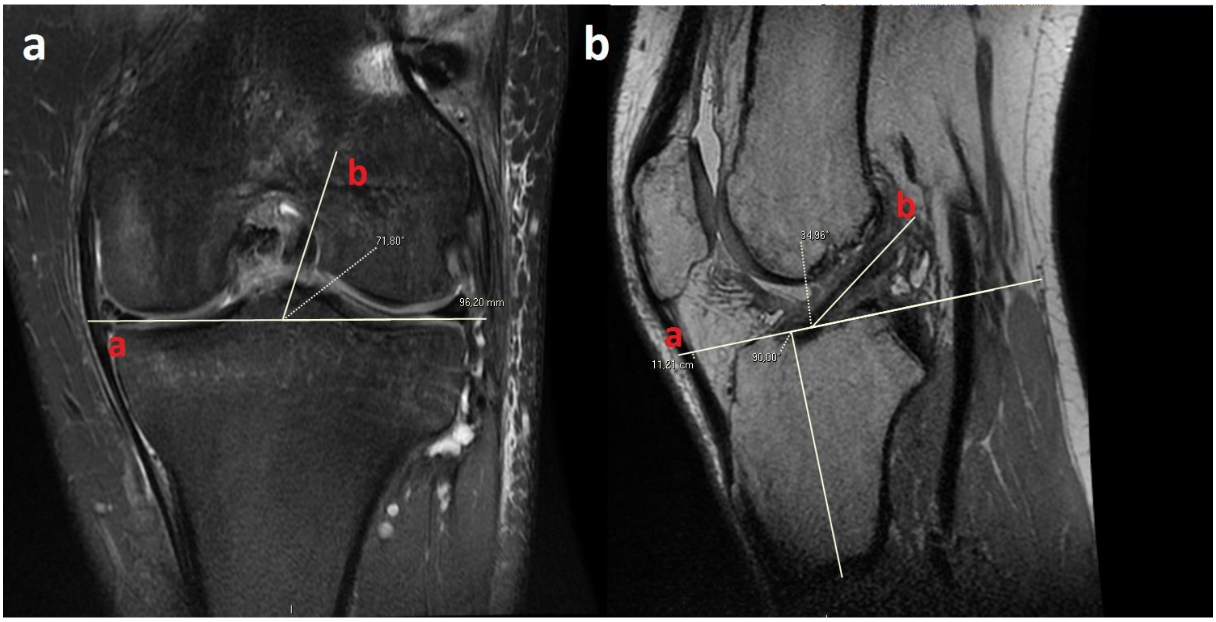
Ziegler et al. [15] as outside the range of 23-33% for depth and 28-38% for height. All three studies reported high rates of malpositioned tunnels in patients with failed ACL reconstruction, according to their cut-offs, especially in those with non-traumatic failures. For CT assessment of the tibial tunnel, measurements have largely been made in the axial plane using a grid method, orienting the grid to be parallel to the posterior border of the tibial plateau. The anterior, medial and lateral borders are then defined by the respective borders of the greatest dimension of the plateau. According to this method, the center of the ACL has been reported at 38.7% from anterior to posterior and at 49.1% from medial to lateral [3]. This method was used to assess failed ACL reconstruction: non-anatomic tunnel placement was defined by Parkinson et al. [13] as being more than 2 standard deviations from the normal position based on the weighted mean of the literature for the antero-posterior position (39 ± 3 %) and the medio-lateral position (48 ± 2%); by Jaecker et al. [14] as being outside the range of 30-44% (presumably from the anterior margin); by Ziegler et al. [15] as outside the range of 36-46% from the anterior margin and 40-50% from the medial margin. Also in this case, high rates of non-anatomical placement were found in failed ACL reconstructions.



Legend: When the CT scan is used, tibial tunnel can be assessed on axial slices (a) while the femoral tunnel can be assessed on sagittal slices (b) according to modifications of the grid methods and with specific cut-off values.

MRI assessment:

MRI has been reported to be sub-optimal for assessing tunnel size and position, due to hardware artifacts [16]. However, it can be useful to assess graft orientation, which can be considered a “surrogate” for tunnel placement. A graft angulated >55-60° on the sagittal plane has been reported in patients with non-anatomical graft placement, failed ACL or greater laxity [16-18]. Sub-optimal results have also been reported with vertical grafts on coronal planes, usually with a coronal angle >75°, even if a consensual cut-off has not been defined [3, 16, 19].



Legend: a) The coronal graft inclination is calculated measuring the angle between the tangent line to the tibial plateau (line a) and the line which best defines the course of the intra-articular part of the graft (line b). A high angle represents a vertical graft in the coronal plane.
b) The sagittal graft inclination is calculated by measuring the angle between the perpendicular line (line a) to the proximal tibial axis, and the line which best defines the course of the intra-articular part of the graft (line b). A high angle represents a vertical graft in the sagittal plane.

Comparing CT and radiographs, a higher ability to identify tunnels has been reported with CT scans [20], leading the author to conclude that CT scanning is required to accurately assess cases where tunnel position is vital. However, experimental settings showed small differences and a high correlation (Pearson correlation=0.840-0858) between CT and radiographic measurements, suggesting reasonable accuracy of the radiographic grid method compared to

CT measurement. In contrast, when assessing potential tunnel conflicts, Tscholl et al. [21] found 9/20 potential conflicts with CT compared to only 1/20 potential conflicts after radiographic assessment. However, the study was performed only on 20 patients and the setting was experimental, using primary reconstruction as a reference group.

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D14) What is the optimal method to assess concomitant ligament injuries?

Consensus answer: Clinical evaluation is crucial (posterior drawer, varus-valgus stress, internal-external rotation) always comparing the injured to the uninjured side. MRI can help to find associated ligament injuries but is less sensitive in chronic cases. Bilateral stress x-rays are helpful to exactly classify laxity in the AP and mediolateral plane.

Agreement: 8.4/9

Grade of recommendation: C

Literature review:

Clinical examination

Clinical evaluation is crucial: posterior cruciate ligament (PCL) laxity is tested by both posterior drawer testing and assessment of posterior sag sign or the quadriceps active test, whereas the lateral and medial collateral ligaments are tested in full extension and 30° of knee flexion[1]. Moreover, a careful examination under anesthesia, including a complete assessment of varus, valgus, and rotational laxity to recognize all associated deficiencies, could be helpful to determine the right treatment[2.]

Posterolateral and posteromedial laxity should be tested with the dial test at 30° and 90° of knee flexion: the last test discriminates the involvement of the posterior cruciate ligament.

MRI

MRI allows us to detect acute associated ligament injuries with direct and indirect signs (i.e. bone bruising and hematoma). Willinger et al.[3] reported that the presence of bone edema at the medial femoral condyle (MFC) adjacent to the dMCL attachment site, and MRI grade II sMCL injury are significant risk factors for having a dMCL injury.

In chronic cases MRI is much less sensitive. See D9 for MRI.

Bilateral stress x-rays

Stress radiography offers objective and quantifiable values with a non-invasive procedure, which can be used to reinforce and confirm the diagnosis of knee ligament injuries. A variety of stress techniques[4,5] have been described that assess ligament stability using an anteriorly, posteriorly, varus-, or valgus-directed force to the knee. Kennedy et al.[6] reported that the gold standard for posterolateral corner (PLC) injuries are varus stress radiographs. Varus stress radiographs have been validated as a reliable and repeatable objective examination for both isolated fibular collateral ligament (FCL) injuries and combined PLC injuries.

Rolimeter

A study by Höher et al.[7] showed how Rolimeter® measurements have delivered comparable results to stress radiograph measurements in the evaluation of posterior knee laxity. Due to its low cost and lack of exposure to radiation for the patient, its use may be considered a valuable alternative to stress radiography in the evaluation of patients with posterior cruciate ligament (PCL) injuries.

KT 1000

As mentioned above, the KT-1000 is the recommended device for assessing suspected ACL reconstruction failure. It could also be a valid option for assessing PCL deficiency; however, stress radiography seems to be superior for the assessment of posterior laxity.[8]

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D15) How can osteoarthritic changes be assessed in the setting of a known or suspected failed ACL Reconstruction?

Consensus answer: The recommended method to assess tibiofemoral osteoarthritic changes is the KL score on weightbearing radiographs (AP full extension), although there are limitations in its use. “No to Mild OA” is defined as Grades 0, I, and II, while “Moderate OA” is defined as Grade III, and “Severe OA” is defined as Grade IV. A flexed weightbearing view (Schuss/Rosenberg) has higher sensitivity than x-rays in extension. The IKDC grading system is a valid alternative to the KL, especially in less advanced OA. Axial view radiographs can be used to grade patellofemoral (PF) OA. MRI provides a comprehensive assessment of early OA, cartilage lesions, subchondral bone status and PF OA.

Agreement: 8.6/9

Grade of recommendation: B

Literature review:

Only one study investigated the optimal method to assess osteoarthritic changes in the specific context of Revision ACL, but only used radiographs [1]. Therefore, the literature regarding primary ACL reconstruction and general knee OA is investigated. To identify the optimal method, the features of instruments (MRI, radiographs), the reliability of OA classification systems and the technical execution of radiological exams should be taken into account.

A 2019 narrative review regarding imaging for OA [2] concluded that “an increasing number of articles have been published over the past year using conventional and compositional MRI to detect early structural joint pathology in subjects with OA or risk factors for OA“. Moreover, MRI has been reported to have a high sensitivity in detecting cartilage lesions, even in the patello-femoral joint [3], and a correlation with radiographic OA grading [4]. Regarding MRI scores such as WORMS and BLOKS, although they have been reported to have high reliability [5], due to their time-consuming nature and limited popularity, use has been reserved mostly for research settings rather than for clinical purposes, especially in the assessment of early OA and cartilage/subchondral bone pathologies [6].

In the context of ACL reconstruction, a 2019 meta-analysis assessed the risk of OA after ACL reconstruction in 41 studies, relying exclusively on knee radiographs [6], which are considered the easiest and cheapest first-line method of assessment, according to the literature. When assessing knee OA through radiographs, several classification systems and scales are available. A study by the Multicenter ACL Revision Study (MARS) group, using 632 patients, assessed inter-observer reliability for 6 common OA scales (KL, IKDC, Fairbanks, Brandt, Ahlback, Jager-Wirth) on standing AP extension and/or Rosenberg views, and the correlation between radiographs and arthroscopic findings [1]. The authors concluded that the IKDC score had the "the best combination of good interobserver reliability (AP=0.59, Rosenberg=0.66) and medium correlation with arthroscopic findings (AP=0.32, Rosenberg=0.37). The KL appeared to have an inferior interobserver reliability (AP=0.38, Rosenberg=0.54) compared to the other scales, but the correlation with arthroscopic findings (AP=0.30, Rosenberg=0.40) was similar or slightly higher. The authors acknowledged that the IKDC system places more emphasis on joint space narrowing than does the more traditional KL system, which relies mostly on the presence of osteophytes and joint deformity. Another recent study assessed the reliability of KL, IKDC and Ahlbäck in 112 patients who were candidates for TKA [7]. The authors reported adequate inter- and intra-observer reliability of all scores, with the IKDC classification having the greatest reliability (imputed to its conservative definitions) and the Ahlbäck and KL classifications better reflecting the spectrum of disease severity encountered in an older patient cohort. This finding was confirmed by Keenan et al. [8] in another cohort of patients undergoing TKA, reporting that KL systems (and Ahlbäck) had the highest correlation with confirmed cartilage loss at the time of TKA. However, these patients presented a more advanced stage of OA when comparing with patients after ACL injury. It is well known that the definition of KL II is the most debatable one [9]. It is of interest that the KL showed a clear clinical implication, since it had a high correlation with subjective clinical scores after HTO [10].

In defining knee OA, a popular meta-analysis assessing OA after ACL reconstruction, in order to pool the results of studies assessing OA through different systems, considered the cut-off for OA diagnosis to be as follows: grade II of KL, grade C of the IKDC and grade 1 for Ahlback [11]. This approach has been used consistently in the literature [6, 12].

Finally, particular mention must be made of the technical execution of radiographs. Based on several comparative studies, postero-anterior radiographs with flexed knees have been reported to have higher reliability compared to standard weightbearing full-extension radiographs [1]; higher correlation with intra-articular cartilage status [1]; the highest correlation with subjective clinical outcomes after HTO [10]; the highest precision in measurement of joint space narrowing particularly on the lateral side [13]; and to possibly influence the management of knee OA in up to 50% of cases compared to the assessment of knee OA using only standard radiographs [14]. The most popular PA views with flexed knee are the Rosenberg view obtained at 45° of flexion (Rosenberg+knee+OA = 46 pubmed results) and with a beam inclination of 10° centered on the patella [15], and the Lyon Schuss view (Schuss+knee+OA = 32 pubmed results) obtained at 30° of flexion and with beam inclination to superimpose the anterior and posterior margin of the medial tibial plateau under fluoroscopic guidance [16]. However, no studies have been found comparing the Rosenberg and Schuss views (Rosenberg+Schuss = 0 pubmed results). Only one study compared the traditional Schuss view with a PA view at 30° without fluoroscopic guidance and standard beam inclination at 10° [17]. In patients with OA and KL grade II-III, the authors concluded that PA views at 30° with or without fluoroscopic guidance to superimpose medial tibial plateau "offer similar reproducibility in Joint Space Width measurement. However, presumably due to its superiority in aligning the medial tibal plateau, the Schuss view [with fluoroscopy] is much more sensitive to joint space narrowing in OA knees". However, considering the radiation exposure, the limited improvement in sensitivity and the time-consuming use of fluoroscopy, this modality should be reserved for the research setting rather than clinical practice.

Considering the advantages of PA views with flexed knee, Roux et al. reported that there are "no differences between Schuss x-ray alone and Schuss plus AP view in detecting femoro-tibial compartment OA features such as osteophytes and JSN in general practice" and that "the superiority of the combination of two images to detect a knee OA with KL ≥ II suggests that Schuss alone should be used in general practice for femoro-tibial OA detection, and the use of both views should be restricted to clinical studies". However, they did not assess patients undergoing revision ACL in which other parameters other than OA should be assessed [18].

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D16) Is there a role for bone scan, PET-CT

Consensus answer: Currently the role of bone scans and PET-CT are subject to scientific investigations and no clear recommendations about their use in ACLR can be given.

Agreement: 8.2/9

Grade of recommendation: C

Literature review:

Very few articles have been published in the past 15 years which correlate the use of bone scans and PET-CT with a revision anterior cruciate ligament (ACL) reconstruction.

All the publications focus on the use of single photon emission computerized tomography and conventional computerized tomography (SPECT/CT) for evaluation of patients after anterior cruciate ligament reconstruction.

The benefit of SPECT/CT in comparison with magnetic resonance imaging (MRI) is under debate. Mathis et al.[1] investigated whether bone tracer uptake (BTU) intensity and distribution in SPECT/CT correlated with MRI findings in symptomatic patients after ACL reconstruction. The study reported that MRI findings such as graft tear, graft signal hyper-intensity, bone marrow edema and knee joint effusion were significantly correlated with increased BTU in SPECT/CT, concluding that SPECT/CT can be used to assess increased loading in lax knee, graft incorporation and bone tunnel remodeling of the bone. However BTU in SPECT/CT is also rather unspecific and can be found in a number of conditions[1].

Hirschmann et al.[2] proposed a novel standardized algorithm using SPECT/CT, which combines the 3D-mechanical information on tunnel placement, bone-graft-fixation and 3D metabolic data, and is helpful in evaluating patients with pain after ACL reconstruction.

A further two papers[3,4] were published by the same authors, in which they reported that SPECT/CT tracer uptake intensity and distribution showed a significant correlation with femoral and tibial tunnel position and orientation in patients with relevant symptoms after ACL reconstruction, but no correlations were found with stability or clinical laxity. SPECT/CT tracer uptake may help to predict ACL graft failure.

Moreover, the BTU intensity and distribution in SPECT/CT may help to predict the development of OA at an early stage.

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D17) Does infection need to be ruled out on a routine basis and if so, how?

Consensus answer: Infection after ACL reconstruction is a rare complication; therefore routine screening is not recommended. While acute infections are mostly easy to diagnose (clinical, CRP, leucocytes, aspiration), low-grade infection is even rarer and more difficult to diagnose. Sensitivity and specificity can be increased by taking tissue biopsies (three but not more than six distinct intraoperative tissue samples). Additionally, newer studies show a higher incidence of occult low-grade infections during ACL revision surgery. Further studies are needed.

Agreement: 8.4/9

Grade of recommendation: B

Literature review:

Septic arthritis after ACL reconstruction is an uncommon complication, with a reported incidence between 0.14% and 1.7%, although most studies have documented rates of less than 1%[1-3]. The highest rate was published by Torres-Claramunt et al.[4] (1.8 % in a series of 810 consecutive ACL reconstruction).

Infection after ACL reconstruction is a rare complication. Alomar et al., in a controlled study, despite finding high rates of contamination on the intraoperative hamstring autograft during harvesting and preparation, or by accidentally dropping the graft in the operating room, found low bacterial counts, below the threshold for infection.[5]

Greenberg et al.[6] found no increased clinical risk of infection with the use of allograft tissue compared to autologous tissue for primary ACL reconstruction; however, the theoretical risk of disease transmission inherent to allograft tissue cannot be eliminated.

Staphylococcus aureus and coagulase-negative staphylococci (*CNS*) are the most common bacteria found in most series. Different methicillin-resistant *Staphylococcus aureus* or anaerobium microorganisms have also been cultured as the origin of such infections[7].

Postoperative infections are divided into three groups: acute infection (less than 2 weeks), subacute infection (between 2 weeks and 2 months) and late infection (after 2 months).

The new ACL, whether autograft or allograft, is nonviable tissue that can be colonized by bacteria (especially low virulence bacteria) for a long time until it is replaced by the host tissue; moreover, concomitant surgical procedures and previous knee surgery can be a risk factor for septic knee arthritis, due to increased operative time and additional or larger incisions[7].

Mouzopoulos et al.[8] recommend the following principles of diagnostic workup: baseline white blood cell count, C-reactive protein, erythrocyte sedimentation rate, culture, and microscopic examination of knee fluid.

Costa et al.[9], in a retrospective study, concluded that a synovial white blood cell (WBC) count is the most reliable test for the diagnosis of septic arthritis after ACL reconstruction. They reported that a cutoff value of 28,100 cells/mL presented the good accuracy, and with the threshold set at 40,000 cells/mL, postoperative infection could be diagnosed with 100% accuracy.

In spite of what was previously mentioned, Everhart et al.[10] and Flanigan et al.[11] reported that bacterial DNA was detectable in between 85% and 87% of their revision ACL reconstructions. This finding did not cause clinically apparent infection symptoms but higher bacterial DNA concentrations were associated with tibial tunnel widening.

Despite infection after ACL reconstruction being a rare complication, as reported before, some studies have demonstrated that septic arthritis following this procedure can be significantly reduced by pre-soaking ACL autografts in a vancomycin solution.[12,13]

In a recent International Consensus Meeting on Surgical Site and Periprosthetic Joint Infection (PJI) it was agreed on the question on "how many intra-operative tissue samples should be sent for culture in suspected PJI cases and cases of suspected aseptic failure?" that more than three but not more than six distinct intra-operative tissue samples should be sent for aerobic and anaerobic culture.[14]

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D18) What is the role of preoperative neuromuscular assessment?

Consensus answer:

Neuromuscular assessment is necessary in cases of discrepancy between subjective instability and objective clinical (laxity) findings. However, preoperative neuromuscular assessment is rarely performed and valid studies are lacking. No specific tests can be recommended at that time, but commonly performed tests currently are isokinetic quadriceps and hamstring strength tests and hop tests.

Arthrogenic muscle inhibition can be very frequent after knee trauma and may contribute to the development of postoperative stiffness.

Agreement: 8.2/9

Grade of recommendation: D

Literature review:

Neuromuscular control is important in predicting failure of ACL reconstruction and a second rupture[1,2].

Studies have shown that neuromuscular deficits after ACL reconstruction are common and persistent in the short and long term, sometimes persisting for longer than 24 months and therefore possibly play a role in ACL revision surgery[3-4]. Tayfur et al.[3], in a systematic review, reported that strength and voluntary activation deficits are accompanied by changes in cortical and spinal excitability for ACL injured patients in both the short and long term, as well as deficits in force control and rapid force production.

Paterno et al.[1] found that altered neuromuscular control of the hip and knee during a dynamic landing exercise, as well as postural instability after ACL reconstruction, are predictors of a second ACL injury. Premature return to high-demand activities or aggressive rehabilitation can alter these neuromuscular patterns; however, improved postural stability and control of the center of mass may help minimize subsequent ACL injury. Premature return to high level sports before complete restoration of neuromuscular control leaves the knee less able to resist stress and more prone to recurrent injury[5]. In a recent systematic review it was found, that returning to level I sports after ACL reconstruction leads to a more than 4-fold increase in reinjury rates over 2 years. RTS 9 months or later after surgery and more symmetrical quadriceps strength prior to return substantially reduce the reinjury rate.[15]

The MARS[6] group reported that rehabilitation-related factors may have the ability to modify clinical outcomes 2 years after an ACL revision. This multicenter study demonstrated that bracing during the early postoperative period is not helpful; in fact patients who had a revision ACL reconstruction and were prescribed a postoperative ACL derotation device (or "ACL functional brace") during rehabilitation were 2.3 times more likely to have subsequent knee surgery within 2 years.

However, patients with a postoperative ACL functional brace for use when returning to sports had a better knee injury and Osteoarthritis Outcome Score (KOOS) for sports/recreation 2 years postoperatively.

In addition, it has been proved that early weight-bearing is safe and in fact decreases the risk of patellofemoral pain[7].

If proper postoperative rehabilitation is not performed, extensor mechanism dysfunction can complicate ACL reconstruction; indeed, inadequate rehabilitation may lead to inhibition of the quadriceps, loss of patellar mobility, and loss of knee motion. If left untreated, patellar entrapment may progress to infrapatellar contracture syndrome[5].

Sonnery-Cottet et al. demonstrated in their scoping review that cryotherapy and physical exercise are recommended in the management of arthrogenic muscle inhibition. This therapy can improve quadriceps activation failure after ACL injury and reconstruction.[14]

Correct surgical technique and adequate postoperative rehabilitation reduce the incidence of extensor mechanism dysfunction[8].

The literature has shown that for revision ACL reconstruction the mean rate of return to sport at pre-injury level varies from 52%[9] to values lower than 40%[10,11]. In view of the above, considering that the return to sport outcomes differ between primary and revision ACL reconstruction, it is important for surgeons to provide patients with adequate and realistic expectations after revision procedures[12].

Dalla Villa et al.[13] reported that a higher compliance in rehabilitation significantly increased the chances of returning to sport at the same pre-injury level after ACL revision reconstruction. Patients have to be motivated to be compliant with the rehabilitation protocol, including an on-field-rehabilitation phase, to increase the possibility of returning to their pre-injury sport level.

A study from Grindem et al shows: More symmetrical quadriceps strength before Return-to-sports and a delayed return to level-1 sports (>9 months) decreases the reinjury rate after primary ACL reconstructions.

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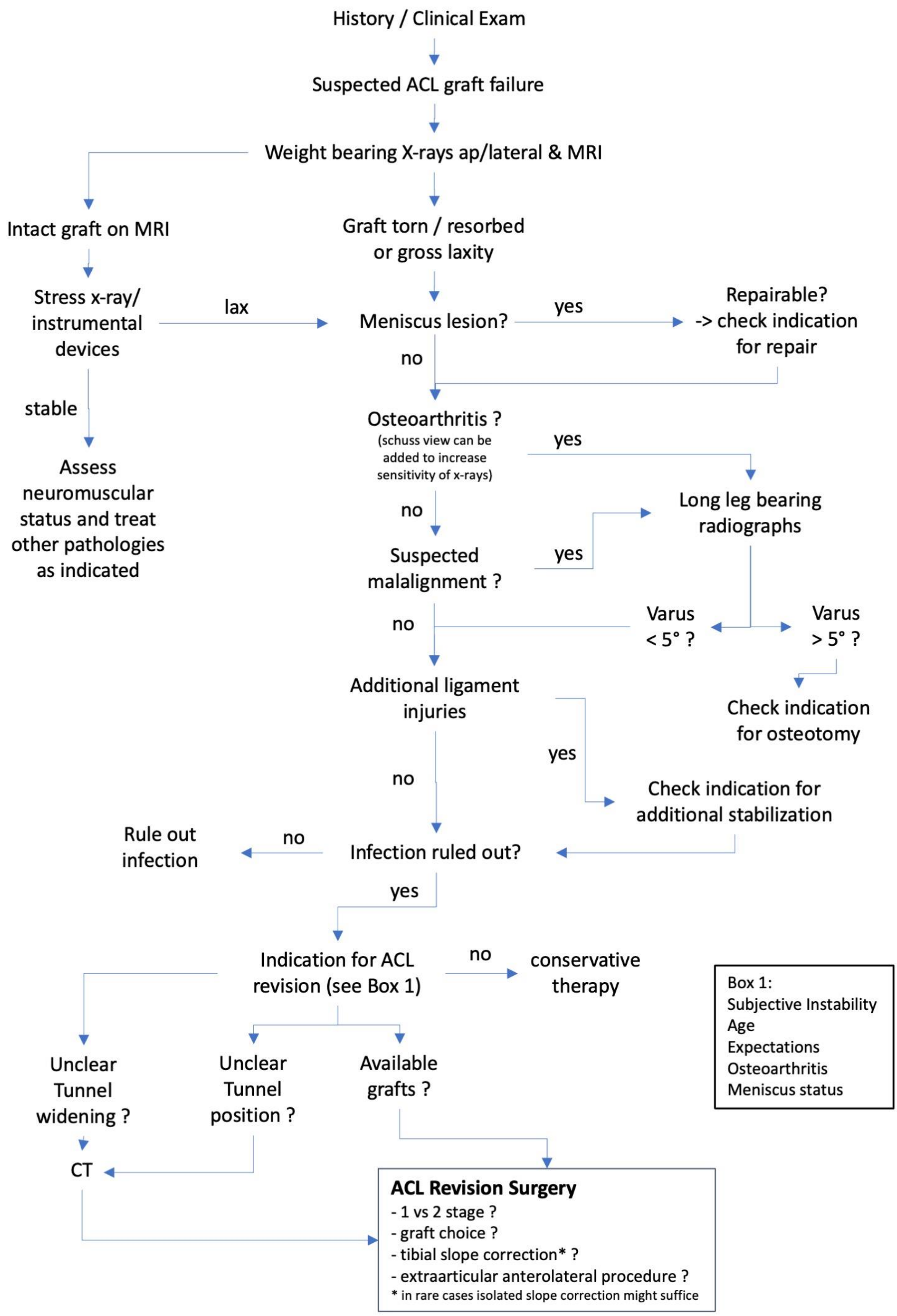
Flow chart Management of failed ACL reconstruction



III. Surgical Strategy (formal consensus)

Introduction:

Revision ACL reconstruction is technically more demanding than primary ACL reconstruction and multiple factors other than ACL insufficiency must be taken into consideration. Preoperative elaboration of a surgical strategy is mandatory in order to be optimally prepared for revision surgery. Essential aspects of the surgical strategy include deciding whether a single-stage procedure is possible or whether a two-stage procedure may be necessary; how to deal with previous tunnels and graft fixation material; the necessity for concomitant procedures to treat accompanying meniscal and chondral injuries, combined ligamentous insufficiency or bony malalignment; and determination of the ideal graft material and graft fixation method. In general, a single-stage procedure should be used whenever possible; however, in certain cases, a two-stage procedure may be necessary. In patients undergoing revision surgery, bony malalignment and concomitant insufficiency of other ligamentous structures, especially of the anterolateral structures and the medial ligamentous complex, is more common than in patients undergoing primary ACL reconstruction. Since these associated pathologies are thought to be important risk factors for ACL graft failure, revision ACL reconstruction must often be combined with osteotomies, anterolateral procedures, stabilization of the medial ligamentous complex and meniscal reconstruction surgery.

S1: Which factors are relevant to the surgical strategy when the decision is made to revise a previously reconstructed ACL?

Steering group answer:

The following factors are relevant to the surgical strategy:

- Range of motion
    - Severely Restricted ROM
    - Significant Hyperextension (>5°)
- Availability of graft material
    - Autograft or allograft? Ipsilateral or contralateral graft harvesting? Bone block or soft tissue graft?
- Previous tunnel size and location
    - Are the tunnel diameters of preexisting tunnels acceptable? Can the tunnels be reused or are new tunnels necessary? Can new tunnels be drilled without creating a bony defect (confluent tunnels)? Can stable fixation be achieved?
- Previous graft fixation
    - Is it necessary to remove previous fixation material? Will removal of fixation material create a relevant bony defect?
- Limb alignment (coronal/sagittal)
    - Is limb alignment a possible factor for ACL graft failure? Can limb alignment be corrected in a single stage procedure or is a two-stage procedure preferred?
- Meniscal status
    - Does a specific meniscal tear need to be addressed (root tear, ramp lesion)? Is significant meniscal loss a possible reason for ACL graft failure? Is meniscal reconstruction or transplantation necessary?
- Cartilage status / Preexisting OA
    - Is a cartilage repair procedure indicated? May an osteotomy to unload unicompartmental OA be an option?
- Concomitant ligament insufficiency

  - Are there relevant concomitant ligament insufficiencies contributing to ACL graft failure? Can all ligaments be treated in a single-stage procedure? May the patient benefit from additional anterolateral stabilization?
- Grade of laxity
  - Is concomitant anterolateral stabilization indicated? Is a posterolateral root tear or posteromedial ramp lesion present?
- Bone quality
  - Can adequate fixation stability be achieved with standard fixation methods? Are alternative techniques necessary (e.g. back-up fixation or oversized screws?)
- Patient activity and expectation
  - May the patient benefit from an additional anterolateral stabilization?
- Infection status
  - Is an active infection evident? Suspected low-grade infection?

Grade of recommendation: B

Literature review:

Revision ACL reconstruction is a complex procedure with several potential complications and pitfalls, and the expected outcome is generally inferior compared to primary ACL reconstruction [1, 2, 3]. Surgeons should therefore be familiar with different techniques and a sophisticated surgical strategy is mandatory to increase the likelihood of a successful outcome. Several factors are relevant for surgical strategy, which have been extensively described in several review articles about revision ACLR [4, 5, 6, 7, 8, 9]. A synthesis of these articles is as follows:

Range of motion: Revision ACL reconstruction should only be performed in knees with an acceptable range of motion. Small restrictions can be treated during revision reconstruction; however, in patients with arthrofibrosis, a staged procedure is necessary to restore range of motion first. Furthermore, generalized joint hypermobility has been associated with inferior outcomes after ACL reconstruction [10] and preoperative hyperextension >5° has been shown to be an independent, significant predictor of graft failure after primary [11] and revision

ACLR [12]. The consequences of hypermobility on surgical strategy remain largely unknown; however, slight modifications of the surgical technique, such as graft tensioning in hyperextension or additional extraarticular stabilization, should be considered.

Availability of graft material: Depending on the graft used for primary ACL reconstruction, the surgeon must decide which graft is the most appropriate for the individual patient. Both autografts and allografts can be used. Graft choice may also be influenced by tunnel size, since a graft with a bone block may allow compensation for larger bony defects.

Tunnel size and location: The surgeon must decide if the position of the previous tunnels is anatomic, partially anatomic, or completely non-anatomic. Furthermore, tunnel widening must be determined since severe tunnel widening may affect tunnel placement and graft fixation. Anatomic tunnels with no significant widening can generally be reused, whereas a new tunnel can usually be drilled in the event of a completely non-anatomic tunnel position. In cases with severe tunnel widening or partially malpositioned tunnels, which may interfere with placement of a new anatomic tunnel, single-stage or two-stage bone grafting should be considered.

Previous graft fixation: It must be determined whether hardware will interfere with new tunnel placement. If hardware has to be removed, the surgeon must make sure to have the necessary instruments available. Furthermore, hardware removal can create a bony defect, which may require bone grafting.

Limb alignment: Coronal (varus/valgus) and sagittal (posterior tibial slope) malalignment can contribute to ACL graft failure. It is therefore necessary to decide whether limb malalignment is considered significant and requires correction. Furthermore, in patients with degenerative changes, an unloading osteotomy may be beneficial to slow osteoarthritic progression.

Meniscal status: Both the medial and lateral meniscus function as secondary stabilizers. Previously untreated meniscal tears, especially root tears and ramp lesions, may have contributed to failure of the primary ACL reconstruction. It is therefore important to adequately treat such tears during revision surgery. Parkinson et al. demonstrated that meniscal deficiency is the most significant factor in predicting graft failure in single-bundle ACL reconstruction (13). Where there is significant meniscal loss, concomitant or staged meniscal transplantation should therefore be considered.

Cartilage status/preexisting OA: In patients with deep focal chondral defects, cartilage repair procedures should be considered. In patients with unicompartmental OA and coronal malalignment, an unloading osteotomy may be more important than revision ACLR, especially in patients with low functional demands.

Concomitant ligament insufficiency: Insufficiency of other ligaments such as MCL or anterolateral structures results in complex instability patterns, which cannot be treated with isolated ACL reconstruction. During revision surgery, all ligaments involved should be repaired or reconstructed.

Grade of laxity: In patients with a high-grade pivot shift, ACL insufficiency is usually combined with other structural damage such as a posterolateral root tear and/or insufficiency of the anterolateral structures. Isolated revision ACLR may not be able to restore normal knee kinematics and all involved structures should be addressed.

***Bone quality*:** Especially in older individuals, bone quality may be reduced, resulting in inferior graft fixation strength. Fixation techniques should therefore be individualized and alternative techniques such as oversized screws or backup-fixation should be considered.

***Patient activity**:* Failure rate is higher in active patients, especially in those involved in pivoting sports. Therefore, additional anterolateral stabilization should be considered.

Infection status: In patients with active or suspected infection, initial treatment requires washout, removal of hardware, and debridement with subsequent antibiotic treatment to achieve complete bacterial eradication.

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S2: Which factors influence the decision to perform a single- vs. two-stage procedure?

Steering group answer:

The following factors influence the decision of single- vs. two-stage procedures:

Absolute indications for two-stage	Relative indications for two-stage
• Clinically relevant reduced range of motion due to arthrofibrosis • Infection/suspicion of infection • Impossible to achieve secure graft fixation at the anatomic insertion sites due to insufficient bone stock	• Tunnel widening around > 12 mm [2, 3,8] (depending on graft choice, drilling technique, and fixation technique) • Partially malpositioned tunnel interfering with a new, anatomically placed tunnel • Complex combined surgery

Grade of recommendation: C

Literature review:

Revision ACL reconstruction can be performed as a single- or two-stage procedure.

Although a single-stage procedure is preferable from both the patient's and the economic perspective, there are specific scenarios requiring other surgical interventions before revision ACLR can be performed. Factors that have to be considered in the decision process include ROM, infection status, tunnel size and position, and concomitant pathologies such as limb alignment, cartilage and meniscal status, and concomitant ligament insufficiency [1, 2, 3, 4]. The decision of whether to perform a single- or two-stage procedure is always an individual decision and the indication is often relative. Overall, the available evidence is low, and recommendations are mainly based on expert opinions and common good clinical practice.

Absolute indications for a two-stage procedure are significantly restricted range of motion due to Arthrofibrosis and active infection or clinical suspicion of infection [1, 2]. In patients with Arthrofibrosis, a staged motion-restoring procedure such as arthroscopic arthrolysis [11] followed by an aggressive rehabilitation program should be performed first. In patients with failed ACL reconstruction and active infection, adequate treatment consists of irrigation, debridement, and synovectomy followed by a period of antibiotic treatment. Revision ACLR should only be performed if eradication has been achieved [7, 12]. In patients with clinical suspicion of infection, a two-stage procedure is also recommended to prove either eradication by multiple biopsies or to treat the patient with irrigation and debridement.

The decision process regarding tunnel management is less straightforward and is also influenced by details of the planned surgical technique, such as graft choice, drilling technique and fixation technique. In general, the inability to achieve secure graft fixation at the anatomic insertion sites due to insufficient bone stock represents an absolute indication for a staged procedure [1,2,6]. Insufficient bone stock can be the result of either excessive tunnel widening or convergence of preexisting partially anatomic tunnels with newly placed anatomic tunnels. In this case, bone grafting of preexisting tunnels followed by staged revision ACLR after bony incorporation of the graft is usually performed [6, 8]. However, no uniform threshold exists regarding the critical tunnel size and values between 10 and 15 mm have been recommended [8]. The value for a critically sized tunnel may also vary with regard to graft choice, drilling technique, and fixation technique. In the authors' opinion, tunnel widening with a diameter of >12 mm is considered a relative indication for a staged procedure. Furthermore, bone grafting must not necessarily be performed as a two-stage procedure but can also be performed concomitant with revision ACLR as a single-stage procedure [9,10].

Another relative indication is the necessity to address one or more concomitant pathologies such as meniscal deficiency, limb malalignment, or combined ligamentous insufficiency. Depending on the pathologies involved, a complex combined surgery may be necessary to achieve the best possible outcome. Such procedures can be performed as a one- or two-stage procedure without evidence in favor for one specific approach. The decision is mainly based on technical feasibility and the surgeon's preference/experience. Another relative indication for a staged procedure is significant varus or valgus malalignment associated with unicompartmental OA Grade III or IV according to KL. In such patients, isolated realignment osteotomy without revision ACLR may be appropriate, especially in older, less active patients with no or only mild instability symptoms. If instability symptoms remain after the osteotomy, revision ACLR can still be performed in a second operation.

If the indications for a staged procedure are relative, the advantages and disadvantages of each approach must be weighted up. The disadvantages of a two-stage procedure are the necessity for more operative procedures, longer rehabilitation, and a prolonged period of ACL deficiency with a potential risk for secondary cartilage and meniscal injuries. However, current evidence suggests that comparable results can be achieved in patients who require a staged approach [4, 6]. Of note, a systematic review from 2018 comparing outcomes and failure rates of single- vs. two-stage ACLR found comparable clinical outcomes and lower rate of revision surgery and clinical failure after a two-staged approach [5]. Although these results must be interpreted with caution, both options for revision ACLR are appropriate in carefully selected patients [4,5,6].

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S3: When is bone grafting of a widened or malpositioned tunnel indicated?

Steering group answer:

Bone grafting is generally recommended if secure graft fixation cannot be achieved in an anatomic position due to an increased tunnel diameter. No absolute threshold exists for the "critical tunnel diameter", with values ranging between 12 and 15 mm. In fact, the threshold may vary with regard to graft choice, drilling technique, fixation technique, and knee size.

Three scenarios exist in which bone grafting may be indicated:

1. A previously partially malpositioned tunnel, which will interfere with a new anatomic tunnel, resulting in a confluent tunnel exceeding the critical diameter
2. A previous anatomic tunnel position exceeding the critical diameter
3. Intra OP widening caused by difficult fixation hardware removal

However, by using specific techniques such as outside-in drilling with a different tunnel trajectory, over the top technique, using grafts with large bone blocks and large interference screws, bone grafting may not be necessary.

Bone grafting is usually performed as a two-stage procedure; however, with specific techniques (e.g. impaction bone grafting) bone grafting can also be performed as a one-stage procedure.

If preexisting tunnels do not interfere with new tunnel placement or graft fixation, they can usually be left alone, and bone grafting is not necessary/indicated.

Grade of recommendation: C

Literature review:

One of the main goals during revision ACL reconstruction is to achieve secure fixation of an anatomically placed graft in good quality bone. However, prior tunnel placement and/or tunnel widening may impair anatomic graft positioning, initial fixation strength, and biological graft incorporation.

A single-stage procedure without bone grafting can generally be performed in patients with appropriately placed tunnels without widening, which can be reused, or in patients with completely malpositioned tunnels that do not interfere with placement of new anatomic tunnels [1, 3, 4, 5].

On the other hand, bone grafting is generally indicated if the position or size of previous tunnels precludes anatomic graft placement and secure fixation in good quality bone [1]. Two scenarios are common in which bone grafting is indicated: (1) A previously partially malpositioned tunnel which will interfere with a new anatomic tunnel, resulting in a confluent tunnel exceeding the “critical diameter”; and (2) a previously anatomic tunnel position exceeding the “critical diameter” [2, 3]. With regard to the “critical diameter”, no uniformly accepted threshold exists. In a recent systematic review of studies reporting outcomes of bone tunnel grafting in two-stage revision ACLR [2], the upper limits of tunnel diameter varied between 10 and 15 mm. These values have also been proposed in other review articles [4, 5]. The critical value of diameter is also dependent on graft choice and graft fixation: an allograft with a large bone block can compensate for a larger bony defect, whereas soft tissue grafts cannot compensate for any bony defect. Furthermore, an interference screw may allow a larger tunnel [15], whereas suspensory fixation may require a smaller tunnel diameter. Therefore, the cut-off value for bone grafting must always be customized to the planned surgical technique [5]. White et al. demonstrated that single-stage revision ACLR could be performed reliably in the majority of patients by using a decision-making algorithm [15]. Furthermore, it has been shown that an inside-out drilling technique with a different tunnel trajectory can be safely performed even in patients with significant tunnel widening [16].

Bone grafting is most commonly performed as a two-stage procedure [3, 9, 10, 11]. During the first stage, all previous graft and fixation material is removed, the tunnel walls are debrided, and the tunnels grafted with autologous or allogenic bone (see also S4). Revision ACLR is than performed in the second stage after a minimum period of 3-6 months and confirmation of good graft incorporation. The advantage of this approach is that new anatomic tunnels can be created without compromises, similar to a primary ACLR. However, the disadvantages of a staged procedure include the necessity for more operative procedures, longer rehabilitation, and a prolonged period of ACL deficiency with a potential risk for secondary cartilage and meniscal injuries. Although two systematic reviews could not demonstrate negative effects of a staged procedure [1, 8], several alternative techniques have been described to avoid a two-stage procedure in the case of partially malpositioned or significantly widened tunnels, including one-stage bone grafting and revision ACLR [6, 7, 12, 14, 17] or using an anterolateral tibial tunnel [13]. Although some case series have been published with encouraging results [6, 7, 12,13], further studies are required before these techniques can be recommended for widespread use. At present, these techniques should be reserved for experienced surgeons who are familiar with these techniques.

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S4: What is the best material for tunnel grafting (autograft, allograft, synthetic bone substitutes)?

Steering group answer:

Both autologous and allogenic bone are suitable for tunnel grafting. Autologous bone is osteogenic, osteoinductive and osteoconductive, whereas allogenic bone is mainly osteoconductive. Therefore, autologous bone may represent the best graft material, but there is some donor side morbidity. Good filling rates have been reported with both graft materials (Salem et al.). Because of limited data and unfavorable results observed after open wedge high tibial osteotomy, synthetic bone substitutes should be used with care. Nevertheless, two studies have reported comparable results between autologous bone and silicate-substituted calcium phosphate (von Recum et al. 2017 / 2020). Whatever material is used, careful tunnel preparation with removal of all graft material and sutures and breaking up of sclerotic bone is important.

Grade of recommendation: B

Literature review:

Options for tunnel grafting include autograft, allograft, and commercially available bone substitutes. The most commonly used material for tunnel grafting is allogenic or autologous bone [1].

Successful incorporation of any graft material depends on mechanical and biological properties and occurs through different mechanisms including osteogenic, osteoconductive, and osteoinductive pathways [3, 4, 5]. Osteogenesis describes bone formation by cells derived from the graft; osteoinduction is the process by which mesenchymal stem cells are recruited and stimulated to differentiate into chondroblasts and osteoblasts; and osteoconduction describes the ability of the graft to provide a scaffold for the ingrowth of capillaries, perivascular tissue, and mesenchymal stem cells [3, 4[. The osteoconductive, osteoinductive, and osteogenic properties of different graft materials used for tunnel grafting are summarized in Table 1.

Table 1: Osteoconductive, osteoinductive, and osteogenic properties of different graft material (modification based on [3])

	Osteoconduction	**Osteoinduction**	**Osteogenicity**
Cancellous autograft	Yes	Yes	Yes
Cortical autograft	Yes	No	Yes
Structural allograft	Yes	No	No
Particulate allograft	Yes	No	No
Demineralized Bone Matrix	Yes	Yes	No
CaP and CaS bone substitutes	Yes	No	No

Because of their osteogenic, osteoinductive, and osteoconductive properties, autologous bone grafts seem to be the ideal material for bone grafting. For tunnel grafting, autograft bone is usually harvested at the iliac crest [9] or proximal tibia [7]. Cancellous bone contains a large number of cells and growth factors and the cancellous matrix provides an excellent scaffold for vascular ingrowth and infiltration of osteoblastic cells [3]. Drawbacks of autologous grafts include donor-site morbidity and limited quantity. Allogenic bone is a favorable alternative but has also specific drawbacks including the potential risk of disease or infection transmission and immunological reactions. For this reason, allogenic bone must be sterilized and processed for storage, which limits its osteoinductive properties. Great variability exists with regard to tissue processing and sterilization processes, which may influence the incorporation of allograft bone [6]. The most commonly used allogenic bone grafts are fresh frozen or freeze-dried. Freeze-drying eliminates the risk of disease transmission almost completely, but also eliminates the osteoinductive properties of the graft [5]. Fresh-frozen grafts have an intermediate immunogenicity and intermediate osteoinductive capacity, but also a higher risk of disease transmission than freeze-dried grafts [5]. Another allogenic option is demineralized bone matrix (DBM), which is produced through acid extraction to remove the mineralized component. DBM contains collagen, proteins, and growth factors and is therefore considered osteoconductive and osteoinductive [3, 5]. However, its osteoinductive properties can vary greatly due to donor characteristics [3].

Synthetic bone substitutes commonly consist of calcium phosphate or calcium sulfate compounds. These materials act as osteoconductive matrices, which imitate the cancellous bony structure and allow for the incorporation and proliferation of mesenchymal stem cells [3].

Only a few studies have specifically analyzed different graft materials for tunnel grafting.

Franceschi et al. [7] performed CT scans 3 months after bone grafting using autologous plugs from the proximal tibia in 30 patients and found complete integration of the bone plug into the tunnel in all patients. Theodorides and Wall [8] used preshaped allograft bone dowels in 19 patients and performed CT scans at an average of 3.6 months (range 3-11 months) after grafting. In 11 cases, the bone integration was rated to be very good (>75%) and in the remaining five cases excellent (100%). Van de Pol et al. [2] examined the histologic properties, graft quality, and graft incorporation of so-called supercritical carbon dioxide sterilized bone allograft for tunnel grafting in 12 patients. After a mean time interval of 8.8 months (range, 6-21 months), the authors found good graft incorporation and remodeling.

Prall et al. [10] compared allogenic (peracetic acid sterilized freeze-dried cancellous bone chips) and autologous (cylindric bone blocks and cancellous bone from the iliac crest) bone grafting in 103 patients. Postoperative CT scans were obtained after an interval of 5.2 months and the filling rates of both graft materials were comparable. In a recent systematic review [1], the outcomes of different bone graft materials for staged revision ACL reconstruction were compared. The analysis included 7 studies with a total of 234 patients. Autograft was used in 4 studies (iliac crest bone graft in 3 studies and tibial bone autograft in 1 study), allograft in 2 studies, and synthetic bone substitutes in 1 study. Based on the available data, autologous bone grafts from the iliac crest were associated with a lower risk of revision ACLR graft failure compared with allograft bone. However, it must be noted that graft failure cannot be attributed solely to the grafting material used, given the multifactorial nature of ACL graft failure. Von Recum et al. [11] compared bone incorporation of silicate-substituted calcium phosphate and iliac crest bone grafts in a prospective randomized controlled trial. No significant differences between the two graft materials were observed with regard to histologic, radiographic, and intraoperative integration. On histologic examination 6 months after grafting, Si-CaP was transformed into immature and lamellar bone formation. In a further study [12] , the same authors compared the clinical results of both groups after revision ACL reconstruction at a minimum follow-up of 2 years and found no difference with regard to laxity, functional scores, or ACL failure rate. Therefore, Si-CaP seems to be a valid option for bone grafting. However, it must be noted that synthetic bone substitutes have been shown to be inferior compared to autologous or allogenic bone after other operative procedures, such as open wedge high tibial osteotomy [13]. Further studies are therefore needed to better define the role of synthetic bone substitutes.

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S5: When is it safe to perform ACLR after staged bone grafting (time)?

Steering group answer:

An interval of 3 to 6 months of follow-up before second stage revision ACLR is recommended after staged bone grafting, and CT imaging could be considered to determine adequate graft incorporation. Incorporation of allogenic bone may require a longer time period as compared to autologous bone.

Grade of recommendation: C

Literature review:

The exact time period required between staged bone grafting and revision ACL reconstruction remains unknown; however, a minimum 3-month period of follow-up is generally recommended [1, 4]. Franceschi et al. [2] performed CT scans 3 months after bone grafting using autologous plugs from the proximal tibia in 30 patients and found complete integration of the bone plug into the tunnel in all patients. However, no details were provided on how this determination was made.

In a recent systematic review [1] of 7 studies reporting outcomes of bone tunnel grafting in two-stage revision ACLR, no consensus was available regarding the length of time that should elapse between the first and second stage or regarding the imaging modality that should be used to determine adequate graft incorporation. The minimum interval before assessing radiographic bone healing was 3 months in 2 studies, 4 months in 3 studies, and 6 months in 2 studies. Therefore, an interval of 3 to 6 months seems to be adequate. Evaluation of graft incorporation was conducted by CT imaging in 5 studies and blurring of the tunnel margins, reactive sclerosis, and presence of bone within the tunnel were used as signs of adequate healing. Standard radiographs were used in 2 studies and the presence of bone resorption, cyst formation, sclerosis, and the appearance of trabecular bone in the grafted area were used to assess adequate graft incorporation.

The most comprehensive analysis of time-dependent incorporation of bone grafts was conducted by Uchida et al. [3]. The authors quantitatively evaluated healing of autologous iliac crest bone block grafting in 10 consecutive patients by CT at 3, 12 and 24 weeks after grafting. Evaluation was performed on 15 axial planes at 1-mm intervals using the following three parameters: occupying ratio, union rate, and bone mineral density of the grafted bone. The average occupying ratio was 81, 85, and 94% at three, 12, and 24 weeks, respectively. The average union rate was 49, 75, and 89% at three, 12, and 24 weeks, respectively. Both parameters significantly increased over time. The same was true for bone mineral density. The authors concluded that both bone density and bone healing were more improved after 24 weeks compared to 12 weeks, indicating that an interval of 24 weeks is favorable for safe implantation and fixation of ACL grafts. It must be noted, however, that only autologous grafts were analyzed and that these data may not be transferable to allogenic grafts. It is thought that incorporation of allogenic bone requires longer compared to autologous bone [5, 6, 7].

In the aforementioned systematic review by Salem et al. [1], the time interval between the first and second staged procedures was 5.8 months, 6.3 months, and 24-30 weeks after autologous grafts, whereas the time interval was 8.7 months and 8.8 months after Si-CaP and allogenic bone, respectively. The authors hypothesized that, although many factors could account for delay between stages, patients treated with autologous grafts may have a decreased interstage time interval.

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S6: When is an additional osteotomy indicated to correct coronal malalignment (Varus/Valgus) in ACL revision surgery?

Steering group answer:

An osteotomy to correct coronal malalignment is indicated in patients with varus or valgus deviation >=5° accompanied by early OA, significant cartilage damage and/or symptomatic meniscal deficiency, and in patients with varus or valgus deviation associated with ligamentous insufficiency (e.g. a thrust phenomenon (dynamic joint space opening)). The threshold of 5° is based on common indications for varus or valgus correction reported in the literature; however, a shift towards even smaller thresholds has occurred in recent years. Therefore, an osteotomy to correct varus or valgus deviation <5° may be indicated in selected cases, such as patients undergoing concomitant meniscal transplantation, cartilage repair procedures, or collateral ligament reconstruction. An isolated varus malalignment without the above-mentioned associated conditions is not an indication per se for an osteotomy.

Grade of recommendation: C

Literature review:

Chronic ligamentous laxity is often associated with malalignment, which can be the cause or consequence of recurrent or chronic instability [1, 3, 4, 5]. Won et al. [6] compared 58 patients undergoing revision ACLR and 116 patients undergoing primary ACLR and found a significantly higher proportion of knees with varus malalignment greater than 5° in patients undergoing ACL revision surgery (19% vs. 8%). Although no comparative data are available for valgus alignment, coronal malalignment in general must be considered a frequent observation in patients undergoing revision ACLR.

Based on the work of Frank Noyes [9], varus malalignment in an ACL deficient knee can be classified in 3 types:

Primary varus: Varus alignment due to the osseous geometry with or without medial joint space narrowing.

Double varus: Varus alignment due to the osseous geometry and separation of the lateral compartment (“varus thrust”) under load.

Triple varus: Varus alignment due to the osseous geometry, separation of the lateral compartment, and increased external tibial rotation and hyperextension with an abnormal varus recurvatum position (“hyperextension-varus thrust”).

Whether a primary varus has a negative impact on a reconstructed ACL remains unclear. Kim et al. [8] compared the results of 201 patients with primary varus knees who underwent primary ACLR. Patients were grouped based on the severity of their varus deformity. After a mean follow-up of 45 months, no difference with regard to stability and functional scores was observed between the groups. The authors therefore concluded that if no medial compartment OA or varus thrust is present, correctional osteotomy is not necessary in primary varus knees undergoing ACLR.

However, in biomechanical studies, both varus and valgus malalignment increased ACL graft forces, especially in the case of an accompanying varus or valgus thrust, respectively [2, 7]. Therefore, significant varus or valgus alignment may be considered a risk factor for ACL graft failure due to repetitive overloading. Furthermore, the prevalence of cartilage lesions, meniscal deficiency, and osteoarthritic changes is higher in patients undergoing revision ACLR compared to patients undergoing primary ACLR, especially in patients with varus malalignment [10]. The rationale for correcting coronal malalignment in patients undergoing revision ACLR is therefore twofold: first, to protect the graft from increased loading and second to unload a degenerative compartment. Indications for osteotomies to correct coronal malalignment are based on low-level evidence and depend on multiple factors such as cartilage and meniscal status. In general, axis deviation of 5° or more accompanied by meniscal or cartilage damage is considered an indication for osteotomy to lower the risk of OA progression [1, 3, 4, 5]. However, a shift towards even smaller thresholds has occurred in recent years [11]. Therefore, an osteotomy to correct varus or valgus deviation <5° may be indicated in selected cases, such as patients undergoing concomitant meniscal transplantation, cartilage repair procedures, or collateral ligament reconstruction [1, 11].

Whether correction of coronal malalignment decreases failure after ACL revision reconstruction in patients without degenerative changes remains unknown. However, given the fact that varus or valgus alignment associated with a thrust phenomenon increases ACL graft forces, realignment osteotomies are theoretical beneficial in protecting the graft from repetitive overloading [1, 2, 7].

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S7: When is an additional osteotomy indicated to correct sagittal malalignment (Slope) in ACL revision surgery?

Steering group answer:

A slope-reducing osteotomy (extension osteotomy) should be considered in patients with failed primary ACL reconstruction and PTS >=12° as measured on lateral radiographs. The indication may be even stronger in patients with increased static anterior tibial translation (>5mm on monopodal stance), multiple failed ACL reconstructions, and/or deficiency of the posterior medial meniscal horn. Careful consideration should be given if there is preexisting hyperextension of the knee as this may be a contraindication.

Grade of recommendation: B

Literature review:

The tibial slope has a direct influence on sagittal plane biomechanics and therefore contributes to the loading pattern of the cruciate ligaments. From a biomechanical point of view, the tibial slope produces an anteriorly directed shear force component when compressive tibiofemoral load or quadriceps muscle force is applied to the knee joint, resulting in anterior translation of the tibia [1, 2]. In a radiographic in vivo study by Dejour and Bonnin [6], a steeper slope resulted in a significantly greater amount of anterior tibial translation in both ACL-deficient and ACL-intact knees. Since the ACL is the primary restraint against anterior tibial translation, the tibial slope has an important effect on the in-situ forces of the ACL or an ACL graft, respectively [8, 9].

A steep posterior tibial slope (PTS) has been shown to be a risk factor not only for primary ACL rupture [17], but also for increased antero-posterior laxity and failure after primary ACL reconstruction [4, 10, 11, 12, 16]. Furthermore, Napier et al. [3] showed that an increased PTS was associated with graft rupture and contralateral ACL injury after revision ACL reconstruction. Biomechanical studies have shown that tibial slope has a strong linear relationship to the amount of graft force experienced by an ACL graft in axially loaded knees and that slope-reducing osteotomies can decrease ACL graft forces [8, 9]. Therefore, slope-reducing osteotomies should be considered in patients with failed ACL reconstruction and an increased PTS [2, 13, 14, 15]. The indication may even be stronger in patients with deficiency of the posterior medial horn, since this condition potentiates the effect of increased tibial slope on ACL graft forces and anterior tibial translation [4, 5, 7]. However, no uniform cutoff value for PTS exists and different measurement methods are used. Most authors recommend considering a slope-reducing osteotomy if PTS exceeds 12° on lateral knee radiographs [14, 15].

An increased tibial slope is usually corrected via an anterior closing-wedge osteotomy at the proximal tibia. Different techniques have been described without evidence that one specific technique is superior [13, 14, 15]. An anterior closing wedge osteotomy can be performed with or without detachment of the tibial tubercle, depending on the surgeon's preference.

It remains controversial to what extent PTS should be corrected and target PTS have been proposed between 8-10° [14] and 3-5° [15]. Range of motion must be taken into consideration and postoperative hyperextension >5° should be avoided [2].

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S8: When is an additional extraarticular anterolateral procedure indicated in ACLR surgery?

Systematic use of additional extraarticular anterolateral procedure should be considered in revision ACL-reconstruction, especially when patients present with gross laxity (pivot shift +++, grade II and III (IKDC) of AP instability and/or in pivoting sports or in hyperlaxity). Also check for laxity on the medial side, because it can also increase anterolateral instability. However, there is still a lack of high levels of evidence in existing studies.

Grade of recommendation: B

Literature review:

The general term additional extraarticular anterolateral procedure has been adopted in this consensus. It merges from different terms which can be found in the literature (Lateral tenodesis, Antero Lateral Complex Reconstruction or ALL reconstruction ...).

Despite the minority of published studies due to the recent emergence of the issue, the available reports have clearly demonstrated a low rate of failure of the revision graft when combined with an extraarticular anterolateral procedure. In a recent systematic review published by Alberto Grassi in KSSTA, twenty-four failures were reported in a total of 658 patients, giving an overall failure rate of 3.6%, over a mid-term follow-up period of 5 years (1). Given that this figure is lower than the failure rate of isolated ACL revision, extraarticular anterolateral procedure stabilization is surely worth considering in a revision setting. In a study published by Porter et al., a pivot shift grade II or more was selected as a criterion for extraarticular anterolateral stabilization (2). The results demonstrated a significant improvement in laxity with an additional extra-articular iliotibial band tenodesis (2).

In a further study, Colombet et al. demonstrated that the addition of an extra-articular procedure provided improved internal tibial rotation control (3). A multicenter study published by the French Arthroscopy Society (SFA) showed a marked improvement in rotational stability and a reduction in re-rupture risk (4). The highly cited study published by Sonnery-Cottet (>300 citations) has captured the attention of the orthopedic community by highlighting the power of additive ALL stabilization in eliminating pivot shift in primary ACL reconstruction (5,9). A study by Trojani demonstrated a marked reduction in the rate of pivot shift when lateral tenodesis was performed: 80% had a negative pivot shift with the tenodesis, versus 63% without (6).

General overall hyperlaxity in an ACL deficient patient has been also defined as an indication for ALL stabilization (7).

The International Anterolateral Complex Consensus group published an expert opinion regarding the indication for ALL stabilization. The group underlined the following indications: ACL revision, hyperlaxity, high grade pivot shift and young patients returning to pivoting activities (8).

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S9: When should additional medial laxity be treated or addressed?

Steering group answer:

Pre-operative medial laxity is a risk factor for poorer ACL revision outcomes. Consideration should be given to concomitant MCL reconstruction for grade 2 and 3 (IKDC C and D) MCL laxity. However, high-quality comparative studies are lacking.

Grade of recommendation: B

Literature review:

- *Basic research:*

Biomechanical studies have shown that partial and complete medial collateral ligament tears increase the load on the ACL (1). MCL deficiency may also lead to increased ACL reconstruction graft strain (3). It has also been demonstrated that single-bundle ACL reconstruction alone cannot restore anterior tibial translation, valgus rotation and external rotation in knees with combined ACL and MCL injury (2). In vivo, animal studies have shown that re-establishing the stabilizing function of the MCL improves biological healing and integration of ACL reconstructions (4).

- *Clinical evidence:*

There is evidence to support the link between MCL insufficiency (grade II and III) and higher failure rates of ACL revision, as has been shown in the study by Alm and Ahn (8, 13). Ahn and Lee detected MCL grade II lesion as a risk factor for ACLR failure (OR 13) and Alms showed that with medial knee instability (grade II and III) in ACL revision, patients had a 17 times greater risk of failure. National registry data have also highlighted a possible link between the presence of a concomitant MCL injury and failure of ACL reconstruction, as shown in a recent systematic review (5). A further recent study by Svantesson et. al (6), based on Swedish registry data, found an increased risk of ACL revision with the non-surgical treatment of concomitant MCL injuries.

Thus MCL should be evaluated pre-operatively and laxity should be considered as a risk factor for subsequent revision ACL graft failure. Both valgus and tibiofemoral rotation should be assessed and taken into consideration when planning treatment. It is noteworthy that significant injuries to the dMCL and sMCL, in the context of ACL rupture, which might lead to AMRI (antero medial rotatory instability), may be missed as there may not be valgus laxity in extension if the POL remains intact. Stress radiographs are important in the determination of a concomitant medial laxity. Laprade et al. demonstrated, in vitro, that > 3.2 mm of valgus opening was associated with smCL rupture and that > 9.8 mm of opening was associated with injury to the whole MCL complex (sMLC and POL) (7). Although clinical thresholds are lacking, surgeons should critically assess gapping and medial rotational laxity. Grade II laxity (5-10mm increased gapping compared to the healthy side) is likely to be a reasonable threshold for intervention (8). Studies suggest that combined ACL / MCL reconstruction affords good results (11, 12). However, Lind et al. (13) found that results were inferior to isolated ACL reconstruction. This may be due to failure of current MCL reconstructions to fully address anteromedial rotational laxity. Unfortunately, clinical studies reporting the results of simultaneous MCL and revision ACL reconstruction are lacking, although some case series report promising results and the results for primary ACL reconstruction with combined MCL reconstruction seem superior. Funchal et al. conducted a prospective randomized trial for primary ACL# + Grade II medial laxity in which they compared ACLR with MCL reconstruction with ACLR alone (N=58 vs 54, FU 24M) (14). ACLR with MCL reconstruction showed significantly fewer failures (2 vs 16) and remaining medial instability, and better functional scores (Tegner, Lysholm). Alm et al. also showed in a small case series that MCL reconstruction led to lower failure rates in patients with combined revision ACLR and chronic medial instability as compared with MCL repair (15).

MCL repair in the acute scenario may be reasonable, while reconstruction should be considered for chronic laxity.

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S10: When should additional lateral laxity be treated or addressed?

Steering group answer:

A true lateral laxity, including a subtle isolated FCL, posterolateral corner or complete lateral injury, should also be detected and is evidently associated with failure of revision. Clinical thresholds regarding gapping are lacking. However a lateral or posterolateral injury has to be clearly delineated from anterolateral instability (which does not cause gapping) and should be treated accordingly to prevent failure of the ACL revision graft.

Grade of recommendation: C

Literature review:

Much of the focus in the literature has been on concomitant anterolateral injuries. However, the influence of injury to more posterolateral structures, including the FCL, is not to be neglected. The biomechanical effect of the FCL on the anterior cruciate ligament has been well described (1). Therefore, the early conclusions of a rather highly cited study are based on biomechanical findings, demonstrating a significant increase in forces acting on the ACL graft after transection of the FCL and posterolateral structures (1). Further biomechanical studies using stress radiography proposed thresholds that assist clinicians during the diagnostic workup (2).

It was further shown that clinician-applied valgus loads at 20° of flexion resulted in 2.7mm of increased lateral gapping, in association with an isolated FCL injury, and 4.0mm or more in association with an additional lesion of the posterolateral corner (2). These thresholds are based on biomechanical tests and a general recommendation of these values in the clinical setting would be difficult, given the wide range of confounding factors. The minority of clinical studies reporting the results of lateral reconstruction set the indication based on at least 2 grades of lateral instability to IKDC objective scoring criteria (3).

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S11: When could an additional meniscal substitute or meniscal allograft be indicated?

Steering group answer:

Meniscus substitutes and meniscus allografts are able to improve clinical outcomes in selected indications. A chondroprotective effect is expected but not yet proven at long-term follow-up. Substitute: With failed previous PARTIAL meniscectomy and meniscus-related complaints, an additional meniscal substitute may be considered in rare cases, in conjunction with ACL

revision for such patients (**Grade** C). However, the implantation of a substitute at the same time as a partial meniscectomy (“prophylactic” substitute) is not recommended (Grade A).
Meniscus Allograft: an additional meniscus allograft may be considered in conjunction with ACL revision in patients with failed previous TOTAL or SUBTOTAL meniscectomy and meniscus-related complaints without significant cartilage wear (Grade B). Meniscal allograft as a concomitant procedure in ACL revision reconstruction may be performed to aid in joint stability when meniscus deficiency is believed to be a contributing factor to failure (G**rade** D).

Literature review:

Although the literature around this topic is somewhat limited, the evidence that we do have points homogeneously in one direction, emphasizing the important association between the meniscus as a secondary stabilizer of the knee joint and the ACL.

The biomechanical importance of the meniscus and its secondary stabilizing role in the knee have been underlined in basic research studies (1,2). Biomechanical studies demonstrated the effect of a meniscectomy on the knee by showing a significant increase in anterior tibial translation at all degrees of flexion. The results of anterior tibial translation were normalized after allograft transplantation (2).

There is also evidence to show that meniscus transplantation in an ACL reconstructed knee adds to stability by further reducing anterior-posterior translation, and improving rotational stability (3). This theoretically provides an ACL protective effect.
On the other hand, patients with meniscal disease who are primarily being considered for a meniscal transplant would also obviously benefit from protective ACL reconstruction (4).

It is fair to say that there still is a lack of evidence regarding combined allograft meniscal transplantation and ACL reconstruction. However, published reports are very promising. Saltzman showed that concomitant ACL reconstruction and meniscal allograft transplantation could provide significant improvements in clinical outcomes and enhancement in objective knee stability (4). Furthermore, the study showed an insignificant degree of radiographic joint-space narrowing changes, with a 5-year survivorship of more than 80% (4).

Stefano Zaffagnini's group showed that in the following situations, a significant benefit is to be expected after a combined meniscal allograft transplant procedure at medium-term follow-up (5): 1) ACL injury in a patient with post-meniscectomy syndrome, 2) failed ACL reconstruction in patients with a meniscus defect, and 3) ACL reconstruction in patients with malalignment due to a meniscal defect.

The International Meniscus Reconstruction Experts Forum (IMREF) recommended meniscal transplantation as a concomitant procedure with ACL revision, especially when deficiency of the meniscus is believed to be a contributing factor to failure (6). However, the issue of donor tissue availability would need particular consideration and may represent a limiting factor in the therapeutic decision tree.

The question of whether a meniscal collagen scaffold is a sufficient substitute has been raised. Despite evidence of some form of regeneration and organization of the scaffold material that is reflected in improvement of clinical scores (14,15), two important questions are yet to be answered, including the long-term chondroprotective effect of the scaffold and its superiority to partial or total meniscectomy (16). The reality is that evidence to sufficiently answer the last two questions is lacking. A general recommendation regarding scaffolds is therefore difficult due to the current scarcity of evidence. At the current juncture, all that may be said is that implantation of a collagen or polyurethane scaffold may improve clinical scores.

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S12: Which factors influence the decision in graft choice for ACLR?

Steering group answer:

Before choosing the proper graft in ACLR, the following questions should be answered:

1. Which previous graft has been harvested?
2. Is there a need to fill bone tunnel(s)?
3. Is there a need for a multiligament reconstruction?
4. What are the advantages and disadvantages of the different autografts (hamstring vs. quad vs. BPTB, …)?
5. What are the respective advantages and disadvantages of autografts vs. allografts (see question 13). What is the allograft availability?
6. Is it pertinent to reharvest the same graft on the ipsilateral knee or harvest from the contralateral knee (see question 15)?
7. Are there abnormalities (e.g. degenerative changes or patella height) of the patellofemoral joint?

Depending on these factors, the choice is often a compromise; in other words a necessity rather than a real choice.

Grade of recommendation: C

Literature review:

The literature provides a variety of proposed graft options that may used in ACL reconstruction and ACL revision. Comparisons have also been performed as shown below.

A recent study compared both hamstring and quadriceps autograft tendons in a revision situation and found no difference regarding outcome (1). Wolf Petersen's group showed no difference between ACL reconstruction using a quadriceps tendon graft or a contralateral semitendinosus-gracilis graft in terms of knee stability and function (2).

The use of hamstring grafts for revision has been well established in ACL revision surgery. The problem of graft availability led surgeons to harvest contralateral tendons. Both ipsi- and contralateral hamstring tendons were shown to provide similar results regarding overall outcome (3).

Further studies looked into the use of bone-patella tendon-bone autografts for ACL revision, the outcome of which was comparable to primary ACL reconstruction using a BTB graft (4).

The MARS group published its findings showing no superiority of one autograft over the other (5). In particular, no differences were noted in re-rupture or patient-reported outcomes between soft tissue and bone–patellar tendon–bone grafts (5).

The MARS group also highlighted factors influencing graft choice in ACL revision surgery (6). They showed that the use of an autograft in the primary reconstruction procedure increases the likelihood of using an allograft during a revision procedure. This indicates that graft availability is undoubtedly a main determinant of graft choice (6).

Interestingly, there are more studies comparing allografts to autografts than comparing different types of allografts in revision ACL surgery. This may be attributed to the increased tendency to use allografts in revision surgery. We therefore refer to the next question for more information in that regard.

The advantages and disadvantages of the various grafts that have been frequently linked to donor site morbidity and rotational stability (7) are less likely to influence graft decision in a revision setting, due to the fact that the individual situation is likely to define the choice of the revision graft.

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S13: Are allografts comparable to autografts regarding outcome?

Steering group answer:

Allografts are more frequently used in ACL revisions than in primary ACL reconstruction. Allografts offer the advantages of decreased operative times and low average pain during the entire rehab period. The disadvantages of allografts include a risk of disease transmission, immune rejection, delay in the remodeling, a prolonged integration process and possibly higher revision rates, depending on graft processing. Historically, results have been recognized to be inferior when using irradiated grafts. Non-irradiated grafts (cryo-preserved or fresh frozen) are a plausible alternatives to autografts, but it is unclear whether failure rates are comparable, and caution still remains for use of allografts in younger patients. Such patients tend to be more active and there is increasing understanding of the higher risks in this age group. The evidence is weak, but allografts in the young are likely to carry increased risk of failure (9). This is an area for further comparative work. The choice for using allografts is based on preference, while taking into account the longer maturation of allografts. Graft availability and donor-site morbidity become the dominant factors in decision making in these clinical situations. Cost issues have also been underlined.

Grade of recommendation: A

Literature review:

There have been several studies comparing allografts to autografts in revision ACL surgery. Keizer et al. demonstrated higher rates of return to sports when using patella tendon autografts compared to allografts (1). The MARS group demonstrated improved sports function and patient-reported outcome measures when an autograft was used. Additionally, the use of an autograft showed a decreased risk in graft re-rupture at the 2-year follow-up (2). In a meta-analysis published in 2017, 32 studies dealing with the question of superiority of autografts over allografts were included. The authors concluded that following revision ACL reconstruction, autografts performed better than allografts, with lower post-operative laxity and rates of complications and re-operations. However, if only non-irradiated allografts were considered, the outcomes were similar to autografts (3).

A meta-analysis published in 2018 in the Journal of Arthroscopy included 3000 patients and showed no difference between autografts and allografts with regard to failure rate (4).

It is still important to mention that there has been some evidence demonstrating poorer results of allografts in revision ACL surgery (5). Martin Lind showed 2.2 times increased re-revision rates after allograft ACL revision, compared to autografts, based on Danish registry data (5). However, it is important to consider the fact that no differentiation between irradiated and non-irradiated grafts was made or at least no clarification in that regard was present in the study. Therefore, the results of the study are to be considered with caution (5).

It is important to underline that irradiation of allografts has deleterious effects on quality and subsequent surgical outcome (6). Guo et al. demonstrated statistically poorer KT-1000 results and higher failure rates in γ-irradiated allografts compared with autografts and fresh-frozen allografts (6). On a basic research level, the maximum stress, maximum strain, and strain energy density were significantly reduced by irradiation of allografts (7).

A randomized controlled study by Sun et al. showed that patients undergoing ACL reconstruction with BPTB non-irradiated allografts were likely to demonstrate comparable clinical outcomes to patients undergoing autograft ACL reconstruction (8).

Looking at infection risk, analyses performed on large cohorts of patients or registries documented that the choice of allograft does not imply a higher risk of infection compared to autografts: a Canadian cohort study on 827 revision ACLRs (225 allografts) found a post-operative infection rate of 0.8% (7 patients) requiring surgery and an additional 1.2% treated by antibiotics only. The authors also demonstrated that graft selection (autograft versus allografts of any type) did not influence the risk for infection (9).

The ESSKA initiative underlined the likelihood that younger patients with high demand may put the allograft at risk in ACL reconstruction (9). However, the evidence is weak. Cost issues in association with allografts and the impact on graft choice have also been emphasized in a recent systematic review (11).

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S14: Is there a role for synthetic grafts or synthetic augmentation?

Steering group answer:

The use of synthetic grafts is not recommended **(grade B)**. For synthetic augmentation there is currently not sufficient data for an evidence-based recommendation **(grade D)**.

Literature review:

Although the use of synthetic grafts has been described for primary ACL reconstruction, there is absolutely no evidence, nor is there any clinical study reporting the use of synthetic material in revision ACL surgery. In primary ACL replacement using synthetic grafts (carbon fibers, polypropylene, Dacron and polyester), high failure rates due to graft failure have been reported due to mechanical fatigue. Reported complications include immunological responses, breakage, debris dispersion leading to synovitis, chronic effusions, recurrent instability and knee OA. Therefore synthetic graft options occupy a controversial position in primary ACL reconstruction (1,2).

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S15: What is the place of graft harvesting from the contralateral knee and graft re-harvesting from the ipsilateral knee?

Steering group answer:

Contralateral graft harvesting is considered a valid alternative to ipsilateral autografts or to allografts.

Although ACL reconstruction using re-harvested BPTB tendon may be possible, tendon quality (histologically) is lower than primary tendon harvest and there is no available literature concerning the quadriceps tendon.

Grade of recommendation: C

Literature review:

Several studies have dealt with the issue of graft harvesting from the contralateral knee. Ferretti et al. concluded that the use of hamstring tendons harvested from the unaffected knee represents a valid option for revision ACL surgery, with satisfying results (1).

Shelbourne et al. concluded that primary ACL reconstruction using a contralateral patellar tendon autograft is an effective means of achieving symmetrical range of motion and strength after surgery (2). He also stated that hypothetically, when the graft is harvested from the ipsilateral knee, the rehabilitations for the ACL graft and for the graft-donor site are different and have opposing goals. Rehabilitation for the ACL graft involves obtaining full range of motion, reducing swelling, and providing the appropriate stress to achieve graft maturation. Rehabilitation for the graft-donor site involves performing high-repetition strengthening exercises to regain size and strength, best achieved when begun immediately after surgery (2).

In a further study by Kartus, comparing ipsilateral re-harvesting of the patella tendon with contralateral patella tendon harvesting, it was shown that re-harvesting the ipsilateral patellar tendon resulted in lower functional scores and a higher rate of complications than revision with the contralateral patellar tendon or primary anterior cruciate ligament reconstruction (3).

A further study demonstrated that patients undergoing revision surgery with a contralateral hamstring autograft experienced a quicker return to sports compared to patients who underwent ipsilateral hamstring grafts in revision surgery (4).

Regarding graft re-harvesting, there have been some reports indicating recovery of the harvested tendon (5,6,7). However, there is no clinical evidence that could be applied to justify the use of the regenerated hamstring as a graft in revision surgery.

A clinical study looking into patella-tendon re-harvesting showed inferior results in terms of recovery of the patella tendon and clinical outcome of the ACL (8).

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S16: What is the minimal tendinous graft diameter in ACL Revision Surgery?

Steering group answer:

The same requirements regarding graft thickness and length are necessary for the grafts used in revision surgery as in primary ACL surgery. A minimum graft diameter of 8 mm is advised and is dependent on many factors (knee size, surgical technique, type of graft, gender).

Grade of recommendation: C

Literature review:

Large registry data demonstrate the importance of choosing a graft diameter of >8mm. This was shown by large reports from both the New Zealand registry and the Swedish and Norwegian national registries.

There is a lack of research dealing with graft size in revision surgery. However, several studies have dealt with that question in primary ACL reconstruction. It would be plausible to assume that the same rules apply to revision ACL surgery.

Magussen et al. demonstrated that hamstring autograft size is a predictor of early graft revision. Use of hamstring autografts 8 mm in diameter or less was shown to be associated with higher revision rates (1). In a large cohort of patients who underwent primary ACL reconstruction with hamstring autografts, an increase in the graft diameter between 7.0 and 10.0 mm resulted in a 0.86 times lower likelihood of revision surgery with every 0.5-mm increase (2). In a further study, it was shown that within the range of 7.0 to 9.0 mm graft diameter, there was a 0.82 times lower likelihood of being a revision case with every 0.5-mm incremental increase (3). The MOON study showed that revision was required in 0 of 64 patients (0.0%) with grafts greater than 8 mm in diameter and 14 of 199 patients (7.0%) with grafts 8 mm in diameter or smaller (P = .037) (4).

It is still fair to mention that despite the above evidence, commonly referring to 8mm or more as the necessary graft size, the Norwegian registry data contradicted prevailing evidence prior evidence by showing that graft size is possibly less important than previously stated (5,6).

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S17: What is the best treatment in the case of a planned ACL revision in a patient with a suspected low-grade infection?

Steering group answer:

Infection after primary ACL reconstruction has a low incidence and there is little evidence to guide the correct treatment. However, in the case of a suspected infection it is mandatory to perform blood tests and joint aspiration (white blood cell count, C-reactive protein, erythrocyte sedimentation rate, culture and microscopic examination). Tissue biopsy may be important to rule out low-grade infection in case of doubt and to identify bacteria (see also question D17).

A multi-staged procedure in suspected low-grade infection is mandatory, with a thorough debridement (including ACL graft remnant excision and hardware removal) and antibiotic therapy prior to the second stage ACL reconstruction.

Grade of recommendation: D

Literature review:

The literature in this regard is scarce. Most of the literature is based on the concepts of treatment of septic joint arthritis. There are some concepts regarding the treatment of septic arthritis in an ACL reconstructed knee. The most important issue that has been emphasized is early diagnosis, based on joint aspiration (1). Joint aspiration allows for a sensitive and specific diagnosis of infection and should be considered upon suspicion (2). The gold standard of treatment in septic arthritis following ACL reconstruction is arthroscopic washout with debridement with graft retention (3). Such an approach is likely to be successful without the need for graft removal (3,4).

Andreas Imhoff's group concluded that while graft-retaining protocols should have the highest priority in the treatment of septic arthritis after ACL reconstruction, two-stage procedures should be performed in cases where graft resection becomes necessary, to avoid future cartilage and meniscal lesions (4). It is important to acknowledge septic arthritis after ACL reconstruction as a complication resulting in reduced long-term subjective, functional, and radiographic outcomes (5).

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S18. Is antibiotic soaking of grafts useful for reducing post-operative infections?

Steering group answer:

Soaking the graft in antibiotics (vancomycin (grade A), gentamycin (grade C)) solution prior to graft implantation is a valid option to reduce the incidence of postoperative septic arthritis. However the development of resistance may be of concern (grade D).

Literature Review

This is a reasonably well-investigated topic in primary ACL reconstruction.

A meta-analysis by Naendrup showed a significant decrease in infection after graft soaking with Vancomycin. The meta-analysis included 5,075 patients with ACL reconstruction, followed from 6 to 52 weeks post-operatively. Of 2099 patients in the routine pre-operative IV prophylaxis group, 44 (2.1%) cases of early septic arthritis were reported. In contrast, there were no reports of septic arthritis following ACLR in 2976 cases of vancomycin-soaked grafts. The meta-analysis yielded an odds ratio of 0.04 (0.01-0.16) favouring the addition of intra-operative vancomycin soaking of grafts (1). This meta-analysis underlines the power of vancomycin soaking in reducing postoperative infections.

In a recent study by Banios et al., it was concluded that septic arthritis following ACL reconstruction can be significantly reduced (or even eliminated) by soaking ACL autografts in a 5 mg/ml vancomycin solution. Of note, this strategy seems to be more effective in the setting of hamstring tendon autograft use, since the risk of postoperative knee infection is significantly higher when this type of graft is used (2). The article was published later and therefore not included in the meta-analysis above.

A further review identified 306 bacterial infections in 68,453 grafts across 198 studies. The overall estimated ACL graft infection rate in our meta-analysis was 0.9% (95% confidence interval [CI] = 0.8% to 1.0%). Hamstring autografts were associated with a higher infection rate

(1.1%, CI = 0.9% to 1.2%) than bone-patella tendon-bone autografts (0.7%, CI = 0.6% to 0.9%) and allografts (0.5%, CI = 0.4% to 0.8%) (Q = 15.58, $p < 0.001$). Presoaking hamstring autografts in vancomycin reduced infection rates to 0.1% (CI = 0.0% to 0.4%) (Q = 10.62, p = 0.001) (3).

A systematic review from Stanford University demonstrated a 15-fold reduced risk of infection after vancomycin graft soaking, based on 10 articles including 21,368 patients (4).

Further study showed that vancomycin presoaking does not affect immediate biomechanical properties or re-rupture rates(5,6).

Regarding revision ACL reconstruction, Schuster et al. showed that soaking of the graft in vancomycin solution prior to implantation dramatically reduced the incidence of postoperative septic arthritis in R-ACLR (7).

Two studies also evaluated the effect of gentamycin and found that gentamycin presoaking also decreased joint infections (8,9).

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IV. Indications

Revision ACL reconstruction is generally recommended in active patients suffering from instability symptoms. To date, no study has directly compared the results of operative and non-operative treatment in patients with failed primary ACL reconstruction. However, as known from primary ACL tears, non-operative treatment is most likely associated with a higher risk of secondary meniscal and chondral lesions, and a reduced activity level. Nevertheless, non-operative treatment may be considered in less active patients or patients with advanced OA in whom pain is the main complaint.

The “Formal Consensus” approach has been used in this section on specific treatment indications not covered by the “RAND/UCLA Appropriateness Method” (RAM) method, please see I1 and I2.

The RAM process was set up specifically to deepen the investigation of the indications for first ACL graft revision. To define treatment indications, the RAM combined the best available scientific evidence with the collective judgment of a panel of experts (corresponding to the Formal Consensus Rating Group) guided by a core panel (corresponding to the Formal Consensus Steering Group). A list of specific clinical scenarios was produced regarding ACL re-rupture with increased laxity in an aligned knee in adults. Each scenario underwent discussion and a two-round vote on a nine-point Likert scale, and scores were pooled to generate expert patient-specific recommendations on the appropriateness of revision ACL reconstruction.

For the appropriateness of indications for ACL revision surgery in different clinical scenarios the base case was defined by age (3 groups: 18-35, 36-50, 51-60 years), sport expectation (3 groups: Tegner 0-3, 4-6, 7-10), instability symptoms (2 groups: subjective instability vs no subjective instability), meniscus status (3 groups: functional meniscus, repairable meniscus, non-functional meniscus) and OA (2 groups: 0,I,II grade vs III grade KL). It was defined without gross osseous malalignment (varus/valgus within 5°, slope less than 12°), no additional ligamentous injuries, no advanced OA (KL IV grade), and over 18 years of age.

However, since older age and advanced OA are also important factors to be considered in the clinical practice when deciding for an ACL revision, they will be commented on below.

I1: What is the indication for performing an ACL revision in people older than 60 years?

Steering group answer: No evidence is available on the outcomes of Revision ACL reconstruction in patients older than 60 years of age. However, based on evidence available for primary ACL reconstruction, revision ACL is not contraindicated, especially in active patients with symptomatic instability and limited OA.

Grade: D

Literature review:

No studies are available on Revision ACL reconstruction in patients older than 60 years. The average age of the ACL Revision case series is usually between 25-35 years [1], with very few patients exceeding 60 years of age [2,3]. Therefore, the data on the outcomes of Revision ACL reconstruction in patients >60 years of age are scarce.

Only one study specifically assessed the role of age in the ACL Revision outcomes: Yoon et al. [4] compared 24 patients over 40 years of age with 62 patients aged less than 40 years, at a minimum 2-year follow-up. The IKDC, Lysholm, AP laxity and Pivot-Shift significantly improved from preoperative status to final follow-up in both groups, without differences between patients older and younger than 40 years. Similar failure rates of nearly 30% were registered in both groups. The authors concluded that outcomes and failures were independent of the patient's age; however, they did not report how many patients were older than 60 years of age, and they reported an overall high failure rate and generally poor outcomes. However, some evidence is available for Primary ACL reconstruction. A recent systematic review titled "*Age over 50 years is not a contraindication of anterior cruciate ligament reconstruction*" [5] reported that ACL reconstruction in patients older than 50 years is a safe procedure with good results that are comparable to those in younger patients, and that physiological age, clinical symptoms, and functional requests are more important than chronological age in the decision process. However, in this review only 2 studies [6,7] specifically included patients older than 60 years. Toanen et al. reported an average 93 points on the Lysholm score, 83% return to sport (50% at pre-injury level) and no knee deterioration at 4-year follow-up in 12 over-60 patients with no or minimum OA (Ahlback 0 or I). The authors concluded that older and active patients with nonarthritic ACL-deficient knees can be considered for a knee stabilizing procedure [6]. Baker Jr et al., screening a 25-year institutional database, found only 15 patients and reported good to excellent clinical results at nearly 10 years of follow-up, return to sport exercise, complete satisfaction, and superior PROMS compared to age and sex-matched patients. The authors concluded that patients of any age who are active, desire to maintain their level of activity and have symptomatic instability can be successfully treated with ACL reconstruction if there are no contraindications [7].

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I2: Are there indications to perform ACL revision in patients with KL IV grade OA?

Steering group answer: ACL reconstruction can be effective in reducing activity-induced pain and instability in early OA. For advanced OA (KL 4) there is no indication to perform isolated ACL reconstruction. Data for combined surgery are only rarely available, but high tibial osteotomy can be combined with ACL reconstruction in special indications to improve symptomatic instability in the OA knee.

Grade: D

Literature review:

It is well known that ACL reconstruction protects the meniscus from further damage and probably slows OA development. However, the literature is very scarce on whether performing ACL reconstruction in cases of already existing OA can be successful, and even less literature is available concerning the revision setting.

Some case series describe successful ACL reconstruction in early OA (1,2,3). Very limited evidence was generated suggesting that ACL reconstruction could be advantageous even in advanced OA (Shelbourne n=3 patients). Fayard et al. showed that signs of medial OA in patients over 50 years of age are indicative of poor outcomes (4). Regarding the outcome of revision ACL replacement, cartilage damage and OA are worse prognostic factors, as the MARS data show (5). Furthermore, ACL revision reconstruction cannot reliably delay the progression of OA (6). A recent systematic review showed that combined surgery with HTO and ACL replacement may be beneficial in selected cases; however, the role of ACL reconstruction in severe OA is unclear, whereas the role of HTO is well evaluated (7). Indications for combining HTO with ACL replacement could include pain from subjective instability. Mehl et al. showed that additional ACL reconstruction versus HTO alone resulted in higher Lysholm and IKDC scores and did not accelerate OA development (8).

References:

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For the indications to perform additional osseous corrections, meniscus surgery, or additional ligamentous procedures please see the chapters on surgical strategy.

RAM (RAND/UCLA Appropriateness Method) - indications

For the RAM consensus method on treatment indications, the scenarios are built around this question:

"A .. -year-old patient with ACL re-rupture presents with an aligned knee, increased laxity, and the following characteristics. How appropriate are the indications for revision ACL reconstruction?"

The term “re-rupture” in the RAM consensus question used to build the scenarios should be interpreted in light of the concept of “failure” as described in D1, which refers not specifically to an acute episode, but rather to a loss of function after a previous primary reconstruction (see D1 for the complete definition).

In more detail, the scenarios are built according to the most important selected factors as follows:

- **Age**: the category 18-35 years old has been chosen to identify the indications in patients in the age group where there are commonly the highest functional requests; i.e. competitive athletes. The category 35-50 years old has been selected to identify patients who are still active but often with lower functional requests, and many years ahead before considering metal resurfacing, which offers poor results in patients younger than 50 years old. A final category of patients from 50-60 years old has been identified, as the functional requests are usually lower and prostheses start to emerge among the suitable options to be considered for treatment indication. A specific Delphi question has been dedicated to the few cases involving patients >60 years of age.
- **Expectations to go back to sport/activity level**: 3 categories have been defined according to the Tegner score (0-3 vs 4-6 vs 7-10, see below).
- **Meniscus status**: as there are countless scenarios related to specific meniscus lesion patterns, the RAM scenarios considered 3 broad conditions: one where the meniscus is functionally working; one where the meniscus is damaged but repairable to return to a functional status; and one where meniscus is damaged to the point that it cannot be considered functional. As scaffolds and meniscus allografts are not commonly available, a specific Delphi question has been previously dedicated to the possibility of restoring meniscus function through scaffolds and allografts.
- **OA**: the level of joint degeneration has been dichotomized into no or mild OA (KL 0 to II grade) vs moderate OA (KL III grade), while a specific Delphi question has been previously dedicated to patients affected by ACL re-rupture in advanced KL IV grade OA knees (see above).
- **Subjective instability**: this has been dichotomized to represent two main conditions: one where patients complain of instability symptoms; and another where they do not perceive instability despite the increased laxity objectively documented by the surgeon (for the methods to document instability please see the specific Delphi question).

10. Competitive sports
- Soccer–national and international elite

9. Competitive sports
- Soccer, lower divisions
- Ice hockey
- Wrestling
- Gymnastics

8. Competitive sports
- Bandy
- Squash or badminton
- Athletics (jumping, etc.)
- Downhill skiing

7. Competitive sports
- Tennis
- Athletics (running)
- Motorcross, speedway
- Handball
- Basketball

Recreational sports
- Soccer
- Bandy and ice hockey
- Squash
- Athletics (jumping)
- Cross-country track findings both recreational and competitive

6. Recreational sports
- Tennis and badminton
- Handball
- Basketball
- Downhill skiing
- Jogging, at least five times per week

5. Work
- Heavy labor (e.g., building, forestry)

Competitive sports
- Cycling
- Cross-country skiing

Recreational sports
- Jogging on uneven ground at least twice weekly

4. Work
- Moderately heavy labor (e.g., truck driving, heavy domestic work)

Recreational sports
- Cycling
- Cross-country skiing
- Jogging on even ground at least twice weekly

3. Work
- Light Labor (e.g., nursing)

Competitive and recreational sports
- Swimming

Walking in forest possible

2. Work
- Light Labor

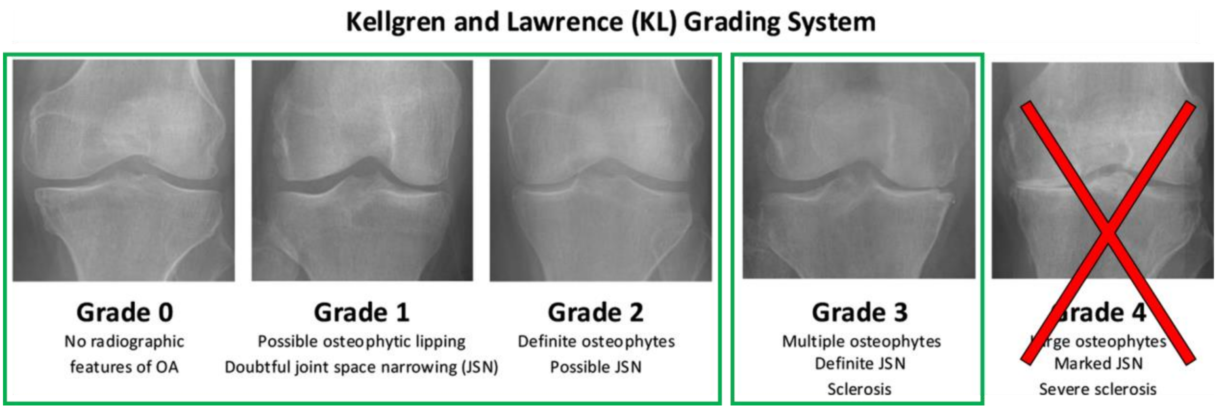
Walking on uneven ground possible but impossible to walk in forest

1. Work
- Sedentary work

Walking on even ground possible

0. Sick leave or disability pension because of knee problems

Y Tegner, J Lysholm. Rating systems in the evaluation of knee ligament injuries. Clin Orthop Relat Res. 1985 Sep;(198):43-9.



Modified from P Chen, L Gao, X Shi, K Allen, L Yang. Fully automatic knee osteoarthritis severity grading using deep neural networks with a novel ordinal loss. Comput Med Imaging Graph. 2019 Jul;75:84-92.

Based on the five clinical variables identified as more relevant for the treatment choice, a set of 108 clinical scenarios was developed. Panelists were asked to individually assess the appropriateness for revision ACL reconstruction for all scenarios, for a total of 108 indications organized in three main chapters based on the three age categories. The appropriateness of the treatment indications in the different scenarios was rated in two rounds, to sort out whether discrepant ratings are due to real clinical disagreement over the use of the procedure ("real" disagreement) or to fatigue or misunderstanding ("artefactual" disagreement). Each panelist ranked, independently from the other panelists, the appropriateness for each scenario on a nine-point Likert-scale, in which a score in the range 1-3 is considered ‘inappropriate’, 4-6 ‘uncertain’, and 7-9 ‘appropriate’. The final scores of the nine-point Likert-scale of each expert were then pooled to generate a median appropriateness score for each scenario. In addition, the presence of “disagreement” was calculated according to the following definition: At least six panelists rate the indication in the 1-3 region and at least six panelists rate it in the 7-9 region. Finally, the use of the treatment for each scenario was classified:

- “appropriate”: median score of ≥7 without disagreement
- “inappropriate”: median vote of ≤3 without disagreement

A scenario receiving a score between 4 and 6, or a scenario with disagreement, was classified as "uncertain". An "uncertain" recommendation can reflect either the ambiguous state of current evidence or equivocal appropriateness either due to a moderately unfavorable risk profile or to limited efficacy. The 'uncertain' classification is not intended to be a negative recommendation or to preclude a priory the use of the treatment for the specific scenario, relying on the physician-patient interaction in determining treatment decision in the context of the individual characteristics, co-morbidities, and preferences.

RAM results

Overall, in 63 scenarios revision ACL reconstruction was considered appropriate without disagreement, in 13 inappropriate without disagreement, and in 32 scenarios the indication was uncertain.

Chapter 1

A **18-35 years** old patient with ACL re-rupture presents to your attention with an aligned knee, increased laxity, and the following characteristics.
How appropriate do you rate the indication for revision ACL reconstruction?

Sport level/expectations	Concomitant meniscal lesion	OA grade	Subjective Instability											No Subjective Instability											Indication n°
			1	2	3	4	5	6	7	8	9	M	DIS	1	2	3	4	5	6	7	8	9	M	DIS	
Tegner 7-10	Functional meniscus	KL 0-I-II	0	0	0	0	0	0	0	0	17	9	A+	0	0	1	0	0	0	2	8	6	8	A+	(1-2)
		KL III	0	0	0	1	0	0	1	4	11	9	A+	1	0	0	0	0	2	7	2	5	7	A+	(3-4)
	Repairable meniscus	KL 0-I-II	0	0	0	0	0	0	0	0	17	9	A+	0	0	1	0	0	0	1	6	9	9	A+	(5-6)
		KL III	0	0	0	1	0	0	1	3	12	9	A+	1	0	0	0	0	0	5	6	5	8	A+	(7-8)
	Non functional meniscus	KL 0-I-II	0	0	0	0	0	1	0	2	14	9	A+	0	0	1	1	0	1	4	5	5	8	A+	(9-10)
		KL III	0	1	0	0	0	1	2	7	6	8	A+	2	0	0	1	1	2	6	1	4	7	A+	(11-12)
Tegner 4-6	Functional meniscus	KL 0-I-II	0	0	0	0	0	0	0	1	16	9	A+	0	0	1	0	2	1	4	5	4	8	A+	(13-14)
		KL III	0	0	0	1	0	0	5	5	6	8	A+	1	0	0	1	2	2	8	1	2	7	A+	(15-16)
	Repairable meniscus	KL 0-I-II	0	0	0	0	0	0	0	1	16	9	A+	0	0	1	0	0	1	1	8	6	8	A+	(17-18)
		KL III	0	0	0	1	0	0	3	6	7	8	A+	1	0	0	0	0	1	9	3	3	7	A+	(19-20)
	Non functional meniscus	KL 0-I-II	0	0	0	0	0	1	2	3	11	9	A+	0	1	1	0	2	5	5	2	1	6	U+	(21-22)
		KL III	0	1	0	0	0	3	5	5	3	7	A+	1	1	1	4	4	3	1	2	0	5	U+	(23-24)
Tegner 0-3	Functional meniscus	KL 0-I-II	0	0	0	0	0	0	3	7	7	8	A+	0	1	2	1	3	2	4	2	2	6	U+	(25-26)
		KL III	0	0	0	1	0	1	8	3	4	7	A+	1	1	2	2	3	3	4	1	0	5	U+	(27-28)
	Repairable meniscus	KL 0-I-II	0	0	0	0	0	0	2	4	11	9	A+	0	0	1	0	1	3	7	4	1	7	A+	(29-30)
		KL III	0	0	0	1	0	1	5	5	5	8	A+	1	0	0	0	2	6	4	4	0	6	U+	(31-32)
	Non functional meniscus	KL 0-I-II	0	0	0	1	1	2	4	7	2	8	A+	1	0	4	3	5	1	2	1	0	5	U+	(33-34)
		KL III	0	1	1	1	2	8	4	0	0	6	U+	2	2	8	2	1	2	0	0	0	3	I+	(35-36)

Appropriateness scale: 1 = extremely inappropriate, 5 = uncertain, 9 = extremely appropriate

Chapter 2

A **36-50 years** old patient with ACL re-rupture presents to your attention with an aligned knee, increased laxity, and the following characteristics.
How appropriate do you rate the indication for revision ACL reconstruction?

Sport level/expectations	Concomitant meniscal lesion	OA grade	Subjective Instability											No Subjective Instability											Indication n°
			1	2	3	4	5	6	7	8	9	M	DIS	1	2	3	4	5	6	7	8	9	M	DIS	
Tegner 7-10	Functional meniscus	KL 0-I-II	0	0	0	0	0	0	0	4	13	9	A+	0	0	2	0	0	1	3	7	4	8	A+	(37-38)
		KL III	0	0	1	0	1	0	1	8	6	8	A+	1	1	0	0	0	1	8	3	3	7	A+	(39-40)
	Repairable meniscus	KL 0-I-II	0	0	0	0	0	0	0	3	14	9	A+	0	0	1	0	0	0	4	8	4	8	A+	(41-42)
		KL III	0	0	1	0	1	0	1	5	9	9	A+	1	0	0	0	1	1	2	8	4	8	A+	(43-44)
	Non functional meniscus	KL 0-I-II	0	0	0	0	1	0	1	3	12	9	A+	0	1	1	1	0	4	4	3	3	7	A+	(45-46)
		KL III	0	1	0	0	2	0	0	10	4	8	A+	2	0	1	2	7	2	2	0	1	5	U+	(47-48)
Tegner 4-6	Functional meniscus	KL 0-I-II	0	0	0	0	0	0	2	6	9	9	A+	0	1	1	0	3	5	2	3	2	6	U+	(49-50)
		KL III	0	0	1	1	0	1	5	7	2	8	A+	1	1	1	2	5	3	2	2	0	5	U+	(51-52)
	Repairable meniscus	KL 0-I-II	0	0	0	0	0	0	2	4	11	9	A+	0	1	0	0	0	1	9	5	1	7	A+	(53-54)
		KL III	0	0	1	1	0	1	3	5	6	8	A+	1	0	0	0	3	8	3	2	0	6	U+	(55-56)
	Non functional meniscus	KL 0-I-II	0	0	0	0	1	0	5	7	4	8	A+	0	1	3	2	6	3	0	1	1	5	U+	(57-58)
		KL III	0	1	0	1	1	3	7	3	1	7	A+	1	1	5	6	4	0	0	0	0	4	U+	(59-60)
Tegner 0-3	Functional meniscus	KL 0-I-II	0	0	0	0	2	2	3	8	2	8	A+	2	0	3	5	3	2	1	1	0	4	U+	(61-62)
		KL III	0	0	2	1	2	1	8	2	1	7	A+	2	2	4	6	1	1	1	0	0	4	U+	(63-64)
	Repairable meniscus	KL 0-I-II	0	0	0	0	1	1	4	8	3	8	A+	1	0	1	0	3	4	7	1	0	6	U+	(65-66)
		KL III	0	0	2	1	0	2	8	3	1	7	A+	1	1	2	3	5	4	0	1	0	5	U+	(67-68)
	Non functional meniscus	KL 0-I-II	0	0	2	0	1	3	6	4	1	7	A+	4	0	7	2	1	2	1	0	0	3	I+	(69-70)
		KL III	2	0	1	3	5	2	4	0	0	5	U+	4	4	7	2	0	0	0	0	0	3	I+	(71-72)

Appropriateness scale: 1 = extremely inappropriate, 5 = uncertain, 9 = extremely appropriate

Chapter 3

A **51-60 years** old patient with ACL re-rupture presents to your attention with an aligned knee, increased laxity, and the following characteristics.
How appropriate do you rate the indication for revision ACL reconstruction?

Sport level/expectations	Concomitant meniscal lesion	OA grade	Subjective Instability											No Subjective Instability											Indication n°
			1	2	3	4	5	6	7	8	9	M	DIS	1	2	3	4	5	6	7	8	9	M	DIS	
Tegner 7-10	Functional meniscus	KL 0-I-II	0	0	0	0	1	1	2	6	7	8	A+	0	3	0	0	1	3	6	3	1	7	A+	(73-74)
		KL III	0	1	1	0	0	3	5	4	3	7	A+	1	2	2	1	4	4	1	1	1	5	U+	(75-76)
	Repairable meniscus	KL 0-I-II	0	0	0	0	2	0	1	8	6	8	A+	0	1	0	1	0	3	7	4	1	7	A+	(77-78)
		KL III	0	2	0	0	1	2	5	3	4	7	A+	1	1	1	2	1	5	4	1	1	6	U+	(79-80)
	Non functional meniscus	KL 0-I-II	0	0	0	1	1	1	7	4	3	7	A+	1	3	0	8	3	1	0	1	0	4	U+	(81-82)
		KL III	0	3	0	0	1	3	6	4	0	7	A+	2	6	5	1	1	1	0	1	0	3	I+	(83-84)
Tegner 4-6	Functional meniscus	KL 0-I-II	0	0	0	1	1	1	5	6	3	8	A+	1	3	3	5	2	1	2	0	0	4	U+	(85-86)
		KL III	0	2	1	0	1	6	5	1	1	6	U+	4	4	5	2	0	1	1	0	0	3	I+	(87-88)
	Repairable meniscus	KL 0-I-II	0	0	0	1	1	0	6	6	3	8	A+	0	1	1	2	3	5	5	0	0	6	U+	(89-90)
		KL III	0	2	0	0	2	3	7	2	1	7	A+	1	5	0	4	4	2	1	0	0	4	U+	(91-92)
	Non functional meniscus	KL 0-I-II	0	0	1	1	3	5	5	1	1	6	U+	3	6	4	1	3	0	0	0	0	2	I+	(93-94)
		KL III	1	2	1	2	6	3	1	1	0	5	U+	6	7	2	0	2	0	0	0	0	2	I+	(95-96)
Tegner 0-3	Functional meniscus	KL 0-I-II	0	1	1	0	3	6	4	1	1	6	U+	3	7	4	1	1	1	0	0	0	2	I+	(97-98)
		KL III	2	0	4	1	2	5	2	0	1	5	U+	7	3	6	0	0	1	0	0	0	2	I+	(99-100)
	Repairable meniscus	KL 0-I-II	0	1	1	0	2	3	7	2	1	7	A+	1	2	3	6	5	0	0	0	0	4	U+	(101-102)
		KL III	2	1	2	1	7	2	0	1	1	5	U+	2	4	7	2	2	0	0	0	0	3	I+	(103-104)
	Non functional meniscus	KL 0-I-II	1	1	2	3	6	2	1	0	1	5	U+	7	6	4	0	0	0	0	0	0	2	I+	(105-106)
		KL III	4	3	5	3	1	1	0	0	0	3	I+	13	3	1	0	0	0	0	0	0	1	I+	(107-108)

Appropriateness scale: 1 = extremely inappropriate, 5 = uncertain, 9 = extremely appropriate

Appropriateness, inappropriateness, and uncertain areas

Experts consider appropriate revision ACL reconstruction for every patient with subjective instability aged ≤50 years, regardless of sport activity level, meniscus status, and OA grade, with the only exception of the 2 scenarios regarding patients having low Tegner level requests, non-functional meniscus, and OA KL III.

If subjective instability is present in patients over 50 years old, revision ACL reconstruction is always indicated in patients with high sport expectations. For lower activity requests (Tegner 4-6), the only cases where the treatment is considered appropriate are patients with functional meniscus and without moderate OA, and patients with repairable meniscus regardless OA grade. For Tegner 0-3 the only appropriate scenario is a repairable meniscus without OA, whereas the revision surgery is considered inappropriate for OA KL III knees with non-functional meniscus. The remaining scenarios are evaluated as uncertain.

The results are much more controversial in patients without subjective instability, and a more significant role is played by age and sport expectation. In fact, for high sport requests (Tegner 7-10), revision ACL reconstructions is indicated in all patients ≤50 years old, with the only exception of patient aged 36-50 with non-functional meniscus and moderate OA. For lower sport expectations or older age, the only area of agreement toward appropriateness is found for patients 18-35 years old, with Tegner 4-6 expectation, with functional or repairable meniscus. Among the remaining scenarios, only 4 are considered appropriate, that are in 3 cases patients with repairable meniscus and no mild OA (aged 18-35 and low sport level, aged 36-50 and intermediate sport level, and aged 51-60 and high sport level) and in one case a patient aged 51-60, with high sport expectation, a functional meniscus a KL 0-I-II OA.

In patients without subjective instability several scenarios are considered inappropriate for revision ACL reconstruction, in particular for non-functional meniscus with or without OA together with lower sport expectations or older age, and in other scenarios regarding older patients with low or intermediate sport expectations. In almost half of the scenarios regarding patients without subjective instability the indication for revision ACL reconstruction is considered uncertain.

Appropriateness changes within parameters

The analysis of the role of the evaluated factors showed a different weight in influencing the treatment indication appropriateness. Beside the presence of subjective instability, which influenced 34 out of 54 treatment indications, sport expectation was the most discriminating factor. Compared to these factors, age, meniscus status, and KL OA grade influenced the appropriateness to a lower degree.

Table. Rate of scenarios evaluated as Appropriate, Uncertain, or Inappropriate, for each parameter considered

	CATEGORIES	A	U	I
AGE	**18-35**	77.8%	19.4%	2.8%
	36-50	63.9%	30.6%	5.6%
	51-60	33.3%	38.9%	27.8%
SUBJECTIVE INSTABILITY	**YES**	81.5%	16.7%	1.9%
	NO	35.2%	42.6%	22.2%
SPORT	**7-10**	86.1%	11.1%	2.8%
	4-6	55.6%	36.1%	8.3%
	0-3	33.3%	41.7%	25.0%
MENISCUS	**FUNCTIONAL**	61.1%	30.6%	8.3%
	REPAIRABLE	72.2%	25.0%	2.8%
	NON FUNCTIONAL	41.7%	33.3%	25.0%
OA	**KL 0-I-II**	66.7%	25.9%	7.4%
	KL III	50.0%	33.3%	16.7%

As reported in the above, the parameters which determined the highest rate of appropriate scenarios were sport level expectation Tegner 7-10 (86.1% of appropriate scenarios), subjective instability (81.5% of appropriate scenarios), and age 18-35 (77.8% of appropriate scenarios). Conversely, the parameters associated with higher inappropriateness rate were age 51-60 (27.8% of inappropriate scenarios), sport level expectation Tegner 0-3, and non-functional meniscus (25.0% each). Interestingly, among meniscal status the parameter associated with the higher rate of appropriateness was repairable meniscus (72.2%), compared to functional meniscus (61.1%) and non-functional meniscus (41.7%). The parameter determining the lowest rate of appropriateness and inappropriateness was OA (66.7% of appropriate scenarios for OA KL 0-I-II, and 16.7% of inappropriate scenarios for OA KL III).

A graphic representation of the most influencing parameters is found below.

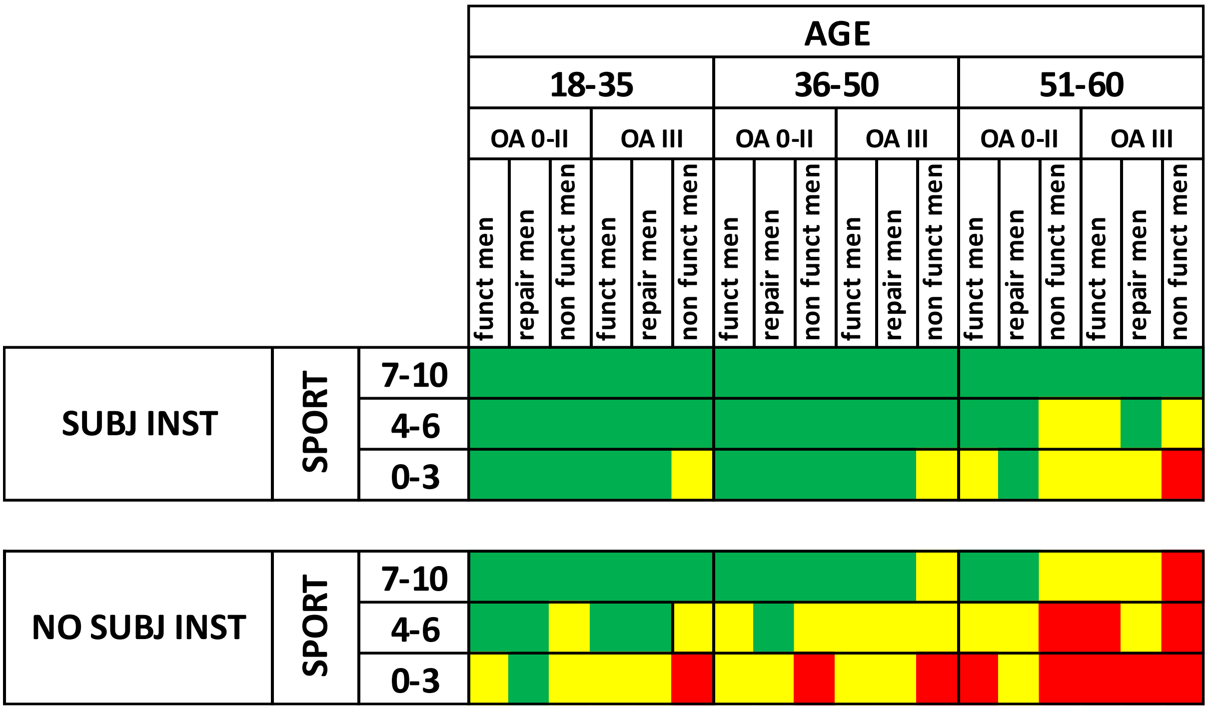


Figure. Schematic representation of the appropriate (green), inappropriate (red), and uncertain (yellow) scenarios for the first ACL revision in adults based on the RAM consensus.