Roland Becker
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Matteo Denti
Romain Seil *Editors*

ESSKA Instructional Course Lecture Book

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ESSKA

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Management of PCL Injuries (ICL 1)

1

Fabrizio Margheritini, Robert La Prade, and Sven Scheffler

The posterior cruciate ligament (PCL) is the primary stabilizer of the knee joint and is the major restraint to posterior tibial translation. PCL insufficiency after the ligament's rupture modifies the knee kinematics and may result in functional limitations in sports and daily activities. The management of PCL injuries remains a matter of debate, largely due to the lack of prospective studies delineating the true natural history of the injury and the absence of randomized trials comparing the outcomes of current modes of treatment.

1.1 Anatomy and Biomechanics of the Posterior Cruciate Ligament

Fabrizio Margheritini

Understanding the anatomy and biomechanics of the PCL is important to diagnosing and treating its injury. This ligament is a complex structure that arises from the posterior tibia 1 cm below the joint line and extends anteromedially to the lateral surface of the medial femoral condyle. The PCL averages in length between 32 and 38 mm and has a cross-sectional area of 31.2 mm^2 at its midsubstance level, which is 1.5 times that of the anterior cruciate ligament (ACL) cross-sectional area. Its femoral (Fig. 1.1) and tibial insertion sites are approximately three times larger than the cross-sectional area at the midsubstance level of the ligament. The large ligamentous insertion sites and the lack of isometry within the fibers of the PCL complicate the task of designing a PCL reconstruction technique that adequately recreates the anatomical and biomechanical properties of the intact PCL. The ligament consists of two functional components referred to as the anterolateral (AL) and the posteromedial (PM) bundles. The AL bundle is two times larger in cross-sectional area than the PM bundle and they behave differently depending on the degree of knee flexion. During passive flexion and extension of the knee, the anterolateral bundle is more

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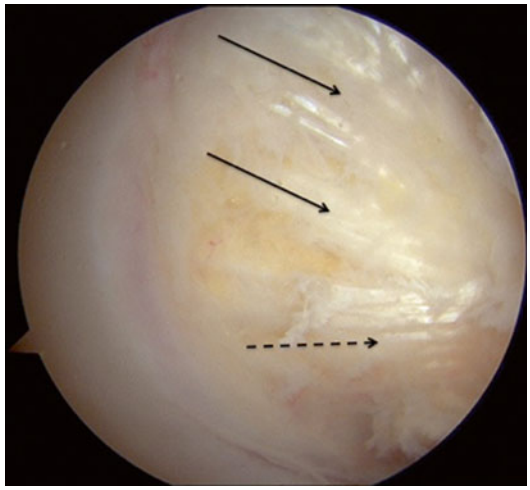

Fig. 1.1 Arthroscopic view of the femoral insertion of the PCL (*continuous black line*) and the anterior meniscofemoral ligament (*dotted line*)

taught in flexion and lax in extension. Conversely, the posteromedial bundle is more taught in extension and lax in flexion. Despite the widespread acceptance of this anatomical division of the PCL, alternate anatomic descriptions of the PCL exist, including three- and four-bundle divisions as well as a continuum of PCL fiber orientation. In addition to the anterolateral and posteromedial bundles, there are two meniscofemoral ligaments (MFL) closely associated with the PCL: the ligament of Humphrey (anterior) and the ligament of Wrisberg (posterior). They originate from the posterior horn of the lateral meniscus, run alongside of the PCL, and insert anterior and posterior to the PCL on the medial femoral condyle. The presence of these ligaments is highly variable and discrepancies exist in the literature regarding their prevalence, but they are believed to be significant anatomic and biomechanical structures that provide stability to the lateral meniscus. Biomechanical studies have shown that the PCL is one of the major stabilizers of the knee. It has a primary function of preventing posterior tibial displacement and a secondary role in limiting external, varus, and valgus rotations. Initial tensile testing reported the tensile strength of the excised PCL to be twice that of the ACL. Studies showed the linear stiffness of the anterolateral bundle (120 ± 37 N/m) to be 2.1 times that of the posteromedial bundle and 2.5 times that of the MFL, and the ultimate load of the anterolateral bundle (1,120 ± 362 N/m) to be 2.7 times that of the posteromedial bundle and 3.8 times that of the MFL. Several biomechanical cutting studies have demonstrated that isolated section of the PCL increases posterior tibial translation progressively as the knee is flexed from 0 to 90°, with maximal increase in translation occurring at 90° of knee flexion. Furthermore, results suggest that a biomechanical interaction exists between the PCL and the posterolateral structures (PLS) in providing stability to the knee. Isolated sectioning of the PCL results in posterior tibial translation by up to 11.4 ± 1.9 mm, while isolated sectioning of the PLS increases posterior translation between 1.5 and 4 mm. However, after sectioning of both the PCL and PLS, posterior tibial translation in response to a posterior load is increased by up to 25 mm. Combined PCL and PLS section increases posterior tibial translation at all degrees of knee flexion greater than isolated PCL section. The PLS is a secondary restraint to posterior tibial translation, contributing to posterior stability particularly in the PCL-deficient knee, while it plays a primary role in resisting excessive varus and external rotational forces. Isolated section of the PLS increases varus and external rotations maximally at 30–45° and has little effect on these rotations at 90° of knee flexion. Combined PCL and PLS section increases varus and external rotations at both 30 and 90°. These findings, in addition to the results pertaining to posterior tibial translation, suggest a synergistic relationship between the PCL and the PLS in providing stability to the knee.

1.2 Evaluation and Indications for PCL Surgery

Sven Scheffler

1.2.1 Evaluation

Evaluation for injuries of the PCL starts with analysis of patient history. The patient should be asked

about existing knee complaints, whether it is pain or instability or a combination of both. In chronic cases of PCL injury, patients often complain about anterior knee pain due to the posterior subluxation of the tibia, especially when a sitting position is maintained for a longer period of time. Sensations of instability are less frequently reported unless combined PCL insufficiency exists. In acute cases of PCL injury, patients are mainly compromised in their knee function due to swelling and pain with instability becoming more relevant after the loss of effusion. It must be evaluated what type of knee trauma occurred. Typical for PCL injuries is a direct trauma to the proximal tibia with the knee in flexion. However, hyperextension trauma of the knee can also result in PCL rupture.

During clinical examination patients should lay in supine position. In acute injuries, general inspection of the knee joint should check for pretibial signs of injury and hematoma in the back of the knee. Typically an effusion can be found, which often limits range of motion. With the knee in 90° of flexion and the foot stabilized by the examiner, the anterior tibial rim is palpated, which should be in front of the femur, which is called the *tibial step-off* (Fig. 1.2). When the tibia is pushed posteriorly, the tibial rim must remain anterior to the femur with an intact PCL. If the tibia can be pushed under or even posterior to the femoral condyles, PCL injury is imminent (*positive posterior drawer sign*). Often PCL injury is mistaken for an ACL injury in clinical examination due to a posteriorly subluxed tibia at the starting position of the anterior-posterior drawer test. Therefore, it is important to first pull the tibia anteriorly until the tibial step-off is palpable before executing the posterior drawer test. Always, clinical test must be examined on the injured and intact contralateral knee to differentiate insufficiency from inherent individual laxity.

Fig. 1.2 Posterior drawer test with palpation of the tibial step-off

In chronic PCL deficiency, a posterior sag of the tibia can be observed at 90° of flexion compared to the intact contralateral knee. Also, a posterior subluxation of the tibia can be provoked by the patient when trying to actively extend the knee flexed at 60° and the food fixed to the examination table (*quadriceps pull test*).

PCL lesions are often combined with injuries to the posterolateral corner, to a lesser extent to the medial structures of the knee joint. First the lateral collateral ligament (LCL) is examined in extension and 30° of flexion by lateral opening of the knee joint (*varus stress test*). Opening only at 30° is associated with isolated LCL injury, while additional opening at extension is suggestive of injury to the posterolateral corner (e.g., arcuate complex) of the knee joint. Injury to the posterolateral structures, such as the popliteus tendon and arcuate complex, results into substantially increased posterior instability, but especially to external rotational instability. This can be evaluated at the 90° flexed knee by rotating the tibia externally while fixing the foot to the examination table and repeating the same test on the contralateral knee. The *dial test* is another clinical technique to analyze rotational instability, especially in combined injuries with the PCL. The patient lies in prone position and an assistant gently stabilizes both knee joints, while the examiner holds both feet of the patient and rotates them externally. The test is performed at 30° and 90° of flexion. If increased external rotation is noticed at 30° and 90° of flexion, combined injury to the PCL and posterolateral structures is probable.

Anterolateral structures are examined in 20° of flexion with increased opening anteriorly compared to the healthy contralateral side. Also, increased internal rotation in 20° and 90° of flexion might be suggestive of such injury. Medial structures are analyzed by valgus opening (*valgus-stress test*) at extension and 30° of flexion.

Increased opening at 0° and 30° of flexion is suggestive of injury to the medial collateral ligament and the posterior oblique ligament, which in most cases requires surgical intervention. Isolated opening at 30° of flexion is caused by injury of the superficial medial collateral ligament, which can heal successfully with conservative treatment.

If acute PCL injury is assumed, conventional x-rays of the knee joint (AP and lateral) are taken to exclude fractures of the tibia and femur. Sometimes, a posterior sag of the tibia relative to the femur can be observed. If PCL injury is suspected and no substantial swelling is present, the patient should be examined under dynamic fluoroscopy on both knee joints for anterior and posterior translation in 90° flexion. If swelling has already occurred, pain will prevent precise examination with the patient awake. If the patient will have to undergo immediate surgery due to related injuries, this examination should be performed in the operation room prior to surgery. Immediate magnetic resonance imaging (MRI) of the knee joint should be carried out, which is highly sensitive and specific for injury of the PCL and intra- and extra-articular peripheral structure periphery. This is of importance to differentiate between a single-ligament and multiligament injury.

Since PCL injury often requires a substantial trauma to the knee joint and associated injuries are frequent, vascular injuries must be excluded. Doppler ultrasound examinations should be performed at the time of injury and repeated at 24 and 48 h to exclude intima lesions that often present with timely delay.

Stress x-rays are not indicated in the acute setting. Swelling and pain will stop patients from relaxing the hamstrings, which prevents valid measurements of true anterior-posterior translation.

In chronic PCL insufficiency, it is detrimental to quantify the extent of posterior instability, especially when differentiating isolated from combined chronic injuries. Objective quantification and comparison of posterior translation of the tibia relative to the femur between both knee joints are of crucial importance. Conventional stress x-rays allow such analysis on exact lateral views with different imaging methods being described, such as Telos (Fig. 1.3) or kneeling

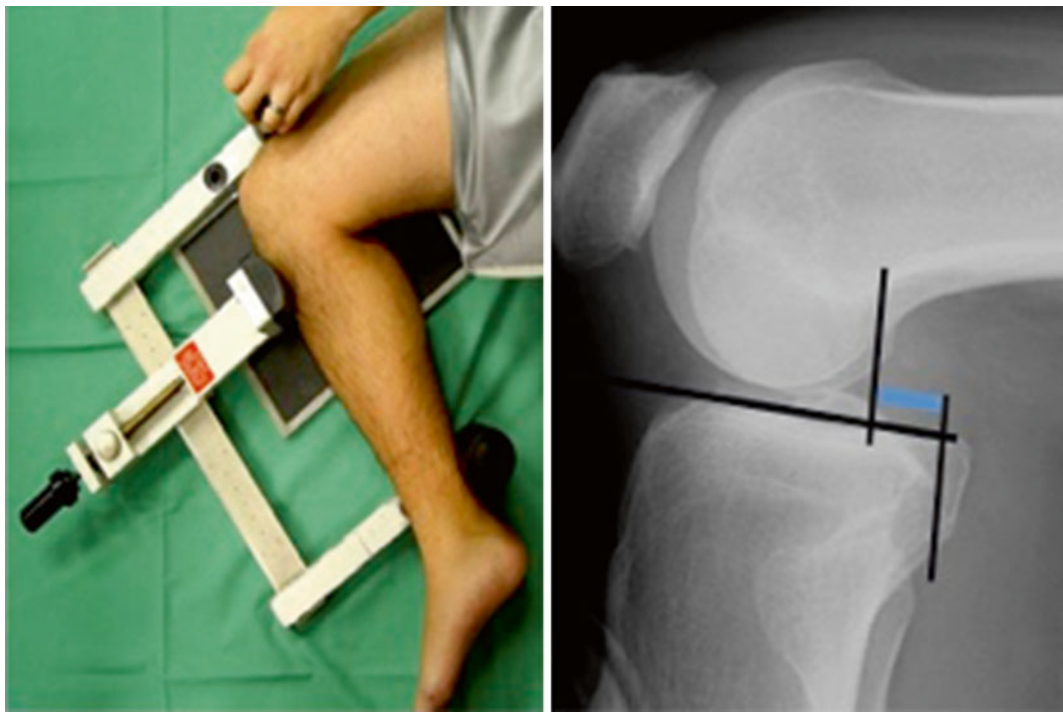

Fig. 1.3 Telos stress x-ray for quantification of posterior translation

technique. It has been shown that side-to-side differences (SSD) of 12 mm or more between the injured and intact knee are highly suggestive of combined PCL injuries, while differences of less than 10 mm are an indicator for isolated chronic PCL insufficiency [1]. Another important phenomenon is the so-called fixed posterior subluxation [2]. It results from permanent posterior tibial subluxation without the possibility of fully restoring anterior-posterior translation in patients with chronic PCL insufficiency. It is of utter importance to exclude such fixed posterior subluxation prior to PCL surgery by conducting stress x-rays in anterior and posterior drawer position on both knee joints. A difference in SSD of 3 mm or more in reduced anterior translation of the PCL-deficient knee is indicative of fixed posterior subluxation on anterior stress x-rays. Such quantification has only been shown until now using Telos technique [2]. If a fixed posterior subluxation is found on anterior stress x-rays, full restoration of anterior-posterior translation must be achieved prior to PCL surgery.

MRI analysis of chronic PCL insufficiency has limited use, since the PCL can recover normal signal intensity during healing independently from its true functional recover. Therefore, MRI imaging has its main use to visualize concomitant injuries, especially to the cartilage of the patellofemoral and medial joint compartment, which are often associated with long-lasting PCL deficiency.

1.2.2 Indications for PCL Surgery

Acute isolated injury of the PCL can be treated successfully with conservative therapy by immobilization of the injured knee in a tibial repositioning knee brace for a time period of 6 weeks. With chronic isolated PCL insufficiency, it is essential to confirm that no combined instability of the peripheral structures of the knee joint exists. If patients complain about clinical symptoms, such as patellofemoral pain and/or subjective instability and clinical examination and radiographic analysis with stress x-rays verify isolated injury of the PCL, a brace test with a tibial repositioning brace should be executed for 3–6 weeks. If clinical symptoms subside, isolated PCL reconstruction should be recommended [3].

Acute combined injuries of the PCL and the medial/lateral periphery of the knee joint often result in permanent knee instability [4]. Therefore, reconstruction of the PCL and its comorbidities is recommended [4]. Most often, PCL rupture is associated with injuries of the posterolateral structures, such as the arcuate complex, the popliteus tendon, and the lateral collateral ligament. The excess of posterolateral injury must be assessed during clinical examination, while MRI will confirm the full extent of injury as long as it is conducted shortly after trauma. It is recommended to reconstruct all impaired structures in a single-time procedure. This avoids overloading of the PCL reconstruction and premature failure due to non-addressed peripheral instability [5]. Less often, PCL rupture is combined with injuries of the medial structures of the knee joint. Identical approach should be taken to restore medial side knee stability at the same time when performing PCL reconstruction [6]. In multiligament injuries of the ACL, PCL, and the periphery, ideally, single-staged reconstruction of all ligaments should be undertaken. It has been shown that suturing of the impaired structures, even in the acute setting, results in increased rates of insufficiency compared to augmentation/reconstruction [7]. If the general condition of the knee joint will not allow for prolonged surgical time, staged reconstruction can be opted for. First, reconstruction of the central ligaments (ACL, PCL) should be performed, while addressing all peripheral structures as soon as the overall knee condition permits further surgical intervention.

In combined chronic PCL insufficiency, reconstruction of all impaired structures is required. It is of fundamental importance to exclude a fixed posterior dislocation of the tibia prior to PCL reconstruction [2] to avoid stabilization of the knee joint in a subluxed position. Surgical reconstruction of all structures should be carried out in a single-staged procedure to prevent excessive loading of the respective structures due to persisting, even partial, instability.

1.3 Surgical Treatment: Arthroscopic vs Inlay

Fabrizio Margheritini

PCL reconstruction techniques can be categorized as arthroscopic (transtibial) or open (inlay). Furthermore, the type of PCL reconstruction can be described as a single- or double-bundle technique, according to the graft construct that is chosen for the reconstruction.

1.3.1 Transtibial Tunnel Technique

The transtibial technique has been popularized by Clancy et al. in 1983 [8]. It is based on the use of a single tibial tunnel that is drilled from the anteromedial aspect of the proximal tibia to the posterior aspect of the proximal tibia at the site of PCL insertion. Even though it was originally described as an open procedure, the technique is now routinely performed arthroscopically.

Following an exam under anesthesia, the patient is positioned using well-padded leg holders, and the tourniquet is placed on the proximal thigh of the injured leg but not inflated during the procedure in order to better control the intraoperative bleeding. Anatomic landmarks are delineated on the skin with a marking pen. Standard anteromedial and anterolateral portals are established on the joint line adjacent to the borders of the patellar tendon. Diagnostic arthroscopy is performed to assess all intra-articular structures and address the torn ligament and associated pathology. Author's preferred method at this point establishes a posteromedial and posterolateral accesses and a transeptal approach is prepared. Even if the transeptal portal is not mandatory for performing a transtibial reconstruction, removing the posterior septum allows a better visualization of the posterior compartment keeping away from the working area the popliteal artery (Fig. 1.4).

Tibial tunnel is drilled using a PCL guide set between 50 and 55° and introduced through the anteromedial portal under direct visualization. The scope can be placed either via posteromedial or posterolateral access allowing an optimal visualization of the posterior area (Fig. 1.5). Care is taken in order to position the tibial tunnel exit within the area of AL bundle attachment in order

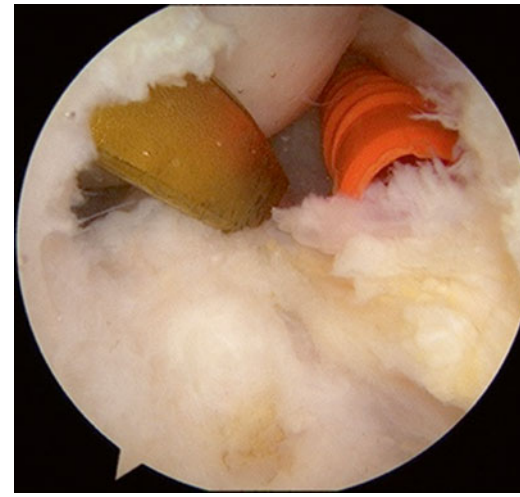

Fig. 1.4 Arthroscopic view of the transeptal approach. Scope is through posterolateral portal controlling the tibial guide placement. The cannula in the posteromedial portal allows using any additional tool to help this step

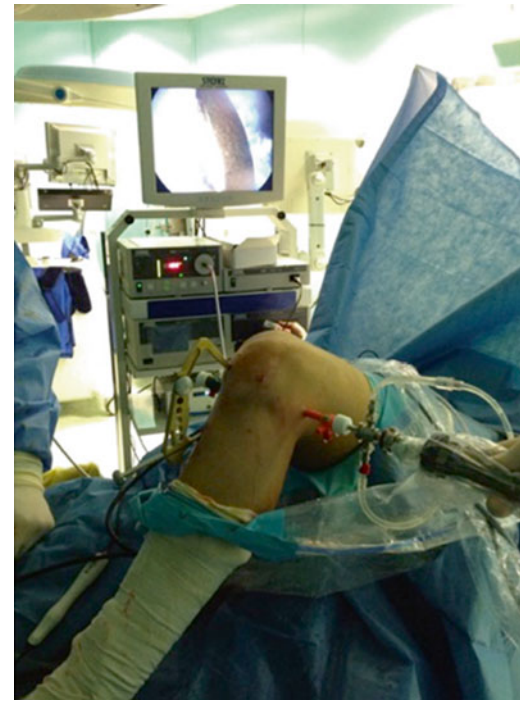

Fig. 1.5 External view of the tibial tunnel preparation by using the transeptal approach. The scope is introduced through the posterolateral portal, while the tibial guides (visible on the screen) through the anteromedial portal

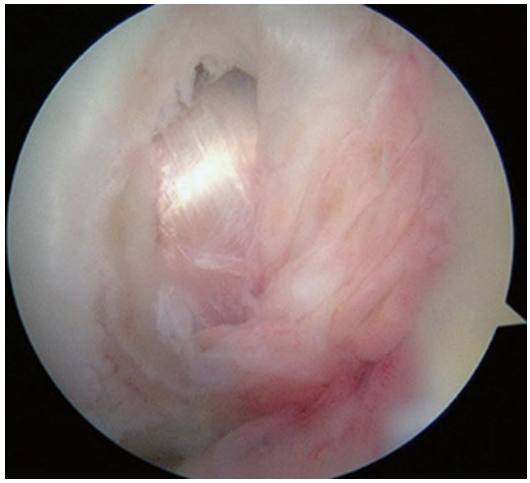

Fig. 1.6 Arthroscopic final view of the femoral PCL tunnel, with graft already fixed. Note the high position of the graft, resembling the Al bundle, with preservation of both the Humphrey's ligament and the PM bundle

to preserve the highest number possible of PM fibers. Then placing the scope through the anterolateral access, the PCL femoral stump is debrided and the femoral tunnel can be drilled either using an outside-in or inside-out technique. Here, great care should be used to preserve the posteromedial (PM) bundle and the meniscofemoral ligament insertion (Fig. 1.6). The graft is pulled through the tibial tunnel, over the posterior aspect of the tibial plateau, and into the femoral tunnel using a looped 18-gauge wire or graft passer.

A blunt trocar introduced through the PM portal can be helpful in assisting the progression of the graft. When using a graft with a bone block, it is advisable to keep it on the tibial tunnel, where the bone density is considerably less than in the femoral tunnel, allowing a stronger fixation and a faster healing process.

Before final fixation, the graft should be preconditioned to minimize elongation; this is accomplished by passively moving the knee through its full range of motion several times while applying tension (10 lb) to the unfixed end of the graft. During fixation of the AL graft (for both the single- and double-bundle techniques), the knee is held in 70–90° of flexion, and an anterior drawer force is applied to recover the normal step-off between the medial femoral condyle and the medial tibial plateau.

1.3.2 Inlay Technique

The inlay technique for PCL reconstruction was first described in Europe by Thomann and Gaechter in 1994 [9] and later popularized in the USA. This technique originally designed to provide anatomic reconstruction of the AL can reproduce the two ligament bundles of the PCL by splitting one tail of the graft.

The technique requires an open posterior approach to the knee, which allows the direct fixation of a bone plug graft complex (patella tendon, Achilles tendon) to a unicortical bone trough at the anatomic site of tibial PCL insertion. This fixation, theoretically, should avoid the sharp angle of the graft observed at the proximal margin of tibial tunnel in the more traditional transtibial technique.

For the inlay technique, the patient is either positioned in the lateral decubitus position (injured leg up) for the entire procedure or requires intraoperative repositioning from a supine to a prone position. These two options for positioning allow access to the anterior and posterior aspects of the knee. In the lateral decubitus position, the hip is abducted and externally rotated, and the knee is flexed to 90° during anterior arthroscopy, graft harvest, and arthroscopic drilling of the femoral tunnel. Following anterior arthroscopy, the knee must be fully extended and slightly abducted to achieve adequate exposure for the posterior approach. If anterior arthroscopy is performed while the patient is supine, the patient must be turned prone intraoperatively to achieve adequate exposure for the posterior approach to the knee. Femoral tunnel is drilled during anterior arthroscopy as described above. A looped 18-gauge wire or graft passer, that is later used to pass the graft, is then placed through the femoral tunnel into the joint. The injured leg of the patient is then repositioned in preparation for the posterior approach.

The posterior approach used in the tibial inlay technique involves an oblique incision lateral to the medial gastrocnemius muscle as described by Burks and Schaffer [10]. The deep fascia of the medial gastrocnemius muscle is incised vertically, parallel to the direction of the muscle fibers. Attention must be paid to the sural nerve, which

runs between the medial head of the gastrocnemius muscle and the semimembranosus tendon.

The head of the medial gastrocnemius muscle is incised and retracted laterally along with the neurovascular structures of the popliteal region. A vertical incision is made in the posterior capsule to expose the site of tibial PCL insertion. A unicortical bone block is removed at the tibial PCL insertion site to create a trough that will accommodate the bone plug of the graft. The bone plug of the graft is placed in the trough and fixed with a 6.5-mm cancellous screw and washer. Using the Ethibond sutures attached to the tendinous end of the graft and the prepositioned looped 18-gauge wire, the graft is passed through the femoral tunnel and fixed.

It remains unclear whether the anatomic fixation of the PCL graft achieved by the inlay technique is more efficacious than the traditional transtibial technique in restoring normal knee biomechanics. Either biomechanical or clinical studies have failed to show significant difference in knee stability when comparing the two surgical techniques. More recently in order to combine the effectiveness of an arthroscopic procedure with the advantage of a direct fixation, a full arthroscopic inlay procedure has been described addressing both the tibial side and the femoral side by Margheritini and Mariani [11, 12]. This technique involves the fixation of the bone block either on the tibial or femoral side by using a full arthroscopic technique. The bone block is placed in the desired position after preparing an adequate slot and fixed by using transosseous suture on a metallic button placed on the medial femoral condyle/anterior tibial border. Despite the enthusiastic early reports, mid- and long-term clinical studies are lacking, restricting the use of this technique to selected cases.

1.4 Conservative Treatment of PCL Injuries

Robert La Prade

The PCL has been reported to have intrinsic healing ability. As a result, acute, isolated PCL tears can often be successfully treated with nonoperative management. A biomechanical study by Kennedy et al. [13] demonstrated that isolated PCL injuries that involve a tear to only one of the bundles result in minimally increased posterior tibial translation (<3 mm) throughout range of motion. This may explain why acute partial tears have a good prognosis with nonoperative management. However, PCL tears that are chronic or involve concomitant ligament injuries to the effected knee have been reported to have improved outcomes with operative management. Posterior stress radiographs are essential to objectively aid in the diagnosis of PCL injury and can be used to distinguish between partial, complete, and associated multiligament injuries. With the use of a standardized posterior force, posterior stress radiographs have repeatedly demonstrated reliable reproduction and objective assessment of posterior tibial translation. Recently, the use of a brace that applies a constant or dynamic anterior force to the posterior proximal tibia has been advocated for treatment of isolated PCL injuries [14].

1.4.1 Conservative Treatment

Studies have reported a range of outcomes with nonoperative management of PCL tears. However, a recent review by LaPrade et al. [5] reported a consistent finding across studies to be that PCL tears with associated ligament injuries resulted in worse outcomes when treated nonoperatively. Torg et al. [15] reported that isolated PCL tears treated conservatively had favorable outcomes at a mean 5.7-year follow-up. The same study reported on nonoperative treatment of PCL tears with concurrent ligament injury and found significantly higher incidences of osteoarthritic progression and fair or poor functional outcomes. Other studies on isolated acute PCL tears treated conservatively reported a healed appearance of the PCL on magnetic resonance imaging (MRI) at 1.7 and 2.6 years after the injury; however, subjective outcome scores in both studies were less than satisfactory. Authors concluded that this discrepancy

between imaging and subjective outcomes was the result of attenuated healing of the PCL. Patel et al. [16] and Shelbourne et al. [17] followed patients with isolated PCL tears treated conservatively and reported radiographic evidence of arthritic changes in 23 % of patients at 7-year follow-up and 41 % at 14-year follow-up, respectively. Of note, only 11 % of patients in the study by Shelbourne et al. had moderate to severe OA, and the majority had full range of motion, good subjective outcome scores, and strength that was nearly equal (97 %) to the uninjured leg.

Braces that apply an anteriorly directed force to the proximal tibia have been proposed to support PCL healing be reducing the tibia to its anatomical location, thereby minimizing PCL elongation. Jacobi et al. [18] reported on a static anterior drawer brace (PCL-Jack brace, Albrecht GmbH, Stephanskirchen, Germany) used for 4 months in patients with isolated acute PCL tears. At 6 months after the injury, the investigators reported restoration of PCL continuity in 95 % of patients based on MRI and significantly reduced posterior tibial sag from initial clinic visit (7.1 mm) to follow-up at 12 and 24 months (2.3 and 3.2 mm, respectively). However, decreases in Lysholm scores reported at 12 and 24 months were clinically insignificant. A study by Janson et al. [19] on PCL bracing recommended that to best support the PCL-deficient knee, braces should apply dynamic forces to the knee joint that replicate the anatomic forces applied by the native PCL. It has been documented that these forces are dependent on the degree of knee flexion, and the maximal force and elongation occurring between 90 and 120°, and decreasing with extension. As a result, LaPrade et al. [14] compared the use of a static (PCL-Jack brace, Albrecht GmbH, Stephanskirchen, Germany) versus a dynamic (Rebound PCL, Össur Inc., Foothill Ranch, CA, USA) anterior drawer brace for the treatment of isolated acute PCL injuries. They reported that the dynamic force brace applied significantly larger forces to the proximal posterior tibia at higher flexion angles compared to the static force brace.

1.4.2 Future Treatment Options

PCL bracing has recently gained popularity. However, further clinical studies are necessary to determine long-term outcomes. Specifically, there is a need for high-quality studies of the dynamic force brace to determine whether the loading characteristics of this brace, which more closely replicated the in situ loading profile of the native PCL, will result in long-term improved posterior knee laxity following isolated acute PCL injury.

Finally we can summarize that the PCL has intrinsic healing ability. Conservative treatment is best reserved for acute isolated PCL injuries. The use of an anterior drawer brace to reduce the tibia to its anatomical position may help decrease posterior tibial laxity.

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Biceps Tendinopathy (ICL 2)

2

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2.1 Variations of the Intra-articular Portion of the Biceps Tendon: A Classification of Embryologically Explained Variations

The long head of the biceps is the common entry landmark when starting a shoulder arthroscopy. Sometimes it may be tricky to differentiate between normal biceps, an innocent congenital variant and a pathological tendon.

Out of two populations of 1,500 arthroscopies each, we collected, in a prospective and retrospective way, all possible variations of the proximal portion of the LHB. The embryology and the evolution of this tendon were reviewed.

We correlated the findings of these 3,000 arthroscopies to this embryology and included 57 cases, or 1.91 % of this population, to define a classification of 12 different form variants.

Their incidences and associated pathologies are investigated.

By offering this new classification; and a physiopathological hypothesis, we hope to help the surgeon in differentiating and addressing some of these variants that can acquire a pathological significance:

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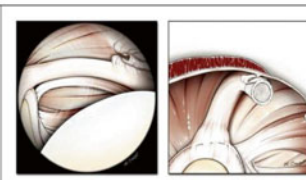
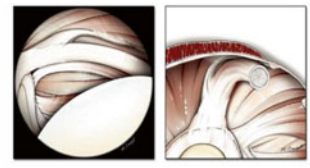
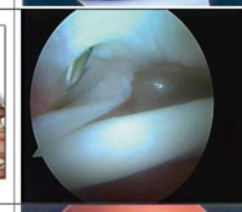
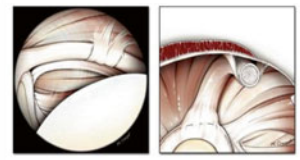
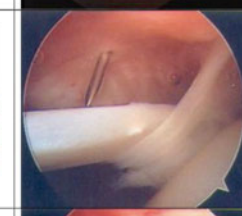
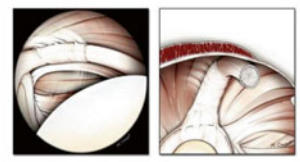
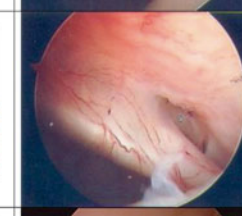
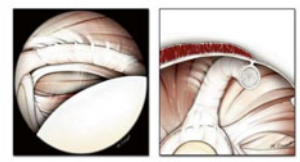
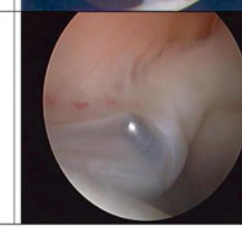
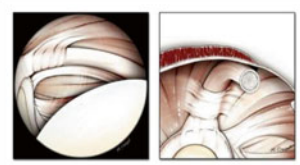
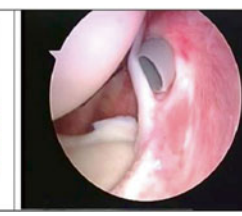
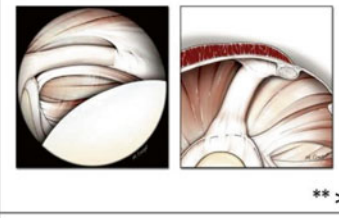
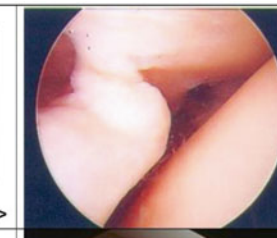
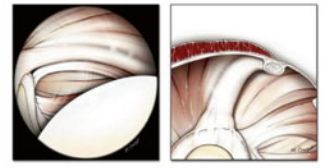
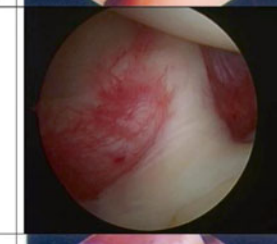
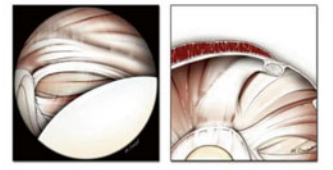
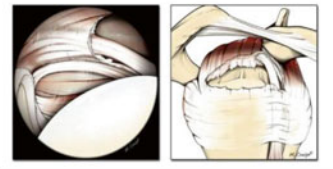
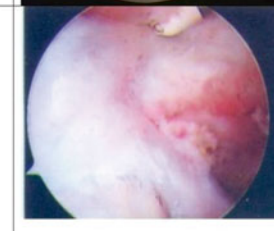
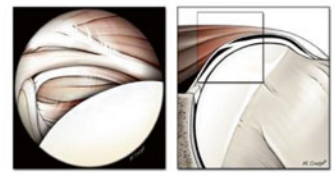
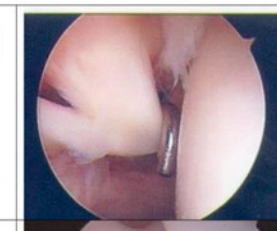
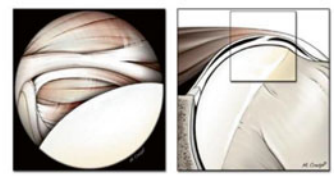
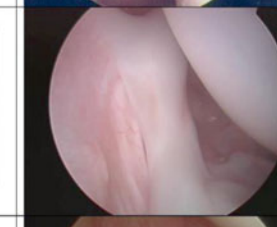
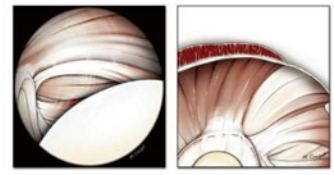
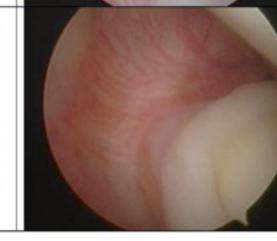
- The partial mesotenon can cause biceps-related complaints.
- The partial lateral adhesion can cause an hour-glass type of impingement, whereas the complete adherent or solid fusion of the LHB tendon to the inferior surface of the capsule (with extension to the upper labrum) can have an associated rotator cuff tear.
- The double-origin biceps and the strong medial adhesion of the biceps to the capsule, which may behave like a double origin, certainly can cause pathology.

Table: Classification: 12 Types Of Variations of the IA LHB, Dierickx & Castagna

	Type	% 57 pts	Illustrations by ©Crespi	Arthroscopic Examples
MESO	**Mesothenon**			
MESO-VI	**A. Vinculae**	7.0%		
MESO-SB	**B. Small Bands**	8.8%		
MESO-PU	**C. Pulley-like slings**	17.5%		
MESO-PA	**D. Partial Mesothenon-**	7.0 %		
MESO-CO	**E. Complete Mesothenon**	10.5 %		
ADH	**ADHERENT**			
ADH-PM	**A. Partially medially adherent to the SSP**	10.5 % *		

ADH-PL	**B. Partially laterally adherent to the SSP**	5.3 %	 ** >	
ADH-CL	**C. Complete adherent; attaching to the Labum**	8.8 % *		
ADH-CO	**D / Complete adherent to SSP; NOT attaching to the labrum**	1.7 %	 	
SPL	**SPLIT BICEPS**			
SPL-DO	**A. Split biceps Double – origin**	15.8 %		
SPL-RE	**B. Split biceps Reversed type**	3.5 % *		
ABS	**complete Absence of LHB**	3.5 % *		

2.2 Clinical Examination in Biceps Tendinopathy

Disorders of the long head of biceps tendon (LHB) are common in adult population with a overall incidence of between 29 % and 66 % [1–3]; they are associated with rotator cuff tears in up to 90 % of cases [4, 5], but in 4 % of patients, an isolated LHB lesion is reported [6].

The clinical diagnosis of LHB pathologies, however, is difficult and poorly reliable because most of the traditional clinical tests show a relatively high sensitivity but a poor specificity and a low level of positive predictive value [1, 7, 8].

The physical examination includes biceps palpation, Speed's test, O'Brien test, the upper cut test and BRF test.

The examiner with the biceps palpation researches the eliciting point of tenderness of the LHB. It consists in palpation of biceps tendon in the biceps groove 3–6 cm below the anterior acromion with the arm in 10° of internal rotation. If the patient complains pain during deep pressure in the bicipital groove, the test is positive [9].

Speed's test is performed with the patient standing with the shoulder elevated to 90° in maximal supination and the elbow extended; the patient is asked to resist the downward force applied to his/her palm by the examiner. The test is considered positive when patient reports pain in the bicipital groove area [7].

O'Brien test is performed with the examiner behind the patient. The patient is asked to resist a downward pressure with the arm at 90° of flexion and 10° of adduction in full pronation (thumb down). The manoeuvre is repeated with the limb in full supination (thumb up). The test is positive if the pain triggered in the first position decreases or disappears with the second manoeuvre [8].

Two new tests are recently described for the lesion of LHB: the upper cut test and the BRF test.

The upper cut test is performed with the shoulder in neutral position, the elbow flexed at 90° and the hand supinated making a fist. The patient is asked to bring the hand up and towards the chin in a boxing-style punch while the examiner places his hand over the patient's fist and contrasts the motion. The test is positive if the patient has pain [10].

In the BRF test, the patient is seated with the arm at the side and the elbow flexed at 90°. The patient is asked to maintain maximal resistance for 5 s, and the BRF strength is recorded with a digital dynamometer linked to the ground [11].

Tenderness on palpation of the biceps tendon is not considered a reliable test for biceps tendon injury. In fact, Gill et al. reported a sensitivity of 53 % and a specificity of 54 % [12]. Their results are consistent with the observations of Nove-Josserand and Walch [13].

The Speed's test shows slightly better results with a sensitivity of 90–67 % and a specificity of 13.8–50 % [7, 12].

The O'Brien test is also limited, showing 38–68 % of sensitivity and 46–61 % specificity [10, 12].

The new tests, upper cut and BRF, show more reliability with sensitivity and specificity values of 77 % and 80 %, respectively, for the upper cut test versus 60 % and 88 % for the BRF [10, 11].

BRF test presents a high specificity probably because it is performed with the arm at the patient's side reducing pain due to concomitant rotator cuff tears. Moreover, since the BRF test is objectively measured by a digital dynamometer, there is less risk of subjective interpretation between observers.

2.3 SLAP Lesions

2.3.1 Pathology

SLAP lesions are combined lesions from the superior (from anterior to posterior) labrum and the proximal insertion of the long head of biceps. The Snyder classification is most commonly used:

Type 1: Degenerative lesion with fraying of the free edge of the labrum but the insertion to the glenoid is unaffected.

Type 2: Labrum and LHB are torn off the glenoid edge. There is no cartilage under the avulsion area and the labral-bicipital complex is highly mobile.
Type 3: Bucket handle tear of the labrum, no interference of the LHB.
Type 4: Type 2 extending into the LHB, often associated with a labral tear.
Types 5–10 are combinations of SLAP lesions with different anterior and posterior labral lesions.

SLAP lesions are considered instability lesions but can also have a degenerative origin.

Traumatic causes as compression injuries (fall on outstretched hand) or traction injuries (hyperextension trauma), repetitive throwing or other overhead motions are typically associated with type 2 and type 4 lesions.

Type 1 lesions are degenerative and often associated with degenerative rotator cuff disease (74 % of patients with rotator cuff tears have biceps lesions often SLAP, and in 40 % of SLAP lesions, there is also a full-thickness RCT). Type 2 lesions differ according to age: in patients over 40 years old, it concerns often a degenerative lesion, whereas under 40 often associated with instability. Type 3 lesions are seldom and can be traumatic or degenerative.

2.3.2 Symptoms

Any pathology of the proximal biceps can present with pain. The pain pattern produced by SLAP lesions is unspecific, and many coexisting lesions exist. Sometimes SLAP lesions elicit a clicking sensation inside the joint. The extent of pathology and inflammation of the biceps distally might influence your decision for treatment. Pain in the bicipital groove radiating to the anterolateral upper arm is suspicious for biceps pathology. On palpation of the groove, the pain can move externally with the rotation and can extend under the level of the insertion of the pectoralis major. Pain can be elicited by internally and externally rotating the arm both in adduction and abduction, and the Gerber test is often painful.

2.3.3 Diagnosis

Many tests are described; some of them have a reasonable specificity but low sensitivity, and because of the overlap with other pathology, careful interpretation is necessary. An accurate method of diagnosing biceps pathology remains undefined. MR arthrogram or CT arthrogram offers on average around 70 % accuracy for SLAP tears but can show associated pathology as cuff tears or labral tears. The definitive diagnosis of a SLAP lesion is often only made at the time of surgery.

2.3.4 Treatment

Options are debridement, SLAP repair or biceps tenodesis or tenotomy. The success rate of the arthroscopic anchor suture repair varies, and on average patient satisfaction is 83 %, with return to sports of 73 %. Residual postoperative pain and stiffness are major concerns, in particular in patients over 40 years of age. The different tissue quality and capacity for tissue repair are possible causes of the failure of healing in this older age group. Tenodesis of the biceps can offer a higher satisfaction rate and return to sports level. Different techniques for tenodesis are described with different results in load to failure. Interference screws seem to have a higher load to failure compared to keyhole, bone tunnels and suture anchors. Interference screws have several advantages: maintaining the proper length to tension relationship of the biceps, the secure fixation allows early rehabilitation and the possibility of resection of a large part of inflamed tendon, and the procedure can be done all arthroscopic. Complications however are persistent pain in the groove, possibly related to small stress fractures, or failure of fixation due to degeneration of the biceps tendon and can be deleterious as in complete humeral shaft fractures. Other techniques as anchor of soft tissue tenodesis, or transfer of the LHB to the conjoined tendon, can be performed arthroscopically with satisfying results.

2.3.5 Conclusion

Our preferred treatment:

SLAP 1: Debridement
SLAP 2: Indications for SLAP repair: highly active (throwers)
- Age under 40
- Isolated lesion or in combination with labral tears
- No distal biceps pathology

CAVE: Stiffness has been a major complication; therefore, inform patient about possible failure and secondary tenodesis
Indications for LHB tenodesis (or tenotomy):
- Age over 40
- Advanced tears in biceps tendon
- Pulley lesions in associated cuff tears

SLAP 3: Debridement
SLAP 4: Repair or tenodesis

2.4 Proximal Biceps Tendinopathy in Elite Athletes, Associated Pathology and Treatment Protocol

Anterior shoulder pain is one of the most frequent causes of disability in overhead sports [16] and often forces athletes and workers to stop their activities.

The underlying pathology can be multifactorial in nature, and understanding the various contributing factors is important if the patient is to be properly treated and rehabilitated. An additional goal should be the prevention of further pathology or symptoms.

The overhead sports most commonly involved are throwing sports such as baseball, tennis and volleyball [27, 29, 30]. However, non-throwing sports including swimming and windsurf have also been shown to produce pathological conditions of the shoulder [15, 20, 21, 25, 37].

Technical deficiencies along with overuse and overload are the most important related factors. As a consequence, the athletes tend to suffer adaptive and pathologic changes that should be taken into account such as biceps tendonitis-tenosynovitis, GIRD and scapular dyskinesis [15, 33, 43].

In our sport-specific orthopaedic practice, the athlete is typically referred because of pain about the shoulder. Usually the diagnosis of the referral is sub-acromial impingement. A common occurrence in these patients is that evaluation of the axial skeleton's dynamics is overlooked. We have observed a recurring combination of signs and symptoms that are linked to shoulder pain in athletes. These observations will be discussed in this article.

Bearing in mind the possibilities of biceps tendinopathy (Fig. 2.1), scapular dyskinesis (Fig. 2.2a–c) and glenohumeral internal rotation deficit (GIRD) (Fig. 2.3) among the spectrum of shoulder pathologies throughout the evaluation of the disabled athlete may be of great help in planning both the protocol of treatment and prevention of recurrence.

It is important to emphasize that neither biceps pathology, GIRD nor scapular dyskinesis is rarely the cause of referral and is usually encountered only through physical evaluation [42, 44].

The use of the ultrasound machine by the orthopaedic surgeon to help and confirm biceps tenosynovitis (Fig. 2.4) or tendinosis is of paramount importance. It allows an immediate diagnosis and, if needed, injection under ultrasound guidance intra-seath but not in the tendon.

Conservative treatment of dyskinesis and GIRD by means of physiotherapy has shown to be effective in terms of return to sports and workplace activities [26, 27, 28, 29, 33, 35].

Unfortunately, in some cases the patient presents to the clinic too late for conservative treatment, and surgery may be needed to treat the underlying pathology [31, 38, 39]. Favourable results may still be obtained if the pathophysiology is fully evaluated and understood [15, 22, 23, 24, 34, 36, 40].

A holistic/comprehensive approach to the athlete's shoulder is advisable to correctly diagnose, treat and prevent these conditions.

In this article these concepts are reviewed along with the related pathology and our observations.

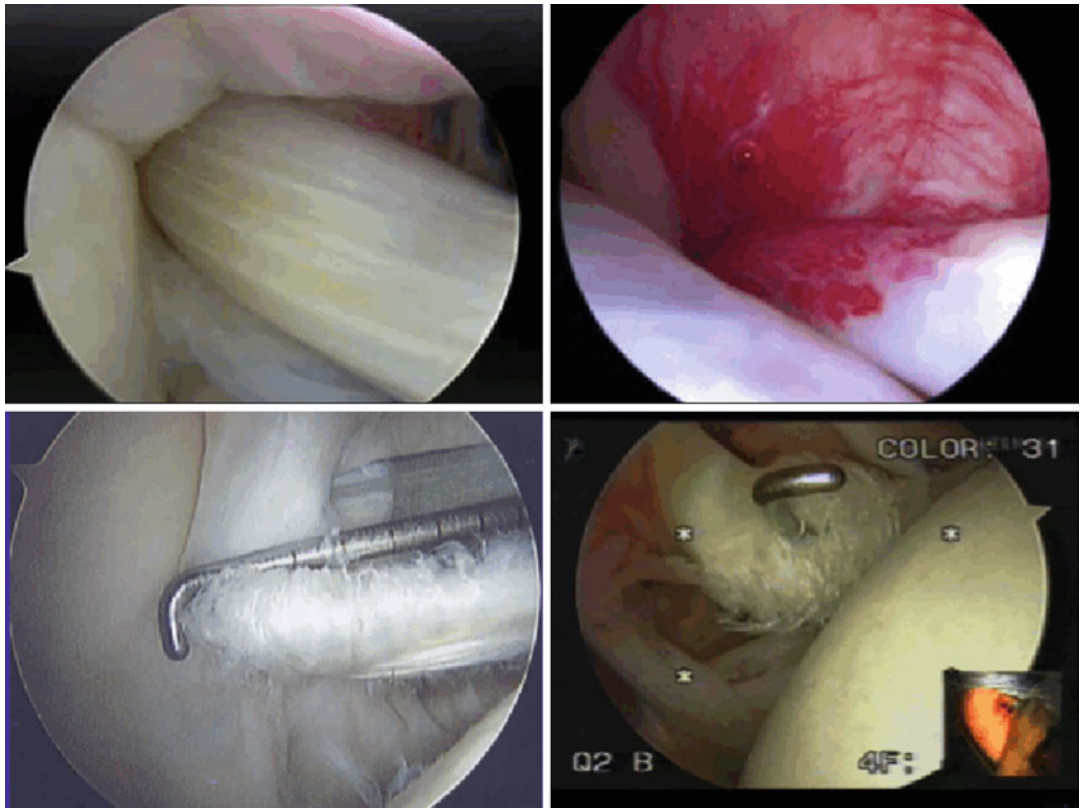


Fig. 2.1 Normal biceps tendnon (*upper row left*), Biceps tendinitis (*upper row right*), Biceps instability and degenerative partial tear of the tendon (*lower row*)

2.4.1 Tennis Shoulder: Biceps Tenderness + Dyskinesis + GIRD

2.4.1.1 Conservative Treatment

The sport of tennis enjoys worldwide popularity among participants of extremely diverse age and skill range.

The most common injuries in recreational players afflict the lower extremity such as ankle sprains, but in those athletes who have reached the elite level, the most frequent pathology involves the shoulder [14].

In our experience, elite players with symptomatic shoulders typically localize the pain anteriorly [33]. It is not uncommon for these athletes to be referred with the diagnosis of sub-acromial impingement [40]. Although it has been published that tennis players suffer a decrease in their sub-acromial space compared to matched controls by ultrasound [41], in our practice we have observed that this pain mainly emanates from the long head of the biceps, both with simple palpation and during ultrasound evaluation [33].

Additionally, a symptomatic long head of biceps is very commonly associated with dyskinesis and glenohumeral internal rotation deficit (GIRD) [33].

We studied 105 elite tennis players in 3 international professional championship tournaments. The study consisted of 210 shoulders in 76 males and 29 females. The mean age was 21.7 ± 4.9 years, mean height 178 ± 8 cm, mean weight 72.2 ± 9 kg and mean tennis hours played per week 19.4 ± 4.9 h. Ranking range was ATP 56–1.600 and WTA 102–1.100. Physical

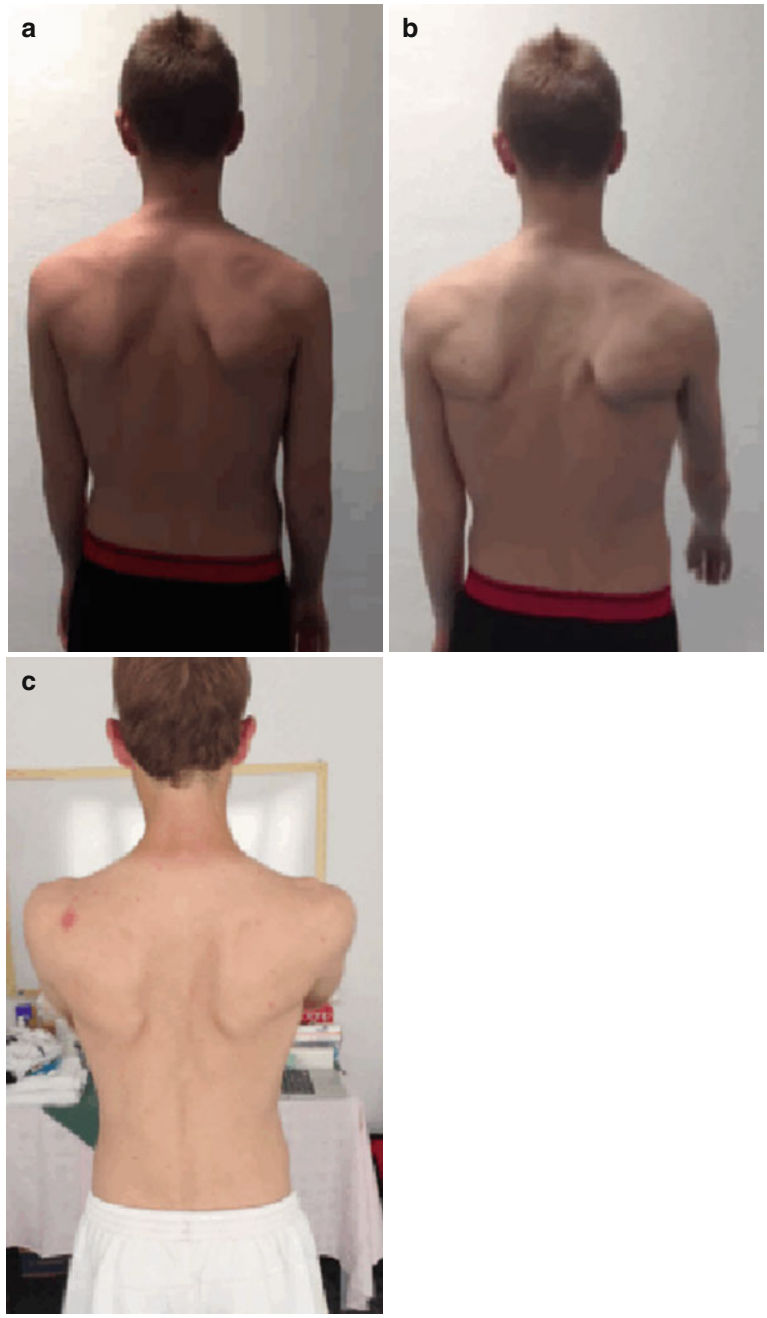


Fig. 2.2 (**a**–**c**) Assessment of the scapula kinesia during shoulder motion. One should look for symmetry or asymmetry of the shoulder blades during motion

Fig. 2.3 Glenohumeral internal rotation deficit (GIRD). The patient is unable to bring the arm into the horizontal position

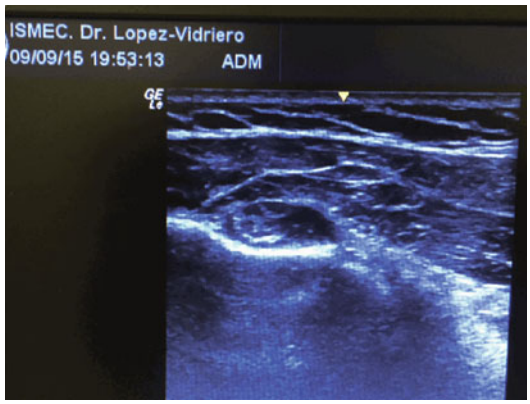


Fig. 2.4 Ultrasound of the shoulder. The probe is positioned perpendicular to the orientaion of the biceps sulcus. A black circle around the biceps tendon, called "Halo-phenomenon" typical for biceps tendinitis

evaluation with a goniometer (Fig. 2.3) and ultrasound measurements were taken.

We found that 34 % of these players exhibited tenderness in the LHB of their dominant arm (Fig. 2.5). Also, 91.3 % had scapular dyskinesis in the dominant arm as well as 90.3 % in the non-dominant arm (Fig. 2.6). The prevalence of GIRD in the dominant arm was 83.5 %.

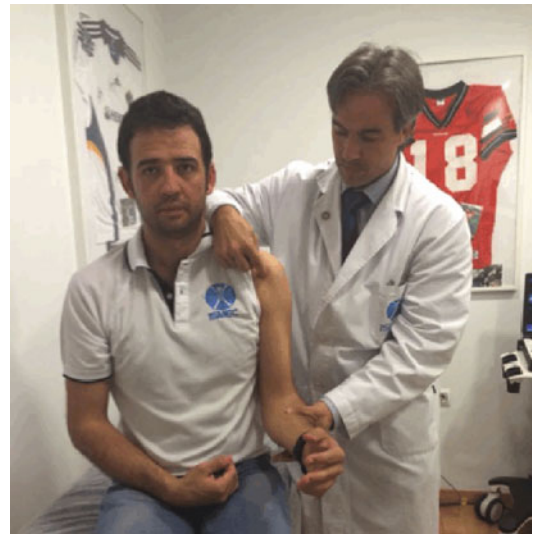


Fig. 2.5 Examination of the biceps tendon. Point of tenderness is exactly over the biceps sulcus during pronation and suppination of the forearm

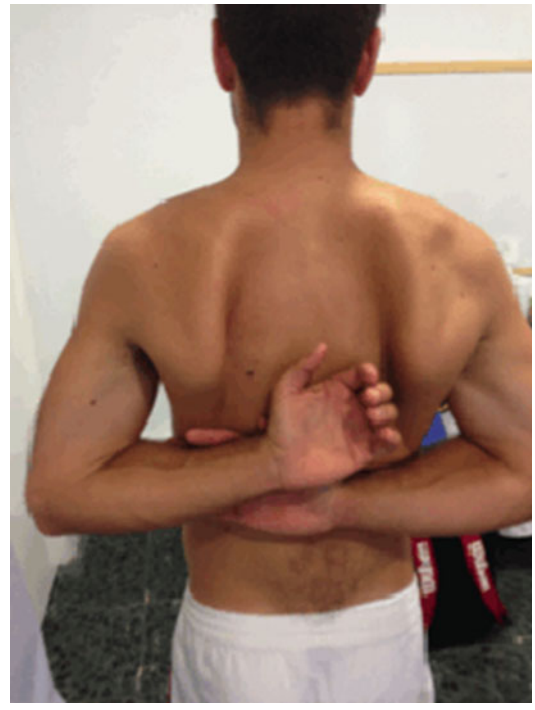


Fig. 2.6 Bilateral scapula alata is caused by muscle dysfunction in case of paralysis of the serratus anterior muscle, rhomboideus muscle or trapezius muscle

Finally, the association of GIRD and dyskinesis in the dominant arm was 75.7 %, while the association of GIRD + dyskinesis + tenderness on LHB was 24.3 %.

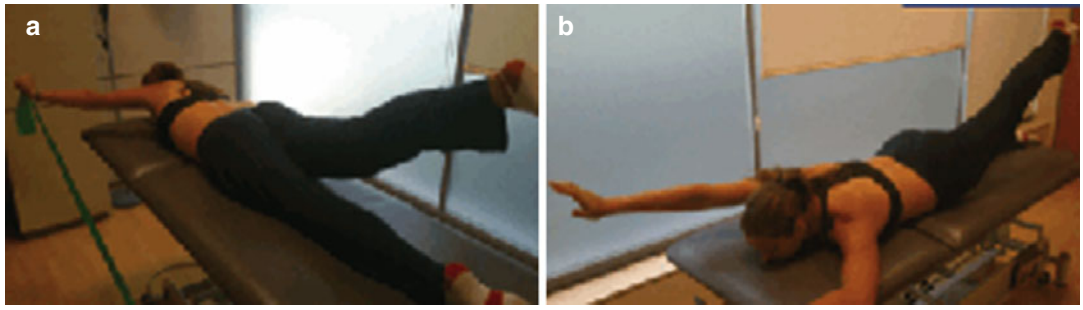


Fig. 2.7 (**a**, **b**) Cross Chain kinetic exercises according to Anne Cool [19]

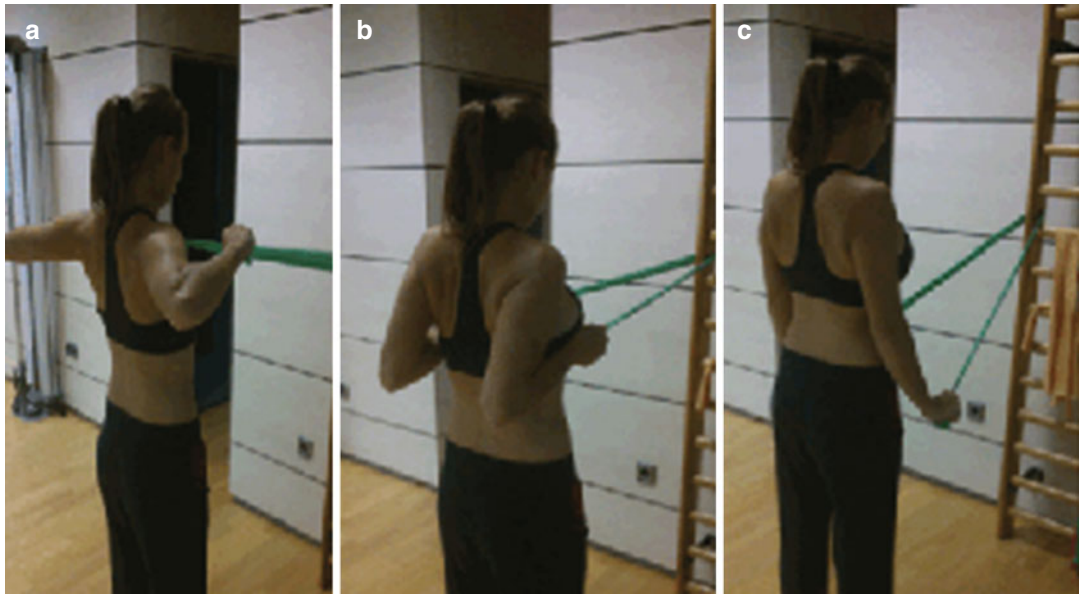


Fig. 2.8 (**a**–**c**) Periscapula muscle strengthening exercise using the TERA® ribbon

A higher frequency of dyskinesis has been reported in throwing athletes [29] and tennis players [41].

Altered dynamics of scapular motion in tennis players is a commonly occurring phenomenon. In our study we found that around 90 % of elite tennis players experienced the problem in one or both shoulders. Such a prevalent condition in these training intensive athletes is likely to be due to overload or fatigue. Errors in technique may also be involved. This same alteration in motion could also lead to further pathology, although at present it has not been reported.

It has been published that amateur tennis players suffer from GIRD more frequently on the dominant side compared to the non-dominant shoulder [43].

In our study we observed that this internal rotation deficit occurs in both shoulders although it is more severe in the dominant arm. This could be explained by the use of both arms for the backhand [33].

Whether these two conditions, dyskinesis and GIRD, are pathologic or adaptive is not known. But in our experience, when overhead athletes are treated by means of directed physiotherapy, the anterior shoulder pain is oftentimes completely alleviated [32, 33].

Our physiotherapeutic approach to the tennis player's shoulder is based on these findings.

Fig. 2.9 Stretching of the posterior capsule in order to treat the internal rotation deficit

Fig. 2.10 The patients lies in the lateral position on the affected shoulder as also shown in Fig. 2.9. The healthy contralateral arm presses the affected forarm onto the stretcher.

In terms of dyskinesis, we follow Anne Cools' approach [19], based on cross-chain kinetic exercises (Fig. 2.7), parascapular muscle strengthening (Fig. 2.8) and stiff structures stretching.

If GIRD is associated, which most often is the case, we use the baseball sleeper's stretch in the lateral decubitus position (Fig. 2.9), but we ask our patients to perform the exercise at least five times a day for at least 5 min. It is crucial to emphasize the importance of stretching the posterior capsule by leaning on the shoulder correctly (Fig. 2.10). At least once a day they visit the physiotherapist to work in a personalized manner [32].

Normally, the incapacitating pathology in the tennis player is pain from the long head of the biceps (LHB), which prevents them from serving, as well as creating difficulty with the volley and forehand. It is therefore important to emphasize to the player the need to treat the underlying condition. Our treatment protocol consists in injecting, under ultrasound guidance, 3 ml of a solution of 10 % diluted corticoid (1 ml = 40 mg triamcinolone acetate) mixed with 9 ml of local anaesthetic (4.5 ml lidocaine 2 % + 4.5 ml bupivacaine 0.5 %) in the biceps sheath. The use of the ultrasound is of critical importance because it allows for accurate injection within the sheath while avoiding injection in the biceps tendon itself (Fig. 2.11).

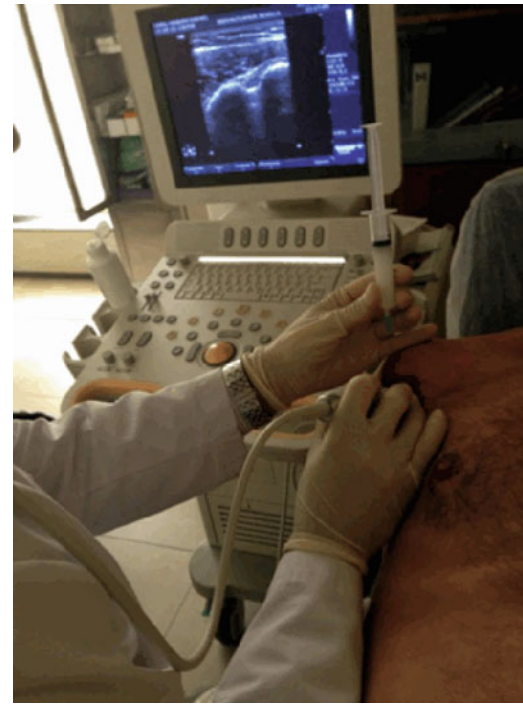


Fig. 2.11 Ultrasound guided injection into the sulcus of the biceps tendon

Although not obligatory, this injection is useful as a diagnostic tool and also allows the tennis player to begin the physiotherapy protocol sooner.

Therapy consists of manual transverse massage on the LHB, eccentric exercises, radial shock wave therapy and galvanic current injection with acupuncture needles (EPI) in the tendon when needed.

By treating our athletes with this protocol, we have shown in a pilot study that they may be pain-free and back to competition in about a month [32, 33].

In summary, the most important observation we have made when a tennis player comes referred for or complaining about anterior shoul-

der pain, the shoulder rotation and the dynamics of both scapulae should be assessed.

If there is an alteration in any of these factors, a holistic approach with directed physiotherapy is effective in treating the pain and pathology.

Based on Anne Cools' studies [19] and on our practice, we have developed a physiotherapeutic protocol.

It is divided into three phases:

Conscious muscle control
Muscle control and strength necessary for daily activities
Advance control during sports movements

2.4.2 Phase 1: Conscious Muscle Control

During this first phase, the objective is to gain conscious muscle control.

The most physiologic way to it is with the exercises that involve closed-chain activities (scapular clock), which are elevation, depression and retraction/protaction exercises with the hand on a wall. Each exercise should be repeated on 3 series of 15 repetitions each.

2.4.3 Phase 2: Muscle Control and Strength Necessary for Daily Activities

Once muscle balance is restored, the patient should start general scapular strengthening exercises.

Elastic bands are recommended to perform these exercises that consist on:

Closed-chain exercises and eccentric exercises for biceps.

For posterior capsule stretching: sleeper stretch and cross-body stretch exercises (Figs. 2.9 and 2.10).

For the scapular dyskinesis, cross-kinetic chain exercises are instructed with elastic bands in the prone position elevating one arm and the contralateral leg at the same time (Figs. 2.7 and 2.8).

Closed-chain exercises are believed to improve dynamic glenohumeral stability through stimulation of the intra-articular and periarticular proprioceptors and enhance co-contraction of the rotator cuff, thus being beneficial in case of shoulder instability [18].

2.4.4 Phase 3: Advance Control During Sports Movements

During this last stage of muscle control and strength, special attention should be paid to integrate kinetic chain into the exercise programme and implement sport-specific demands by performing plyometric and eccentric exercises, such as back push-ups or push-ups in parallel bars and on the floor.

Throwing athletes should perform eccentric exercises for external rotators with weight balls and elastic resistance tubing.

Swimmers on the other hand should focus on core stability exercises doing exercises such as W-V exercises, in which the patient is prone on a Swiss ball and perform movements, forming a W and a V with his arms [17].

In our experience, the described protocol was very effective in a pilot study [32] of patients, and they were able to return to their former occupation and sportive activities in a month and almost without any pain.

2.5 Arthroscopic Knotless Suprapectoral Tenodesis of the Long Head of Biceps: Clinical and Structural Results

2.5.1 Purpose

The purpose of this study was to evaluate the clinical, cosmetic and structural results of arthroscopic suprapectoral knotless epiosseous tenodesis of the long head of biceps.

2.5.2 Methods

Forty-nine patients (16 women, 33 men; mean age 58; mean follow-up 36.4 months (range

24–57 months)), in whom a tenodesis of the long biceps tendon (LHB) has been performed, were included into this study. The clinical evaluation included the constant score as well as the LHB score. In addition elbow flexion and supination strength were assessed. The integrity of the tenodesis construct was evaluated indirectly by sonographic detection of the LHB in the bicipital groove.

2.5.3 Results

The overall constant score did not reveal any significant differences comparing both sides (mean, 86 ± 19 points vs. 89 ± 16 points (n.s.). The mean LHB score reached 88.3 points (range, 54–100 points). Thirty-four patients (69.4 %) presented an examiner-dependent upper arm deformity although only 3 patients (6.1 %) confirmed a subjective cosmetic deformity.

Both flexion and supination strengths were significantly decreased compared to the non-operated side ($p < 0.05$). In five patients (10.2 %), it was not possible to verify the LHB sonographically in the bicipital groove. Therefore, the biceps tenodesis was classified as a failure.

2.5.4 Conclusion

The arthroscopic suprapectoral epiosseous knotless tenodesis of the LHB provides good functional results. The high rate of examiner-dependent upper arm deformities can be explained by a non-physiological situation of the primary length-tension relationship or an elongation of the tendon after fixation.

Take-Home Massage

- When a patient is referred with anterior shoulder pain, the physician should rule out biceps tendinosis or tenosynovitis as the main diagnosis. Also, the dynamics of the scapular movement and the range of motion of the glenohumeral joint should be evaluated and treated if altered.
- Tennis players usually present with LHB tenderness in combination with dyskinesis and GIRD.
- Conservative comprehensive physiotherapy treating all the pathologic entities is effective.
- In terms of biceps tenosynovitis, our protocol with injection under ultrasound guidance, manual transverse massage on the LHB, eccentric exercises, radial shock wave therapy and galvanic current injection with acupuncture needles (EPI) in the tendon when needed is useful.
- In terms of scapular dyskinesis, most of the time, conservative treatment based on conscious parascapular muscle control, strengthening and advance performance during daily life and sport-specific tasks is useful
- For GIRD, physiotherapy based on stretching the posterior capsule by means of physiotherapist and home exercises is advised.
- There is still no consensus on the ideal treatment of LHB pathology as recent studies show equal subjective results for tenotomy and tenodesis, whereas postoperative biomechanical results are in favour of tenodesis.

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Recent Advances in Cartilage Repair (ICL 3)

3

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3.1 Introduction

Articular cartilage possesses low intrinsic healing property due to its lack of vascularity and progenitor cells. Thus, damage to the hyaline cartilage may lead to a progressive degeneration of the joint and eventually to osteoarthritis (OA). In the last years, different surgical techniques have been introduced in the clinical practice to overcome this issue. Bone marrow stimulation, for example, is a widely known method to allow cell invasion from the bloodstream to the site of damage. However, the reparative tissue has different morphological and biomechanical properties when compared to the native cartilage. In particular, the newly formed fibrocartilage has a low amount of proteoglycans and a higher concentration of type I collagen. This different matrix composition leads to a decrease in the mechanical strength and to a poor integration of the reparative tissue with the native cartilage.

For these reasons, new techniques have been developed to enhance the regeneration of the hyaline cartilage. In this regard, the integration between basic science and tissue engineering has led to promising results both in animal models and in the clinical practice. In particular, the increased knowledge in stem cell therapy has

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allowed for the introduction of bone marrow or adipose-derived mesenchymal stem cells for cartilage repair. Moreover, the advances in tissue engineering contributed to the development of new scaffolds, which may be eventually associated with a cellular component. These constructs often combine a bony part with a cartilaginous component; in fact, the importance of the subchondral bone in cartilage repair has indeed progressively increased, as many lesions affect both the chondral surface and the underlying bone.

The aim of this chapter is to describe the most recent advances in cartilage repair. Thus, we will first present in details the currently used techniques of bone marrow stimulation; then, we will give a brief overview on cell therapy and on osteochondral tissue engineering. In this regard, we will also summarize the latest animal and human studies on cartilage repair.

Finally, we will comment on the importance of the conservative treatment and physical therapy for focal cartilage lesions.

3.2 State-of-the-Art Treatment

3.2.1 Bone Marrow Stimulation

Marrow stimulation techniques are key first-line treatment options for small symptomatic articular cartilage defects [16]. Their guiding principle is to establish a communication of the articular cartilage defect with the subchondral bone marrow compartment. This is achieved (often arthroscopically) either by focal perforation of the subchondral bone plate with drill bits (subchondral drilling), awls (microfracture), or by its generalized and limited abrasion with round burrs (abrasion arthroplasty).

In general, marrow stimulation techniques are indicated for symptomatic small (<3–4 cm^2) focal chondral defects in young patients. Other indications are degenerative focal cartilage lesions with intact adjacent articular cartilage in middle-aged patients. Cartilage defects in juvenile patients are also another indication. Here, marrow stimulation is a first-line treatment option even for the larger defects (which might be treated by autologous chondrocyte implantation in adults). In elderly patients, marrow stimulation techniques are only rarely indicated.

Cartilage defect needs to be meticulously prepared. The borders of the defects are debrided to achieve stable and vertically oriented peripheral margins. The next step is the preparation of the cartilage defect base. The entire calcified cartilage layer has to be removed [6]. Then, marrow stimulation is performed either by subchondral drilling, microfracture, or abrasion arthroplasty. When the communication of the cartilage defect with the subchondral bone marrow compartment is established, a blood clot forms and pluripotent progenitor cells from the subchondral bone marrow subsequently migrate into the defect, differentiate into chondrocytes, and over time form a fibrocartilaginous repair tissue [40, 41].

A fibrocartilaginous repair tissue is the result of all marrow stimulation techniques. Good to excellent results have been reported in the majority of the cases. Physically active patients and patients younger than 30–40 years have better results. Also, the results are better when the defect is located in the femoral condyles, compared with the femoro-patellar joint [40, 41].

Hereafter, the individual techniques (subchondral drilling, microfracture, and abrasion) will be discussed and placed into perspective with data originating from recent translational animal studies.

3.2.1.1 Subchondral Drilling

Subchondral drilling was proposed for the treatment of osteochondritis dissecans (OD) by Smillie already in 1957 [53] and for osteoarthritis (OA) by Dr. Kenneth Pridie in 1959 [50]. Subchondral drilling is often termed Pridie drilling. When performing subchondral drilling, the tip of a Kirschner wire (K-wire) or drill bit is placed on the base of the prepared cartilage defect. At high speed, the rotating drill bit cuts through the subchondral bone plate into the subarticular spongiosa [47, 56]. Multiple drill holes are introduced into the subchondral bone plate of the defect, their numbers depending on the defect area.

Interestingly, Pridie recommended using a drill bit with a diameter of 1/4 in. (6.35 mm) in

his original publication. Nowadays, smaller instruments are more commonly used. In a rabbit model, Marchand et al. did not observe a specific effect of hole diameter on cartilage repair when two different drill hole sizes were applied to one single full-thickness cartilage defect in the trochlea [37]. On the other hand, larger holes would allow for an amplified access of reparative elements to the cartilage defect; however, they would induce a greater disturbance of the microarchitecture of the subchondral bone, while smaller holes might limit such subchondral bone damage by better reflecting the physiological subarticular trabecular distance. These two different opinions on hole diameter were tested in a sheep model of a full-thickness defect treated by subchondral drilling. After 6 months in vivo, drilling with 1.0 mm K-wire led to significantly improved histological matrix staining, cellular morphology, subchondral bone reconstitution, and average total histological score as well as significantly higher immunoreactivity to type II collagen and reduced immunoreactivity to type I collagen in the cartilaginous repair tissue compared with 1.8 mm defects. Moreover, restoration of the microstructure of the subchondral bone plate below the chondral defects was significantly improved after 1.0 mm compared to 1.8 mm drilling. Taken together, the data show that small subchondral drill holes that reflect the physiological trabecular distance improve osteochondral repair in a translational model more effectively than larger drill holes. These results have important implications for the use of subchondral drilling for marrow stimulation, as they support the use of small diameter bone cutting devices [7].

3.2.1.2 Microfracture

Microfracture was first described by Dr. John Richard Steadman about 20 years ago [55]. Here, multiple perforations of the subchondral bone plate are induced [55] with the sharp tip of a microfracture awl, allowing for the access of reparative pluripotent progenitor cells from the subchondral bone marrow cavity to the cartilage lesion [52]. Utmost care has to be taken not to penetrate the subarticular spongiosa too deeply or to damage the subchondral bone plate by a deflection of the cutting tip of the instrument [40, 42]. To avoid collapse of subchondral bone bridges created during the microfractures, it is advisable to start to perform the perforations for the lesion area close to the arthroscopic portal and then proceed onward, to avoid possible confluence of holes. Bone debris is carefully removed. Following the decrease of the arthroscopic pump pressure to about 30 mmHg, fat droplets and blood appear, confirming the successful performance of the marrow stimulation.

In a translational animal model, the hypothesis to test was that osteochondral repair is improved when the subchondral bone is perforated with small awls [46]. Full-thickness chondral defects in the knee joint of sheep that were debrided down to the level of the subchondral bone were treated with awls of two different diameters in a standardized fashion. Compared with untreated control defects, histological cartilage repair at 6 months was always improved following application of both awl sizes. Application of 1.0 mm microfracture awls led to a significantly improved histological overall repair tissue quality and surface when compared with larger awls. Subchondral bone cysts and intralesional osteophytes were frequently observed following either microfracture treatment [46]. The data show that small diameter microfracture awls improve articular cartilage repair in the translational sheep model more effectively than larger awls. From a clinical standpoint, the data support the use of small microfracture instruments and warrant prolonged clinical investigations.

3.2.1.3 Abrasion

Arthroscopic abrasion arthroplasty is a technique that has been described by Dr. Lanny L. Johnson in the 1980s. It is a modification of open Magnusson "housecleaning" arthroplasty [22]. Here, the subchondral bone plate of the defect is abraded – thinned out – by removing about 1.0–1.5 mm of its thickness, without completely eliminating the subchondral bone plate. It is thus different from a simple debridement, which is characterized by a sole removal of superficial cartilage fragments. The abrasion exposes the

vascularity of the subchondral bone plate, providing the connecting link to the subchondral bone marrow.

A rabbit study by Menche et al. investigated articular cartilage repair of full-thickness defects treated with abrasion arthroplasty versus subchondral drilling [39]. Animals treated with subchondral drilling had increased fibrocartilaginous repair, with a slight increase in degenerative changes. Abrasion arthroplasty produced a significant decrease in cartilaginous coverage of the exposed surface as well as progressive increase in degenerative changes [39]. A retrospective analysis of the clinical results of patients with isolated chondral lesions of the medial femoral condyle that were treated with arthroscopic abrasion showed at 10 years postoperatively and at final long-term follow-up at a mean of 20 years a positive functional outcome in 68 % of the patients [57]. In the same study, functional results for patients with small defects (<4 cm^2 area) were better than those for patients with large lesions. Abrasion arthroplasty has no proven value in the treatment of large osteoarthritic lesions.

Altogether, marrow stimulation techniques are important techniques indicated for small symptomatic lesions. They are technically feasible in most knee joint regions. Crucial technical aspects have to be respected. Marrow stimulation techniques are characterized by good clinical outcome within the first years postoperatively. Continuing clinical and translational research will further improve cartilage repair based on marrow stimulation.

3.2.2 Bone Marrow-Derived Mesenchymal Stem Cells for Cartilage Repair

In the last years, mesenchymal stem cells (MSC) have been presented as a valid alternative for the OA treatment (Fig. 3.1). The capacity to differentiate into cells of the chondrogenic lineage and produce extracellular matrix together with their proven anti-inflammatory potential brought to focus MSC as a potential treatment for OA.

Fig. 3.1 MSC preparation. Isolation of mesenchymal stem cells

MSC effects in chondrogenic repair have been documented in mice, rabbits, pigs, sheep, and horses. Francesc Soler's group published a feasibility and safety study in horse and ovine models, with intra-articular infusion of 40×10^6 autologous expanded bone marrow MSCs (BM-MSC), with no local or systemic pathological alterations seen in necropsy after 6 months, and showing clear chondral regenerative findings.

MSC may be obtained from bone marrow, adipose tissue, blood, periosteum, synovium, skeletal muscle, placenta, and deciduous teeth. But not all MSC offer the same versatility and therapeutic potential: the chondrogenic potential of BM-MSC "in vitro" is higher than those MSC from adipose tissue (AT-MSC). Some studies in animal model showed BM-MSC to be more effective than AT-MSC. BM-MSC generates cartilage lineage cells when cultured in TGF-β-enriched medium [34]. This should be considered when attempting to regenerate articular cartilage.

These encouraging results in animal model allowed to try translating the procedure to human therapy. Francesc Soler's group published the outcomes of a pilot study for knee OA treated with autologous expanded MSC (EudraCT 2009-017407-11 and NCT01183728). Twelve patients were treated by means of intra-articular infusion of 40×10^6 autologous expanded BM-MSC. Excellent results were reported according to pain (VAS), algofunctional, and

disability tests (Lequesne and WOMAC). No adverse side effects were described [45].

Cell therapy effectiveness is dose dependent: in human adults, MSC rate in bone marrow is 1:10.000–100.000 mononucleated cells (MNC), in G0 phase. Research on stem cell transplantation suggests that the clinical results depend on the dose [49]. Applying the product before expansion would render a low amount of MSC in G0 phase, not enough to expect some kind of effect in cartilage.

The main target of this therapeutic approach is OA, which is a diffuse deterioration of different joint areas, not a focal injury. In order to accurately evaluate the cartilage quality without performing a biopsy, Francesc Soler's group chose the T2 mapping MRI as a technique to determine the grade of disorganization of the extracellular matrix. In the pilot study, statistically significant changes in cartilage quality, assessed by means of T2 mapping MRI, were observed [45].

The same group proved the viability, security, and efficacy of the application of 40×10^6 autologous expanded BM-MSC for the treatment of knee OA under a single articular infusion. This study allowed to carry on with the treatment under the supervision of the Spanish Medicines Agency (AEMPS).

Recently Francesc Soler's group published the results at 12 months of the first 50 patients following the same procedure described in the pilot study [54]. All patients were satisfied with the treatment, and 43 out of 50 patients (86 %) reported lasting pain relief greater than 45 % throughout a 1-year observation period.

New studies assessing different cell doses and carriers to enhance cell viability and efficacy are indeed necessary, but in the meantime, the researchers concluded that there is a belief that treatment with autologous expanded MSC through infusion is a feasible, safe, and effective treatment for joint OA.

3.2.3 Lipoaspirate Injections for the Treatment of Early OA

As we mentioned earlier in this chapter, another feasible source of mesenchymal stem cells is the adipose tissue, which is indeed readily accessible and simple to harvest, and can be used to provide cushioning and filling of structural defects. In addition, adipose tissue has been shown to have an abundance of bioactive elements with phenotypic and gene expression profile similar to MSC and pericytes. These cells have been shown to secrete multiple trophic mediators, which act in a paracrine fashion within the recipient tissue to elicit angiogenic, antiapoptotic, and antifibrotic responses. Adipose-derived MSC is routinely obtained from the enzymatic digestion of fat lipoaspirates as stromal vascular fraction (SVF), which may undergo prolonged ex vivo expansion, with significant senescence and decline in multipotency. These techniques have complex regulatory issues, and they often lead to clinical results below expectations. We here present the efficacy and potential benefits of using minimally manipulated, autologous micro-fragmented adipose tissue (Lipogems®) in patients with knee OA. Compared to the enzymatically digested lipoaspirates, the Lipogems® product is composed with a significantly higher percentage of mature pericytes and MSC and lower amount of hematopoietic elements.

Lipogems® is a disposable device that progressively reduces the size of adipose tissue clusters, washing the tissue from pro-inflammatory blood, oil, and cellular debris through an "enzyme-free" minimal manipulation in an aseptic closed system, while maintaining intact stromal vascular niches with mesenchymal stem cells and pericytes (Fig. 3.2). The entire process is a one-step procedure, and it is performed in immersion in a saline solution, which minimizes any trauma to the cellular products.

The study included patients with knee OA. In all patients, the presence of OA symptoms was confirmed by clinical examination, X-ray, and MRI. Patients underwent a three-step procedure of lipoaspiration, adipose tissue processing using the Lipogems® device, and reinjection into the knee. Clinical outcomes were assessed using KOOS, KSS, and VAS pain scale and taken at baseline 1-, 3-, 6-, and 12-month follow-up.

The improvement of the symptoms occurred few days after treatment and steadily increased

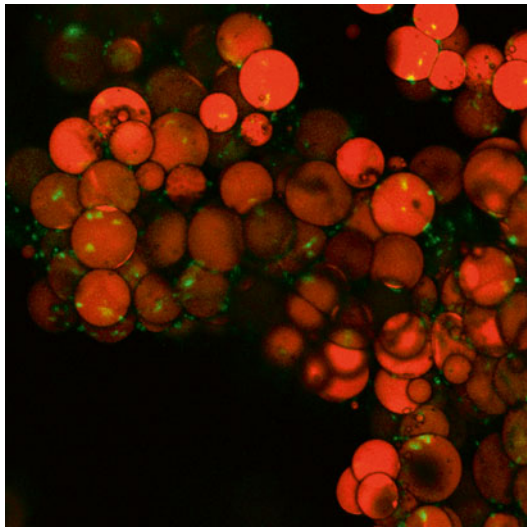

Fig. 3.2 Lipoaspirate. Microscopic image of the Lipogems® products

throughout the whole period of our study. The results of all KOOS subscales showed gradual statistically significant improvement of an average of 21.8 points for each subscale.

These results are very encouraging and point to Lipogems® as an easy, safe, and effective intraoperative procedure to obtain micro-fragmented minimally manipulated autologous adipose tissue for the treatment of knee OA.

3.2.4 The Use of PRP for Cartilage Lesions

Progresses have also been obtained in the use of platelet-rich plasma (PRP), which nowadays represents a valid and less invasive alternative to other bone marrow stimulation techniques.

PRP is indeed a blood derivative with a higher platelet concentration than whole blood. Platelets, once activated, release a group of biologically active proteins that bind to the transmembrane receptors of their target cells, leading to the expression of gene sequences, which ultimately promote cellular recruitment, growth, morphogenesis, and also modulate inflammation [14]. Thus, PRP represents an appealing biological approach to favor healing of tissues otherwise doomed by a low regenerative potential, such as cartilage. This led to the wide use of PRP in the clinical practice, showing promising results for the minimally invasive injective treatment of cartilage degeneration and OA. Therefore, an increasing number of both preclinical and clinical studies on PRP were performed and they overall displayed positive results [27].

Literature clearly demonstrates the safety of PRP injections, with no major adverse events recorded and only some reports of self-limiting immediate pain and swelling reaction [27]. Moreover, all studies seem to agree on an overall clinical benefit of PRP. Even recent randomized controlled trials (RCTs) have shown support in favor of PRP intra-articular injections, which have been shown to be better than saline injections, and some studies suggest a slight superiority of PRP with respect to viscosupplementation [17, 48, 51]. However, literature also presents some controversial findings, and the real potential of PRP for the treatment of knee degeneration is far from being proven. The largest available double-blind RCT comparing PRP and hyaluronic acid (HA) injections was not able to demonstrate any difference in the several subjective and objective outcome measures prospectively documented in 192 patients for up to 1-year follow-up [13]. Platelet concentration, dose, timing, and modality of application may have influenced the results, thus explaining the conflicting outcomes with other trials. It is also likely that many aspects such as cellularity, activation modality, mechanism of action, and targets need to be further explored to improve the potential of this biological treatment. It is also well known that the clinical benefit reported after PRP injection may be attributable to other action mechanisms. Both the rapid clinical benefit and the limited effect over time are in contrast with the timing required by an induced cartilage regeneration process. It is more likely that an intra-articular injection does not target only cartilage, as PRP might influence the entire joint environment. Some in vitro studies indeed confirm the effects of PRP on other cell sources

such as meniscal, synovial, and mesenchymal stem cells [14]. PRP might not lead to hyaline cartilage regeneration and might not change the clinical history with significant disease-modifying properties, but it still might offer a clinical and functional improvement and it might possibly delay the degenerative process. The clinical benefit is limited over time and can roughly be estimated in less than 1 year [27]; this outcome might suggest that this treatment should be applied in cycles to ensure longer-lasting results and postpone more invasive procedures.

Finally, another aspect emerges from the literature analysis. Not all patient categories present the same results, as younger patients affected by an early degeneration have a better outcome. Thus, it appears clear that there is room for a better targeting of PRP application. The understanding of the best treatment indications, together with the understanding of the mechanism of action of PRP will allow the optimization of the procedure and the improvement of this biological minimally invasive approach for the treatment of cartilage degeneration and OA.

3.2.5 Surgical Solutions for Osteochondral Defects

As mentioned in the introduction, the subchondral bone and its importance for a successful regenerative therapy of osteochondral lesions and the articular surface unit recently came into focus [15], as severe symptomatic and unstable osteochondral defects are difficult to treat [33]. Reasons for these lesions are, e.g., osteochondritis dissecans, osteonecrosis, or trauma. Traditional treatments for osteochondral defects consist of surgical transplantation of either autologous or allogeneic tissue. Autologous osteochondral transplantation was shown to offer a good and long-lasting clinical outcome [11], but with several limitations when addressing lesions bigger than 2.5 cm^2, due to donor site morbidity issues [12]. On the other hand, the use of allogeneic osteochondral plugs is a viable option for bigger lesions but presents limited availability. With the aim of overcoming the abovementioned limitations, regenerative strategies have been developed. Initially, techniques developed for the cartilage layer were modified to address osteochondral defects, such as ACI combined with the use of autologous bone to fill the bone defect [8]. However, a relatively high incidence of subchondral bone alterations has been highlighted for these procedures [47]. Moreover, high costs and morbidity, related to the double surgical procedure, pushed the development of new products with a bilayer structure reproducing the different biological and functional requirements of the entire osteochondral unit, in order to guide in one surgical step the growth of both bone and cartilage tissues, respectively [30]. The aim of these cell-free devices is to provide the right stimuli to regenerate the osteochondral tissue, supporting and guiding cell differentiation in situ toward bone and cartilage.

Among the many scaffolds commercialized for clinical application, a very few of them has currently been reported in the literature.

A bilayer scaffold made of a porous PLGA-calcium-sulfate biopolymer (TruFit, Smith & Nephew, Andover, MA) in form of mosaic-like cylinder plugs was the first reported. After promising preclinical results, the plug was initially introduced into the clinical practice for backfilling autologous graft donor sites, but it has also been directly implanted for the treatment of focal articular surface defects, where it showed some controversial findings [3, 62].

Dhollander et al. reported a failure rate of 20 % (3 out of 15 patients) at 12 months, paired with fibrous vascularized repair tissue at biopsies [5], and Joshi et al. reported 70 % of 10 patients undergoing a second surgical procedure due to implant failure within the first 24 months after plug implantation for patellar lesions [23]. Finally, the comparison with mosaicplasty in two groups of patients treated for similar defects showed significantly higher outcomes for the latter ones [20].

A three-layer nanostructured implant made of collagen and hydroxyapatite (MaioRegen™, Fin-Ceramica, Faenza, Italy), mimicking the

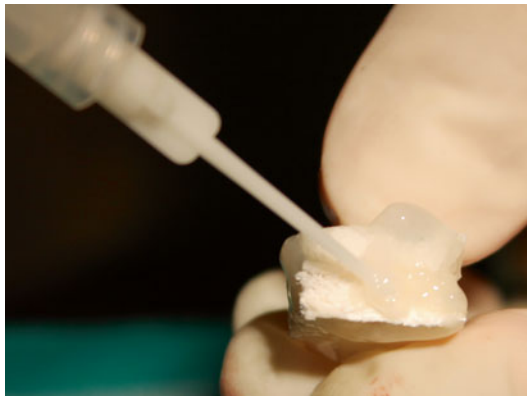

Fig. 3.3 Macroscopic picture of a Collagen-hydroxyapatite scaffold. The implantation technique involves the use of fibrin glue on the *top* and borders to maximize the primary stability of the patch

composition of the extracellular matrices of cartilage and bone tissue [59], showed promising results during in vitro and animal studies either with or without adding cells [25] and was therefore introduced in the clinical practice as a cell-free approach (Figs. 3.3 and 3.4).

Its clinical application has been widely reported up to midterm follow-up. A study on 27 patients showed a significant improvement in all the scores used that was stable until 60 months of follow-up. Also, MRI evaluation of 23 lesions revealed significant improvements in both mean magnetic resonance observation of cartilage repair tissue (MOCART) score and subchondral bone status over time. Nonetheless, some abnormalities persisted, even if no correlation was found between imaging and clinical outcomes [28].

Positive results at short-term follow-up have later been reported in a larger study on 79 patients [29], and the effectiveness of this approach was confirmed also in studies on specific patient subgroups, such as OCDs [9], tibial plateaus [32], large [2, 4], or complex [10] articular lesions involving the subchondral bone. Lastly, this biomimetic patch was successfully applied as part of a combined approach as salvage procedure for unicompartmental OA patients [36].

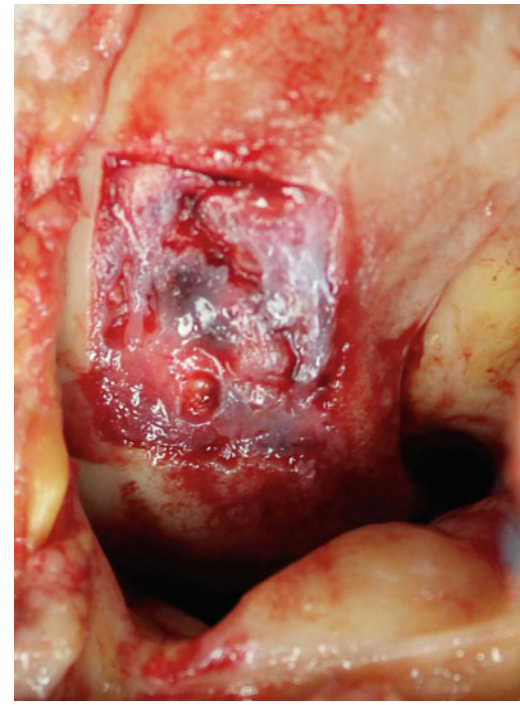

Fig. 3.4 Collagen – hydroxyapatite scaffold implantation for femoral condyle osteochondral defect. The articular surface and margins are covered with fibrin glue

More recently, an aragonite-based osteochondral scaffold was developed (Agili-C™, CartiHeal, 2009 Ltd, Israel). It is a rigid cell-free implant in cylinder shape that consists of two layers: a bone phase made of calcium carbonate in the aragonite crystalline form and a superficial cartilage phase composed of modified aragonite and hyaluronic acid. Preclinical analysis showed biodegradability and intrinsic restorative potential and the ability to recruit cells from the surrounding tissues, allowing the one-step implantation without any cell augmentation [31]. Currently, a single case report describing the clinical use of this construct is available in the literature: a 47-year-old nonprofessional sportsman affected by a post-traumatic osteochondral lesion around 2 cm^2 on the medial femoral condyle was treated successfully and resumed his pre-injury sport activity after 18 months. The MRI evaluation

performed at 24 months of follow-up also showed good results with the restoration of the articular surface, but larger studies need to be performed to confirm the promising preliminary findings [26].

3.2.6 Regenerative Treatment of Deep Osteochondral Defects

While many authors report good to excellent long-term results after treatment of small osteochondral lesion with osteochondral transplantation [19], less is known about treatment options for large and deep osteochondral defects, as the complication rate of osteochondral transplantation correlates to defect size. Few alternative treatment options are described in literature. However, resection of large adult OD lesions resulted in bad clinical outcome and development of OA. Refixation of large grade 4 ODs failed to integrate into the surrounding bone and showed no clinical improvement in long term [24]. However, in recent years, regenerative treatment approaches for large osteochondral defects showed promising results.

The combination of matrix-guided autologous chondrocyte transplantation (MACT) with bone augmentation has indeed been proposed [61, 65]. Ochs et al. saw a remodeling of articular cartilage and subchondral bone after bone grafting and MACT for treatment of deep OD lesions [44]. For bone augmentation monocortical cancellous cylinders were used to reconstruct the subchondral layer. The cartilage defect filling and the lamina remodeling grades correlated significantly with each other and clinical outcome. Vijayan et al. described a method of impaction bone grafting of the defect with cancellous bone harvested from the medial femoral condyle and covered with MACT [63]. However, some defect locations and geometries especially toward the notch border, where osteochondral defects are often located, are not suitable for impaction bone grafting due to the missing defect containment. Könst et al. used a full-thickness corticospongious autologous bone graft from the medial or lateral condyle for bone augmentation and covered it with a gel-type autologous chondrocyte implantation [33]. Although the reconstruction of the subchondral plate seems to be mandatory for a successful treatment of deep osteochondral defects [15, 44], there is still a lack of information about the best method to address the bony part of the osteochondral lesion.

In one of our more recent studies, we treated the largest number of patients with deep osteochondral defects with bone augmentation combined with MACT. According to defect depth and size, bone defect filling was performed with cancellous bone impaction or implantation of an autologous bicortical bone graft from the iliac crest covered with MACT. 51 patients were followed up at 3 and 6 months and 1, 2, and 3 years and clinically evaluated using the International Knee Documentation Committee (IKDC) score and the Cincinnati score. An MRI evaluation was performed at 3 months and 1, 2, and 3 years, and the MOCART score with specific subchondral bone parameters (bone regeneration, bone signal quality, osteophytes, sclerotic areas, and edema) were analyzed.

At the 1- and 3-year follow-ups, both the IKDC and the MOCART scores have significantly increased with the time. Thus, the new bone block augmentation technique combined with MACT might represent a valid treatment for large osteochondral defects.

3.2.7 The Role of Physical Therapy for Conservative Treatment

Despite the progressive improvement of techniques for cartilage repair, we should always remember that specific focal cartilaginous lesions can and should be treated conservatively, especially if young patients are involved. In these cases, physical therapy plays a major role in the conservative treatment. Thus, we dedicated a section of this chapter to the role of the physical

therapist in the rehabilitation of patients with cartilage lesions.

"The need for speed," "no pain, no gain," and "what doesn't kill you makes you stronger" intimidating myths? Yes, and the physical therapist (PT) should professionally deal with these myths.

Young athletes with knee cartilage lesions indeed present with clear mechanically induced articular and/or peri-articular complaints but with not well-recognized movement dysfunctions. When insidious cartilage injuries occur, the final diagnosis of underlying cartilage lesions takes time. Here there is a clear "need for speed." Frequently recurrent or persistent tendinitis or nonspecific joint line tenderness influences unfortunately to the great extent the power output and professional performance and puts the joint even in a vulnerable "prone to injury" position. Each PT should be able to recognize the clinical representations of cartilage injuries, the injury mechanisms, and the maladaptive or compensatory neuromuscular control strategies. Once the exact diagnosis of the cartilage lesion (size, location, concomitant lesions) is set, the "need for speed" simply applies on smart goal setting and criteria-based rehabilitation [43].

"No pain, no gain" and "fear avoidance" are possible behavioral movement strategies when confronted with pain. If patients behave continuously with one of these strategies, "undesirable and inevitable" pain will occur more easily, resulting in less capacity to enjoy physical efforts. Respectively, insight, respect, and renewed trust in healing and training should be restored or at least positively initiated. We "know" that local healing capacity of damaged cartilage is limited, one more reason to use a "feel good" approach with intense functional training.

"What doesn't kill you makes you stronger" does not take into account chondrocyte apoptosis. Chondrocytes are essential to maintain cartilage and its key functional characteristics of shock transducing and friction-free movement. Local mechanical overload and excessive shear forces during altered biomechanics can result in subclinical chondrocyte apoptosis. Since cartilage is aneural, surrounding innervated tissues such as the subchondral bone and the joint capsule inform us for possible threat. Typically, when clinical symptoms follow during joint reactivity or joint homeostasis loss, patients adapt their movement behavior.

The first goal of PTs is to inform patients and to help them to restore joint homeostasis. Exercise to facilitate neuromuscular control, temporary adjustments in activities of daily living (ADL), and intensifying training focus are typical to be addressed [64]. Specific low-load exercises can improve recovery of joint homeostasis, local nutrition state at the "repair" site, key signaling pathways to chondrocytes, periarticular lymphatic drainage, and local muscle tone and control [21]. Especially the local, more phasic muscles can dramatically loose muscle tone and need stimulation, preferably executed actively during ADL. Also in order to improve transfers with or without crutches, a temporarily adapted motor control strategy is recommended, of course depending on cartilage lesion site. If implemented correctly, the chances to locally overload the repair site, to provoke joint reactivity, and to increase pain perception are minimized. Besides neuromuscular retraining, proximal muscle strength exercises are desirable as soon as possible to overcome the "use it or lose it" phenomenon.

The role for physical therapy is both in analyzing movement strategies and follow-up training to improve joint function. Following cartilage injury, this is a lengthy process [60]. Fortunately, in the young athletes, good, satisfying progression is possible without jeopardizing a healthy fit future. Conservative treatment should be progressive but not aggressive. Following cartilage defects exclusive physical therapy may fail to restore full joint function. Consequently, and last but not least, an important role of the PT is to refer to a dedicated cartilage surgeon. The ideal timing of surgical cartilage repair interventions is not well documented. Some reports suggest an ideal window of opportunity between 10 weeks

and 6 months after cartilage injury. One should take this into account when no optimal functional recovery is reached with a progressive, criteria-based, conservative, and feel good treatment.

3.3 Future Perspectives

Preclinical and in vitro studies have recently suggested some intriguing glimpses in the future of cartilage repair.

Considering the continuing widespread use of scaffolds and matrices, some of the "seeds" of cartilage tissue engineering lay certainly in the development of a new generation of therapeutic tools that allow for a progressive release of growth factors able to promote chondrocyte differentiation and cartilage matrix production. These are generally called "smart scaffold" and are preloaded with different molecules as transforming growth factor-β (TGF-β), bone morphogenetic protein-2 (BMP-2), insulin-like growth factor-I (IGF-I), and others or even a combination of these factors. In this regard, recent in vitro experiences suggest that an alternative way to deliver growth factors may come from "viral infections." Actually, pre-made recombinant adeno-associated viral vectors, retroviruses, or plasmids carrying a gene for a bioactive protein as IGF-I, fibroblast growth factor-2 (FGF-2), growth and differentiation factor-5 (GDF5), TGF-β, or transcription factor SOX9 have been shown to increase the synthesis of cartilage matrix and to enhanced proliferation of both chondrocytes or MSCs. The combination of these viral vectors inside polymer scaffold or self-assembling peptides, which can form stable hydrogels, allows for an effective, progressive, and controlled delivery of genes to the cells. This "gene-activated matrix" is indeed conceived for a vector release controlled by scaffold degradation preventing passive bolus release of the gene, and they may reasonably represent a future perspective for cartilage repair. Obviously, when biotechnology meets engineering, new possibilities arise again, and one of the present options coming from this perspective is represented by the concept of nanostructured membranes. Nanoscaffolds, made by tridimensional texture close to the dimension of extracellular matrix components, allow for a better "cross talk" between cells and materials and are able to improve cartilage differentiation and matrix formation, but they offer also some biochemical advantages. Specifically, nanostructures (i.e., carbon nanotubes) are able to adsorb more growth factors than traditional scaffold components as collagen. Moreover, at the level of "nanospace," some interesting phenomena occur, and one can observe that MSC, in contact with membranes of electrospun fibers of poly-L-lactic acid (PLLA) loaded with nanoparticles of hydroxyapatite (HA), shows a chondrogenic differentiation pathway in the absence of any chondrogenic medium. So, all these first experiences are unique and fascinating and certainly, in the future, more can be expected from the science of biomaterials.

From the standpoint of the use of blood derivatives for cartilage repair, many aspects are still to be clarified following the recent conflicting evidences. Indeed, if the value of PRP alone as a chondrogenic device may be mistrusted, it is unquestionably accepted the strong potential of PRP as a natural well-tolerated and individualized pool of bioactive molecules. From this point of view, a combined use of PRP together with other biologic agents may be hypothesized as a potential therapeutic preparation to increase cartilage repair. Recent evidences have shown promising results of PRP associated with hyaluronic acid or vascular endothelial growth factor (VEGF) antagonist or TGF-β or granulocyte-colony stimulating factor (G-CSF). However, beside these captivating hypotheses, the continuing research for the proper method to obtain a preparation of PRP suitable for cartilage repair is still proceeding. At this regard, some new clues about the positive effect of monocytes and lymphocytes have been described, allowing for the definition of a neutrophil-depleted, mononuclear

cell-enriched (monocytes and lymphocytes) PRP able to promote collagen production as a putative formulation to be further studied for improving cartilage repair. Ultimately, the growing interest in platelets and their content has pointed out the importance of microvesicles and miRNA in platelet physiology and, recently, the delivery of miRNAs alone (i.e., miRNA 23b) has been used to promote chondrogenic differentiation of MSC. Future reports will reveal if this captivating paradigm may have a role as a therapeutic alternative for preclinical and clinical studies for improving cartilage regeneration.

Nevertheless, if all these elements may have an important role in cartilage tissue engineering, the key factor for cartilage repair is still the cell. Indeed, the choice of cell source is fundamental and recent clinical studies are offering multiple possibilities, from bone marrow concentrate or adipose stromal vascular fraction to autologous culture MSC derived from lipoaspirate or allogeneic MSC combined with chondrons, as presented in the recent IMPACT trial from Saris et al. [1]. Nevertheless, basic science lesson shows that new candidates are emerging in this horizon. Autologous or allogenic juvenile minced cartilage fragments may represent potential candidates of chondrocyte reservoir, considering the "activated" phenotype, observed in chondrocyte migrating from the "micro-explants," similar to the cell from the superficial zone of articular cartilage. Moreover, an appealing option may reside in the use of induced pluripotent stem (iPS) cells as an "immortalized non-tumorigenic cell line" to be differentiated toward chondrogenic pathway. As suggested by Takahashi et al. since 2007, iPS cells can be generated from adult human fibroblasts, differentiated into cell types of the three germ layers, and expanded infinitely [58]. So, iPS cell-derived chondrocytes may be obtained and applied in vitro and in vivo, even if a non-negligible risk of tumorigenesis (i.e., teratoma) has been observed in mouse models.

Moreover, a growing interest in the use of umbilical cord stroma (UC) as a source of stem cells is present in literature. Beside the well-known UC blood-derived mesenchymal stem cells (hUCB-MSC) [18], recent reports propose the use of cells derived from UC structure as a noncontroversial attractive alternative, since cells are derived from a formerly discarded material entangling few ethical problems and legal concerns. Indeed, the UC contains two umbilical arteries and one umbilical vein and a mucous proteoglycan-rich connective tissue, named Wharton's jelly, covered by amniotic epithelium. So, MSC can be isolated not only from mononuclear cell fractions of umbilical cord blood but also from umbilical vein subendothelial layer, from the outer layers of umbilical vessels (the perivascular region), from the intravascular connective space, and from the subamnion region. Furthermore, the cord blood seems to contain small amount of mesenchymal precursor cells and its efficiency is hampered by the low quantity of blood obtainable and a low success rate of isolation. Data from literature suggest that the frequency of circulating MSCs in cord blood is approximately 0.002 ± 0.004 per 10^6 initially plated cells, while the number of CFU-F from a "classical" stem cell source as the bone marrow can be estimated as 83 ± 61 per 10^6 [35]. Conversely, in our experience, from the UC obtained during cesarean birth, a mean of 32 g of UC can be retrieved [38] and, for each gram of original UC tissue, 0.8×10^6 cells are obtained. This "mixed" heterogeneous MSC population has been able to differentiate toward osteogenic, adipogenic, or chondrogenic pathway. Moreover, both in pellet culture and in tridimensional scaffold culture (namely, collagen I/III and HYAFf-11 hyaluronic acid derivative membrane), chondrogenic commitment of UC-MSC is enhanced in hypoxic environment (Fig. 3.5), similarly to that of bone marrow MSC. For all these reasons, we believe that UC-MSC may be an appealing potential source for clinical allogeneic use to treat chondral and osteochondral lesions, and they may well represent a candidate for "universal off-the-shelf" stem cell products in the field of orthopedic tissue engineering.

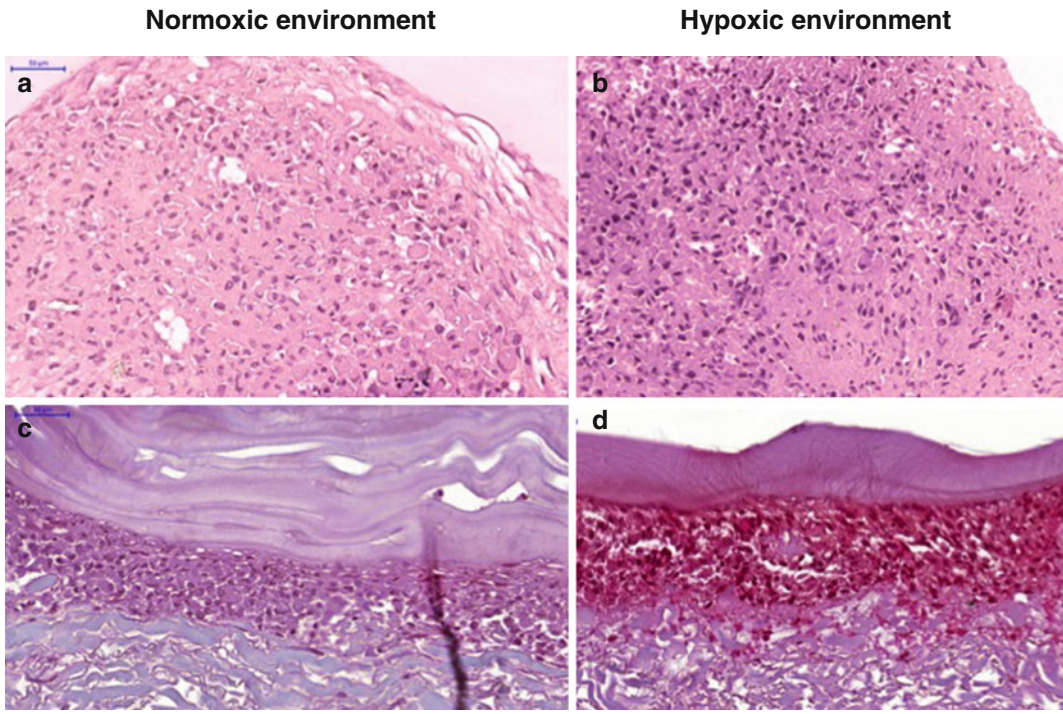

Fig. 3.5 Chondrogenic commitment of UC-MSC in hypoxic conditions. SAFRANIN-0 staining; (**a**, **b**) = pellet culture at 4 weeks, umbilical cord-derived mesenchymal stem cells (UC-MSC) at P2 were grown in chondrogenic medium; (**a**, **d**) = scaffold culture (collagen I/III) at 4 weeks, UC-MSC at P2 were stabilized at the top of the scaffold with fibrin glue and grown in chondrogenic medium; (**a**, **c**) = normoxic environment (21 % O_2); (**b**, **d**) = hypoxic (10 % O_2) environment; cultures grown at low oxygen tension showed more positive SAFRANIN-0 staining, consistent with increased sulfated glycosaminoglycan (*sGAG*) production, than that of cultures grown at standard normoxic conditions

Take Home Message

Cartilage repair still remains a challenge due to the specific properties of this tissue, mainly its avascularity and its lack of progenitor cells. Major improvements in this field have been made, thanks to the development of new tissue engineering techniques. In this chapter we described the most recent methods for cartilage repair. In particular, we focused on the novel strategies of cell therapy and on the new available biomaterials.

However, the choice of the best cell source and of the best biomaterial still remains a challenge; scientists are therefore trying to converge their efforts on these unsolved problems.

In conclusion, the future for cartilage tissue engineering so far appears an open landscape in which the combination of cells, membranes, and blood derivatives offers new fascinating pictures for cartilage repair. The best choice among all these strategies should take into account the type of damage, the general conditions of the joint, and also the patient's characteristics and expectations. Some of those treatments apparently seem still far from a clinical application; however, the "joint venture" of basic researchers and clinicians can shorten the distances, which are still too wide, because it is only this conjoined force that can shape the course of the future.

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Common Errors in ACL Surgery (ICL 4)

4

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4.1 Introduction

Anterior cruciate ligament reconstruction (ACLR) is one of the most commonly performed knee surgery procedures. While it is established, complications and disappointing outcomes do occur. The following chapter aims to highlight the errors of decision-making and technique that are responsible for this.

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4.2 Choosing the Right Patient

4.2.1 Copers Versus Non-copers

There are two main reasons why we propose operative treatment for ACL-deficient patient. One would be to enable the patient to return to pre-injury activity levels and second to prevent early osteoarthritis. Paradoxically there are patients who are able to achieve the same level of activity despite nonsurgical treatment and those who develop early osteoarthritis despite operative treatment [1].

The priority is therefore good patient selection for surgery. A "coper" is an ACL-deficient patient, who despite no surgery functions well and does not feel clinical symptoms of instability, has the ability to return to pre-injury level of sport activity [1, 2], and does not develop early osteoarthritis, or at least develop it much later than others. Non-copers become symptomatic (feeling instability) and are more often middle-aged (35–44 years old), female, and had a non-contact ACL injury [3].

As far as the risk of early osteoarthritis is considered, there are two dominant risk factors: meniscus tears and unfavorable limb alignment. Of course in itself unstable knees have a high risk of subsequent meniscal injury. According to Papastergiou [4], as many as 57 % of ACL-deficient patients develop meniscal tears within the first weeks post ACL injury (>6 weeks).

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4.2.2 When to Operate?

According to Shelbourne [5], delaying time for ACL reconstruction beyond 3 weeks lowers risk of subsequent arthrofibrosis, comparing to those patients who underwent surgery within the first 3 weeks. However, most experienced surgeons realize that it is safe to operate as soon as full active extension is achieved and the knee is "quiet" – that is, the presence of a non-tense effusion or less, comfortable flexion over 100° flexion, and little knee pain. Many knees can safely undergo ACL reconstruction sooner than 3 weeks but others may need much longer, and those which develop a fixed flexion deformity will need a preliminary arthroscopic clearance. Rather than a timed approach, the status of joint inflammation is better.

4.2.3 Pediatric Cases

In pediatric cases (with open growth plates), there is lack of clear evidence on whether to reconstruct the ACL or which technique is the best. Most data are based on relatively small groups of patients and with highly variable skeletal maturity. However, almost all authors agree that there are poor long-term results in children with ACL-deficient knees not treated with surgery, mainly due to the fact that in up to 70–80 % of cases tear menisci within the first year after the injury [2].

The major concern in ACL reconstruction in children is open growth plates, which could be damaged while drilling tunnels, thereby causing growth disturbance. With small well-placed tunnels completely filled with soft tissue, the risk of developing growth arrest is minimal [6–9]. It looks like either way, we risk something or develop early osteoarthritis or limb deformation due to injury to growth plate.

4.2.4 Concomitant Chondral Injuries

The presence of significant chondral lesions often leads to disappointing outcome after ACL reconstruction.

It is often best to avoid simultaneous treatment of chondral lesions and ACL reconstruction as the rehabilitation for one problem may adversely affect the other.

4.3 Graft Choice and Harvest Techniques

There are a number of graft choices for ACL reconstruction. Either autografts or allografts have been extensively utilized over years. Synthetic grafts were also introduced in the late 1980s with poor results. However, graft choice remains controversial and the ideal graft probably does not really exist. Graft choice depends on consideration of their strength, biology, harvesting technique, indications, and failure rates.

4.3.1 Strength of the Graft

The native ACL has a tensile load of 2,160 N [10]. A 10-mm-wide patellar tendon (B-PT-B) graft was found to have an ultimate tensile load of 2,977 N [11], while the same-size quadriceps graft resists up to 2,174 N [12]. A four-bundle composite hamstring graft has an ultimate tensile load of 4,090 N [13]. Overall, all the grafts currently used for ACLR have exhibited enough strength and the mechanical properties to fulfill the intended function.

4.3.2 Biology

Both autograft and allograft undergo an incorporation process in the joint that involves cell death, revascularization, fibroblast migration and, finally, remodeling [14]. This ligamentization process took about 6 months in the cases of autografts and is much longer (at least 9 months) in allografts [15].

Therefore, a longer period of protection for patients with an allograft ACLR is advised. The healing process is also important at the insertion sites. Within the bony tunnels, a bone block can heal within 6 weeks [14], while soft tissue autograft healing occurs at 8–12 weeks from surgery [16]. Consequently a less aggressive rehabilitation process is probably better when using soft tissue grafts.

4.3.3 Technical Issues

Besides the risk of patellar fracture, B-PT-B autograft harvesting is associated with an increased risk of problematic anterior knee pain (AKP). Conversely, the use of hamstring autografts reduces this problem [14, 17]. AKP may be due to a number of issues: cartilage lesions, patellar "tendonitis," fat pad scarring, injury to the *Saphenous* nerve and its infrapatellar branch, and poor rehabilitation. Minimizing operative trauma has greatly reduced the morbidity of B-PT-B graft harvest. Also, the fat pad should not be violated in arthroscopic ACL reconstruction. *Saphenous* nerve lesions are less common with use of two small transversal skin incisions.

Interestingly, in one study, no difference for anterior knee pain has been found between patients with BPTB autografts and those with allografts [14]. This suggests that anterior knee pain is quite a complex issue and its origin is not only related to the graft but also to some other facts as poor rehabilitation technique.

Hamstring harvesting often causes numbness in the lateral aspect of the knee due to an injury of the infrapatellar branch of the *Saphenous* nerve. Also, residual hamstring weakness and a less stiff ACL graft with more laxity are common complaints [18, 19].

One major error when harvesting hamstrings is truncating them prematurely or amputating their muscle belly. This can be avoided by careful digital dissection of the thick fascial bands and accessory insertions of the hamstring prior to using the stripper. There may be more weakness and persistent hamstring pain if the tendons are "filleted" out of their muscle bellies [20]. Alternatively the tendons can be amputated at their junction to the muscle.

Finally, the infrapatellar branch of the *Saphenous* nerve may exhibit a number of anatomical variations, making avoidance of nerve injury difficult.

Besides its strong ultimate load to failure and cross-sectional area, quadriceps graft has the advantage of an incision for harvest at the superior pole of the patella, thereby avoiding the infrapatellar branch of the *Saphenous* nerve. Its main weakness compared to B-PT-B is the fact that it only has one bone block.

4.3.4 Failure Rate

In a meta-analysis comparing BPTB and hamstring autografts for ACLR that includes 1976 patients, significantly lower rates of graft failure have been found in the BPTB group [17]. Also hamstring tendon grafts have a much higher rate of failure compared with BPTB in a female population [18]. However, graft choice did not affect ACL graft rupture in a recent case series [21].

With regards to the allografts, although no significant differences in knee laxity or outcomes have been encountered when compared to autografts for ACLR in some studies [22], recent evidence has shown inferior results. The MOON group recently demonstrated an overall retear rate of 8.9 % in primary allograft ACLR in comparison to 3.5 % when autografts were used. This difference was more evident in younger patients, under 18 years of age, with over a 10 % difference in failure rates [23]. More recently, allografts were found to be predictors of increased graft failure [24]. The place of allograft in primary ACL reconstruction is therefore questionable.

4.3.5 Relative Indications

Finally, there are certain situations in which one graft may be favored over another. B-PT-B autograft is generally accepted as the "gold standard" due to its biomechanical profile and faster bone-to-bone healing. However, hamstring tendons have certain theoretical advantages for those that need to knee leg carpet fitters or Judo players; those who jump, e.g., netball/basketball; when there are preexisting patellofemoral problems; or in adolescents with open physes.

The absence of donor site morbidity, the minimal scar needed, and the faster recovery make allograft tissue an alternative to be considered in a number of instances. However, based on the existing literature, it seems prudent to reserve allografts for ACL revision in cases of recreational athletes over 50 and in patients with low demand.

Finally, synthetic ligaments may be an option for extra-articular use or as augmentation in cases of small-size autografts. However, there is a lack of literature to support their long-term outcomes.

4.4 Common Errors in Tunnel Positioning

By far the most common technical error in ACL reconstruction has been non-anatomic tunnel placement, accounting for 70–80 % of technical failures, with an improperly placed femoral tunnel being the cause in most cases.

4.4.1 Femoral Tunnel Position

Three techniques can be used to place the femoral tunnel: the "transtibial technique," the "anteromedial (AM) portal technique," and the "outside-in technique." Regarding the literature, the transtibial technique shows the higher rate of malpositioning [25]. The AM portal technique allows free choice of the femoral tunnel position as does the out-in technique. The latter tends to push the drill guide to the optimal position automatically due to the effect of notch shape on the guide.

The clock-face concept position (e.g., 10 o'clock/11 o'clock for the right knee) is used as it is an easy concept to grasp. However it is overly simple and can lead to a lack of appreciation of the three-dimensional position of a tunnel as there is no concept of depth in the femoral notch. It is therefore better to rely on and refer to anatomical landmarks.

There are useful arthroscopic landmarks for identifying ACL femoral footprint as the remaining femoral ACL stump, the "residents' ridge," the intercondylar ridge, and the bifurcate ridge on the lateral notch. To best see these landmarks, the AM portal has to be used for viewing the anatomic ACL femoral attachment site. Another key to avoiding excessively anterior femoral tunnel placement is adequate visualization of the over-the-top position before tunnel placement. This largely depends on arthroscopic surgical skills.

Despite all the landmarks, the actual optimal femoral tunnel placement is still controversial, and not agreed! What is certain is that the tunnel should be placed within the femoral footprint. Some prefer a central footprint position (and have used the term "anatomic" to describe it without any real justification) and others a tunnel aperture in the AM bundle position. Argument rages as to which is best.

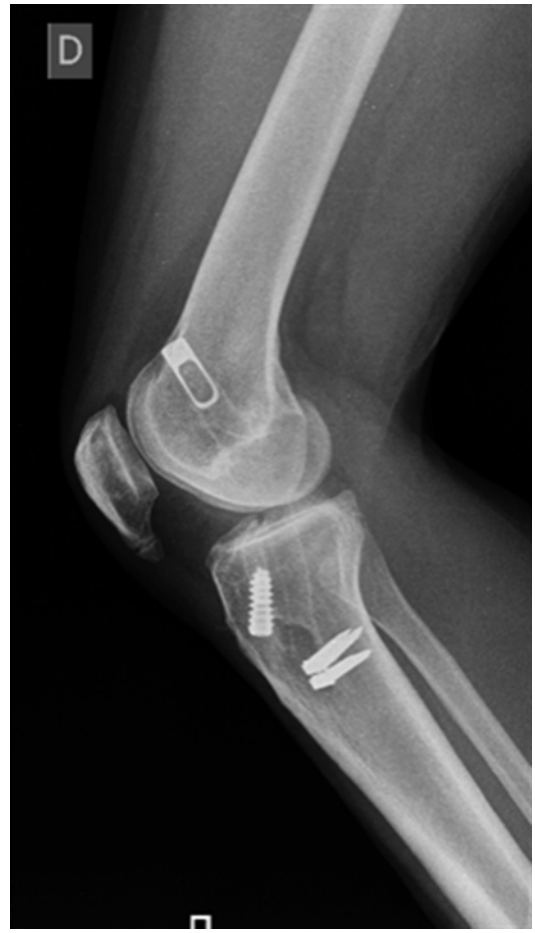

Fig. 4.1 Sagittal X-ray view of a failed transtibial (TT) ACL reconstruction. Note the far anterior femoral tunnel. Two tibial tunnels can be seen on the tibial side, the most posterior corresponds to the first TT reconstruction

The femoral tunnel is often placed in a position that is too anterior, resulting in graft constraint in flexion and laxity in extension (Fig. 4.1). The femoral tunnel may also be placed too posteriorly. This may result in loss of fixation due to posterior wall "blowout" and, on occasion, constraint in extension due to non-isometric tunnel position.

4.4.2 Tibial Tunnel Position

The tibial ACL attachment site is more variable but most surgeons agree that they wish to provide a tunnel entering the joint in the central tibial footprint. A tibial tunnel placed too anteriorly may lead to impingement of the graft with the intercondylar

roof subsequent graft rupture or fixed flexion deformity which is usually poorly tolerated. An excessively posteriorly tunnel may lead to an incompetent excessively vertical graft or impingement against the PCL causing restricted flexion (Fig. 4.1).

ACL remnant preservation may be useful and may simply aid tibial drill-guide placement. However there is no proven advantage in terms of stability and proprioception recovery for this technique, although there are a number of reports claiming this.

Notchplasty is less performed now, but may be needed for an excessively anteriorly placed tibial tunnel to prevent graft impingement against the femur. A recent animal study shows that notchplasty has increased anterior tibial translation.

Intraoperative X-ray may help improve accuracy and consistency of tunnel placement.

Knowledge of ACL anatomy is the key to avoid technical errors in tunnel placement and has greatly improved in recent years. Unfortunately there is still no consensus on where to place the tunnels!

4.5 Management of Concomitant Injuries

Although often described as "isolated," ACL ruptures are always associated with some other damage, such as the lateral and posterolateral soft tissues [26]. This damage may be minor, and subsequently heal, and have little or no impact on the outcome of ACL surgery. Also anatomical factors such as malalignment and joint surface orientation can profoundly influence how truly "isolated" an ACL tear is. It is most important to recognize these elements in order to address them if required, to avoid either a suboptimal result or later failure of reconstructive surgery.

4.5.1 Associated Ligamentous Injuries

In the 1990s, there was an increasing recognition of the contribution of the role of other ligamentous structures in the pathophysiology of ACL rupture. At that time, descriptions of the anatomy of the "posterolateral corner" and in particular the presence of the popliteofibular ligament led to a dramatic increase in posterolateral corner reconstruction as part of both primary and revision ACL surgery. It was often suggested that not reconstructing the posterolateral corner was frequently proposed as a reason for failure of supposedly technically good ACL reconstructions. The importance of associated injuries should not be underestimated but, in retrospect, it is highly likely that many of the cases that failed around that time would relate to vertical graft position failing to control rotational laxity, rather than being caused by posterolateral corner injury. Nevertheless significant posterolateral corner injuries that are not stabilized are a cause of ongoing issues post ACL reconstruction. Similarly, associated anterolateral soft tissue injuries, which are now being focused on, following description of the anterolateral ligament in recent literature, are also correctly recognized as an important issue in ACL reconstruction. As a result there is renewed interest in adding lateral tenodesis and anterolateral reconstructions at the same time as intra-articular ACL reconstructions.

Medial collateral ligament (MCL) and posteromedial injuries are frequently seen in combination with both anterior cruciate and indeed posterior cruciate ligament injuries. The majority of these can be managed successfully nonsurgically with bracing of grade 2 and 3 MCL tears prior to a delayed ACL reconstruction if needed. However, especially in athletes, surgery for the MCL may often be needed as persisting MCL laxity in this group may significantly compromise outcome or lead to re-rupture of the ACL graft.

The fundamental basis of avoiding problems related to other soft tissue injuries is high-quality clinical examination in clinic or under anesthetic, systematically assessing each of the main ligament complexes. MRI scans are an extremely valuable tool in the assessment of associated ligament damage, but do not replace clinical assessment.

4.5.2 Medial Meniscal Lesions

The role of the posterior medial meniscus in resisting anterior tibial translation is established, and therefore loss of this part of the meniscus

will add stress to an intra-articular ACL graft. If possible, tears in this region should be sutured. Especially in cases with major anterolateral instability, such as revision cases, with loss of most of a medial meniscus, a meniscal allograft transplant should be considered. The "ramp" lesion (usually a menisco-capsular separation of the posterior third of the medial meniscus) occurs in approximately 20 % of acute ACL ruptures. It is often unrecognized as it can only be viewed with the arthroscope introduced through the intercondylar notch into the posteromedial recess, or via a posteromedial portal. They are biomechanically important and need suture.

4.5.3 Alignment Issues

In all ACL ruptures, the patient's natural bony alignment in both coronal and sagittal planes needs to be considered. Many patients have congenital varus or valgus. In these patients, the ACL graft will be subject to increased loading. The same is true of patients with increased posterior tibial slope. Osteotomy is a powerful tool in neutralizing these forces and should be considered especially in gross deformity and in ACL revision cases. Be mindful that medial proximal tibial opening wedge osteotomy tends to increase tibial slope.

4.6 Poor Rehabilitation, Inappropriate Return to Play, and Lack of ACL Rupture Prevention Strategy

ACL reconstruction aims to restore functional stability and enable patients to return to unrestricted activities. Most patients undergoing surgery hope to return to some level of sporting activity. Despite high rates of successful outcome in terms of knee impairment-based function, Ardern et al. [27] report that only 63 % had returned to their pre-injury level of sports participation and 44 % had returned to competitive sport at final follow-up. Failure to return to the pre-injury level of sport is multifactorial including not only surgical details and rehabilitation but also social, psychological, and demographic factors [28, 29, 30].

Following ACL reconstruction, a biological process takes place, which involves ligamentization of the graft [31]. The aim of rehabilitation is to restore the function, strength, and neuromuscular control as quickly as possible without compromising the graft and the biological process that is taking place.

A patient-focused approach is essential for optimal outcomes to be achieved. Before embarking on reconstructive surgery, the patient must understand not only the surgical process but also the rehabilitation required and importantly the rationale behind the criteria for progression. Clear lines of communication need to be established involving the surgeon, patient, and rehabilitation team. The value of this patient-focused, multidisciplinary approach must never be underestimated. While most units will have a well-documented rehabilitation "pathway," the rate of progression should be individually based and should involve all members of the multidisciplinary team.

Elite-level athletes are highly motivated and are able to dedicate time to their rehabilitation. However, nonelite athletes will commonly have to balance rehabilitation, and their desire for success, with their occupation. The nonelite athlete must demonstrate understanding and be able to commit appropriate time to the rehabilitation, especially immediately post-surgery. The patients' ability to dedicate time may impact on the timing of surgery.

Rehabilitation in ACL surgery should commence immediately following the ACL rupture prior to surgery. The immediate aim is to reduce swelling and restore motion. In patients who present acutely the surgery may take place once the swelling is reduced and the joint is moving freely. Unfortunately, for numerous reasons, many patients will not present acutely. Often, by the time of presentation, the knee has recovered from the initial trauma and there is no effusion and a full range of movement. However, the knee is commonly in a poorly conditioned state with weakness of the quadriceps and hamstrings and poor neuromuscular control. Pre-ACL surgery rehabilitation is therefore required, and while there is little evidence to support this, there is clear logic behind optimizing the condition of the knee and the body prior to surgical intervention.

Pre-surgery rehabilitation also enables the patients to gain a greater understanding of the postsurgical program and enables relationships to be developed with the rehabilitating team.

Immediately following surgery, the rehabilitation should focus on reducing swelling and restoring motion. Rest, ice, compression, and elevation (RICE) are essential for swelling management. Cold therapy compression systems, such as the "Game Ready," and electrostimulation may also be used. Full active and passive extension must be achieved as early as possible. Electrostimulation may be helpful in patients who struggle with quads activation immediately post-surgery and may help reduce muscle atrophy in the early phase. Patella mobility must also be restored as early as possible. Once the swelling is down and a full range of motion (including patella mobility) is restored, the patient may progress to strength and conditioning exercises.

During the strengthening phase of the rehabilitation, there will and should be a focus on quadriceps and hamstring strength with the aim of achieving side to side symmetry. However, pelvic and trunk stability must not be overlooked. In order to achieve good neuromuscular control of the knee, the patient must first of all achieve proximal stability. Core and gluteal muscle strengthening is therefore essential.

Progression through the rehabilitation program should be dependent on the patient achieving appropriate milestones as opposed to the time line from surgery. It is important that the patients understand that the time line on rehabilitation programs refers to the minimum time expired before progression to the next stage, which is linked to the biological process taking place. In reality, most nonelite athletes take longer than this time line to achieve the milestones. In this scenario, patients should be reassured and encouraged that they are making safe and steady progress to avoid them becoming demoralized by a perception of failure to progress. It is essential for all members of the multidisciplinary team to remain involved in this process. Healthcare institutions must also recognize that many patients will require additional support and input in order to achieve optimal outcomes. This is particularly relevant in the current economic climate with funding for physiotherapy and outpatient services constantly under threat.

Progression to running is an important milestone. Patients must demonstrate good neuromuscular control and should be able to do a single-leg squat and jump without any difficulty prior to running. A minimum of 3 months must also have passed since the surgery. In reality most patients are not ready to commence running until 4 months post-surgery. Prior to running patients should have also achieved a reasonable level of aerobic fitness by utilizing the bicycle, cross trainer, rowing machine, and swimming with the aid of a pull buoy between the legs.

When to return to play is a complex decision, and while there is extensive literature available [32–34], there is a paucity of robust scientific evidence to use as a guide. The decision must involve the whole team and all aspects of the patients care must be taken into consideration. As a prerequisite, the patient must have demonstrated good pelvic and trunk stability and have good neuromuscular control of the knee. There should be symmetry between the two legs with regard to hamstring and quadriceps strength as well as in functional testing such as single-leg hop height and distance and triple hop distance. The patient must be aerobically fit and must have completed a sport-specific training program including complex training drills. On examination, the knee must lack an effusion and have a negative Lachman and pivot shift. Finally, the player must have confidence in the knee. Any lack of confidence is a clear sign that the player is not ready to return.

Return to play must involve a graduated program with a slow increase in the minutes played. If problems such as swelling are encountered during this process, the player must be withdrawn temporarily, while the swelling is reduced before being slowly reintroduced.

Attention to detail with all aspects of the patient care, both pre- and post-surgery, coupled with a well-motivated patient will result in a high success rate following ACL reconstruction. However, "absolute normality" can never be achieved post ACL surgery; hence, every effort should also be made to prevent such injuries taking place. The FIFA 11+ program is a simple, and easy to implement, sports injury prevention program comprising a warm up of 10 conditioning exercises (Fig. 4.2). Adherence to the program

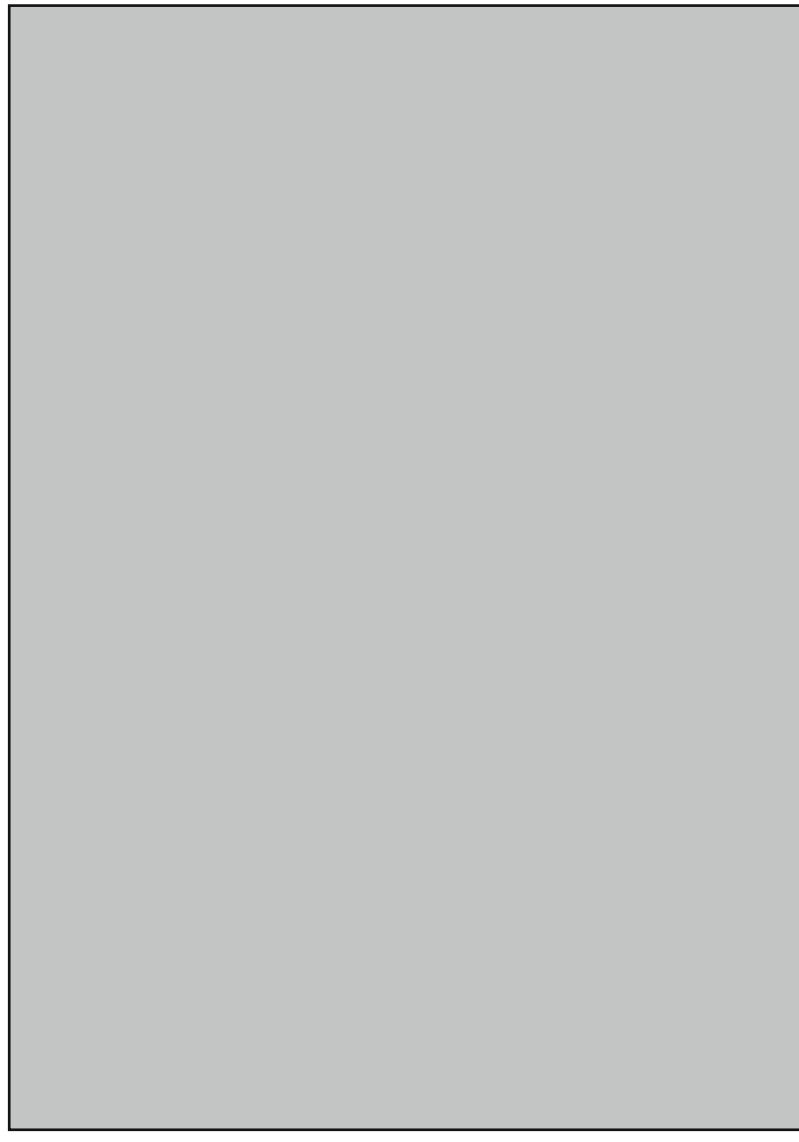

Fig. 4.2 Algorithm of the FIFA 11+ Training Program on Injury Prevention. For seeing the details please go to the website and download "The "11+" Manual – A complete warum-ip programme to prevent injuries". http://www.f-marc.com/downloads/workbook/11plus_workbook_e.pdf

results in an estimated risk reduction of all injuries by 35 % [35]. Other injury prevention programs aim at identifying players who are at increased risk of ACL rupture due to neuromuscular deficits. The exercises used in such injury prevention programs have the potential to improve cutting task biomechanics by ameliorating neuromuscular deficits linked to ACL rupture [36].

Having a well-thought-out rehabilitation program is essential. However, for optimal results, there must be good communication and understanding. Progression through the program must be individually based with the whole multidisciplinary team being involved throughout the process. Poor rehabilitation will result in suboptimal results no matter how good the surgical reconstruction is.

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Stress Fractures in Sport (ICL 5)

5

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5.1 Introduction

Stress fractures arise from the inability of bone to tolerate repeated mechanical loading and are characterized by damage to the bone's microarchitecture. Repeated mechanical loading can cause an uncoupling of osteoblast bone formation and osteoclast bone resorption [1]. This can lead to bone loss and subsequent micro-damage that can result in localized bone weakening, resulting in stress fracture development. The etiology of stress fractures is multifactorial. The rate of occurrence depends on the bone composition, vascular supply, surrounding muscle attachments, systemic factors, and type of athletic activity. From a biomechanical standpoint, stress fractures may be the result of muscle fatigue, which leads to the transmission of excessive forces to the underlying bone. Muscles may also contribute to stress injuries by concentrating forces across a localized area of bone, thus causing mechanical insults that exceed the stress-bearing capacity of the bone (Table 5.1) [2, 3].

From a biomechanical point of view, fatigue fractures are the result of specific, cyclical, and repetitive muscle action until exhaustion, with load transfer to the bone exceeding its adaptation capacity. The shear and compression forces stimulate bone transformation according to Wolff's law, that is, the compression forces promote osteoblast activity and bone deposition leading to a strengthening of bone structures, adapting to the applied load, while shear forces lead to the reverse process of bone resorption by stimulating osteoclast activity. As a result, the majority of stress fractures are located in the areas of shear stress.

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Table 5.1 Potential risk factors and possible mechanics and inter-relationships for stress fractures

Potential risk factors	Possible mechanisms and inter-relationships
Intrinsic mechanical factors	
Bone mineral density	Decreased bone strength
Bone geometry	Decreased bone strength
Skeletal alignment	Elevated bone strain, unaccustomed bone strain, muscle fatigue
Body size and composition	Elevated bone strain, menstrual disturbances, muscle fatigue, low bone density
Physiological factors	
Bone turnover	Low bone density, elevated bone strain, inadequate repair of micro-damage
Muscle flexibility and joint range of motion	Elevated bone strain, unaccustomed bone strain, muscle fatigue
Muscular strength and endurance	Elevated bone strain, unaccustomed bone strain
Nutritional factors	
Calcium intake	Low calcium intake: greater rate of bone turnover, inadequate repair of micro-damage
Caloric intake/eating disorders	Altered body composition, low bone density, greater rate of bone turnover, reduced calcium absorption, menstrual disturbances, inadequate repair of micro-damage
Nutrient deficiencies	
Hormonal factors	
Sex hormones	Low bone density, greater rate of bone remodeling, increased calcium excretion
Menarcheal age	
Other hormones	
Physical training	
Physical fitness	Elevated bone strain, unaccustomed bone strain, greater number of loading cycles, muscle fatigue, inadequate time for repair of micro-damage, menstrual disturbances, altered body composition
Volume of training	
Pace of training	
Intensity of training	
Recovery periods	
Extrinsic mechanical factors	
Surface	Inappropriate surface: elevated bone strain, unaccustomed bone strain, muscle fatigue
Footwear/insoles/orthotics	Inappropriate footwear: elevated bone strain, unaccustomed bone strain, muscle fatigue
External loading	Higher external loading: elevated bone strain, muscle fatigue
Others	
Genetic predisposition	Low bone density, greater rate of bone remodeling, psychological traits
Psychological traits	Excessive training, nutritional intake/eating disorders

Adapted from Bennell et al. [3]

Stress fracture prevalence in elite athletes and military recruits ranges from 1 %, 4 %, to 21 % (!), and most commonly manifests in the lower limbs (tibia, 49 %; tarsal bones, 25 %; metatarsals, 9 %) [3–6]. Although stress fractures have been described in nearly every bone, they are more common in the weight-bearing bones of the lower extremities. Specific anatomic sites for stress fractures may be associated with individual sports, such as the humerus in throwing sports, the ribs in golf and rowing, the spine in gymnastics, the lower extremities in running activities, and the foot in gymnastics [4, 5].

Various conditions contribute to the pathogenesis, which may be classified into group of intrinsic and extrinsic factors. In general, extrinsic factors are related to the type and rhythm of training, the use of unsuitable footwear and sports equipment, precarious physical conditioning, the training location, environmental temperature, and insufficient recovery time of previous injuries. Intrinsic factors include age, sex, race, and bone density and structure; hormonal, menstrual, metabolic, and nutritional balance; sleep pattern; and collagen diseases [2, 7–9].

Prospective and retrospective studies show a higher incidence of stress factors among Caucasians, and compared to American black and Hispanic individuals, white individuals are more susceptible to stress fractures [9, 10]. The same occurs with age: older individuals present a higher incidence of such fractures. Stress fractures are less common in children than adolescents and adults. In relation to sex, some studies have shown that military women have an incidence five to ten times higher than men [10–12]. With regard to genetic factors, studies on identical twin military recruits submitted to the same treatment in quantity, duration, and intensity reveal fatigue fractures in the metatarsal bones [12].

Analysis on structure factors showed that high longitudinal arch of the foot, difference in the length of the lower limbs, and a marked varus foot are associated with multiple stress fractures. Cavovarus feet have recently been gaining more attention as being a significant risk factor for various conditions of overuse, especially stress fractures. This shape of foot is known for being relatively rigid, with weak capacity for attenuating shock. Supination and pronation of the feet are associated with a significant increase in the risk of stress injuries [12–16].

Stress fracture amenability may also have genetic origins, supported by reports of monozygotic twins developing similar stress fracture injuries, multiple stress fractures occurring in the same individual, stress fractures occurring in some individuals but not in others undertaking identical training protocols, and a family history of stress fracture injury acting as a risk factor [16–18].

Genetic associations with stress fracture period prevalence in military personnel have been investigated using a variety of single nucleotide polymorphisms (SNPs) previously associated with receptors known to influence bone mineralization, remodeling, and endocrine abnormalities. Disturbances in bone remodeling and the inability of the bone to withstand repeated bouts of mechanical loading are implicated in the development of stress fracture injury. SNPs located near genes in the RANK/RANKL/OPG signaling pathway are significantly associated with stress fracture injury [19].

5.2 Stress Fractures of the Pelvis and Hip

Stress fractures of the pelvis are considered low-risk stress fractures [20–22] and significantly less common than lower extremity stress fractures (1–7 % of reported stress fractures) [8]. Multiple etiologic extrinsic and intrinsic factors play a role in their evolution: repetitive loading to the axial skeleton, resulting from ground reaction forces and muscle contraction, is inherent to these injuries [5]. Long-distance runners and female military recruits may incur pelvic bone stress injuries at a significantly higher rate [23–25] approx. 4 % of stress fractures in track and field athletes [25]. Female military recruits have the highest reported incidence at 22 % of all stress fractures [23], and low level of aerobic fitness prior to starting training has been found to be a cause of it [26]. The history of amenorrhea has been found to be a risk factor for stress fractures in general [23, 27, 28] due to direct effect of decreased estrogen on bone and subsequently low bone mineral density [29].

Femoral neck stress fractures present about 5–10 % of the fractures in the femoral neck [30]. More common are stress fractures on the compression side (the inferior aspect) of the femoral neck than stress fractures on the tension side (the superior aspect). Weight-bearing forces from the trunk cause a compressive force on the inferior aspect of the femoral neck. They may exceed three to five times the body weight in the femoral neck during running. The load of the runner's body weight is transmitted down the lower extremities through the bones. Muscles help to absorb forces and distribute load, especially the gluteus medius, whereas the superior aspect is subject to tensile forces [23, 31] which could disrupt the blood supply to the femoral head and cause avascular necrosis of the femoral head [31]. Other hypothesized risk factors for femoral neck stress fractures include improper footwear, leg-length discrepancies, and a change of the running surface.

5.2.1 Diagnostics

Pelvic and hip region stress fractures are very difficult injuries to diagnose because the pain associated with such an injury may be poorly localized. A thorough clinical history and physical examination are essential in the diagnosis. Any change to a more intensive training regimen [8, 20, 21, 32, 34], increase in repetitive weight-bearing activities, fresh or previous injuries and stress fractures, or past medical history of metabolic and rheumatologic diseases (e.g., female triad amenorrhea, disordered eating, and osteopenia/osteoporosis) [27, 28] give increased association to the development of stress fractures [27]. The last issue should be an important consideration in the evaluation of the female athlete, with regard to menstrual history and screening for nutritional deficiencies [27].

Clinically, most common symptoms in *pubic symphysis stress fractures* are direct tenderness on the pubic symphysis and on the insertion of the adductors [32, 34], but it could be also presented as chronic pain in the pubic symphysis or groin area and abdominal, scrotal, or perineal pain exacerbated by any type of running activity or kicking [23, 25–36]. The rectus abdominis muscle, adductors, and gracilis muscles are thought to contribute to the development of this injury [32, 35].

Sacral stress fractures are more common presented with an insidious onset of asymmetric low back pain or gluteal pain [33, 34]; pain in the hip, groin, pelvis, and/or lumbar radicular; or sciatica-type [23] symptoms. Most common is tenderness upon palpation on the sacroiliac joint of the affected side and a painful range of motion [37]. Clinically, it is presented by a positive FABER test (flexion, abduction, external rotation of the ipsilateral hip).

In *pubic rami stress fractures*, patients report a history of insidious onset pain on the groin, perineal region, buttocks, or thighs [32, 33], noticeable limp with walking, and direct tenderness on the pubic ramus, with normal or decreased hip range of motion [33].

In *femoral neck stress fractures*, *pain* may be poorly localized in the hip and may be referred to the thigh or back. It is not possible to palpate the femoral neck and determine the presence of the usual bony tenderness of a stress fracture. Pain at the extremes of passive range of motion (ROM), especially external and internal rotation, associated with log rolling, axially loading a supine patient (heel tap), and with single-leg standing or hopping, is the most sensitive sign for stress fractures.

Any lumbosacral nerve root involvement should be excluded by the neurologic examination.

Radiographs of the pelvis (AP, oblique, and outlet views) should be obtained initially for patients with suspected pelvic, sacral, or hip stress reactions/fractures. While early radiographic changes may show faint cortex radiolucency or periosteal reactions in the later stages [38], repeat radiographs after at least 2 weeks of rest may show evidence of bone healing with callus formation. In pubic symphysis stress injuries, plain radiographs may show sclerosis or erosion of the symphysis [34, 35]. *Magnetic resonance imaging* (MRI) has high sensitivity and specificity for detecting and staging of stress fractures ranging them from soft tissue swelling, cortical and medullary bony edema, and the presence or absence of a distinct fracture line [38]. *Nuclear scintigraphy or bone scans* may also be used to not very specific evaluate stress fractures as an increased radiotracer uptake in areas with stress reactions/fractures [38]. *Computed tomography* (CT) scans are not routinely used for evaluation of stress reactions/fractures.

Failure to diagnose femoral neck stress fractures may lead to avascular necrosis of the femoral head and the need for a hip replacement in otherwise healthy young individuals [30, 39–41].

Endocrinal, *mineral*, *metabolic*, *and nutritional assessment* and *evaluation of the athlete's training regimen and equipment* should also be done to address the possible factors contributing to the development of the stress fractures in pelvis, sacrum, and hip region.

Differential diagnosis for pelvis or sacrum stress fractures are muscle injuries including adductor strain, piriformis syndrome, etc., tumors, infection/osteomyelitis, metabolic bone disorders, referred pain from gastrointestinal or genitourinary tract, lumbar disk disease/spinal stenosis, spondylolisthesis or spondylolysis for sacral stress fractures; and for hip stress fractures are: femoral neck fracture, head avascular necrosis, groin injuries, hip dislocation fracture, pointer, tendonitis and bursitis iliopsoas tendini-

tis, osteitis pubis, piriformis syndrome, sacroiliac joint injury, slipped capital femoral epiphysis, snapping hip syndrome.

5.2.2 Management

Most *stress fractures of the pelvis and sacrum* can be treated nonoperatively. The treatment plan should be tailored to the athlete for optimum recovery and return to play [42, 43]. Important for prevention are thorough assessment and modification of training activities (to decrease impact loading of the affected bone) and nutritional factors (adequate calcium and vitamin D intake). Physical therapy could include a core and hip-strengthening program, while the cross training by biking or swimming may be allowed after 1–2 weeks with no symptoms, to avoid deconditioning. The athlete would then be allowed to a gradual increase in activity, if pain-free. Total rehabilitation time for optimum healing and return to activity may take upwards of 4–8 weeks [42].

Non-displaced compression-side hip stress fractures may be treated conservatively. In acute phase, patient should provide a physical therapy treatment with non-weight-bearing and RICE program, with a gradual progression to touch-down weight-bearing and partial weight-bearing activities then to no crutches in 4–6 weeks depending on the clinical response. Activities such as running in water with an appropriate floatation vest, upper-extremity resistance exercises, and aerobic training can be helpful. Upon a gradual return to a running program that takes approximately 2–3 months, if pain returns, decrease the patient's activity until walking is pain-free again.

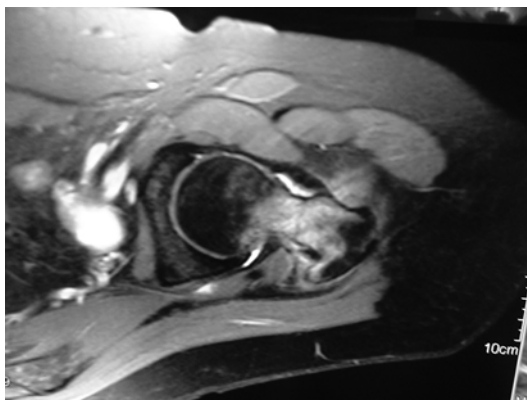

Fig. 5.1 Preoperative MRI of non-displaced tension-side fracture

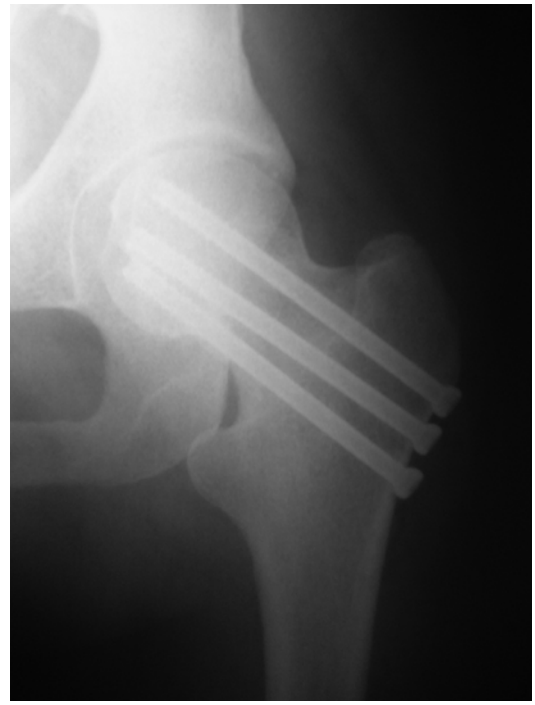

Fig. 5.2 Postoperative X-ray of non-displaced tension-side fracture

Non-displaced tension-side fractures should be treated with operative fixation (Figs. 5.1 and 5.2) [44]. *Displaced fractures* are treated always surgically.

Medications such as nonsteroidal anti-inflammatory agents or in severe cases opioid analgesics may be used in the short term for pain control. In female athletes with a history suggestive of the female triad, oral contraceptive pills may be used to address the amenorrhea.

Take-Home Message

The diagnosis and treatment of pelvic and sacral stress injuries/fractures are made based on an increased index of suspicion. It is important to have knowledge of proper training techniques and adequate nutrition for the prevention of overuse injuries. This should translate not only to the athlete but also to the coaches, athletic training staff, and support staff.

5.3 Femoral Stress Fractures

Femoral stress fractures are usually associated with specific activities, such as long-distance running, jumping, and ballet dancing. Athletes who are older, female, and white are at greater risk for developing this injury and can occur anywhere along the length of the femur. Many authors reported that this injury was under diagnosed in athletes. Distal femoral stress fractures are rare. SF in the shaft of the femur are divided simply as proximal, middle, or distal. They can occur medially or laterally. Distal femoral fractures are also classified as supracondylar, condylar, or subchondral (Fig. 5.3) [6, 7].

Although it is relatively uncommon injury, femoral stress fracture requires prompt diagnosis. Delayed or missed diagnosis can result in complete or displaced fracture that requires more aggressive treatment and associated with high risk of complications [45, 46].

5.4 Tibial Stress Fractures

Factors that predispose tibial stress fractures are very similar as for stress fractures in other regions. *Posteromedial tibial* stress fractures most often occur along the popliteal-soleal line in the middle and distal third of tibial diaphysis and are considered lower risk for complication.

Anterior tibial stress fractures are anterior tension-type fractures and are considered high risk. They are and may be fundamentally different from other tibial SF showing tendency for delayed healing. This tibial area is may be hipovascular which predispose it to malunion or nonunion. The radiographic appearance is a thickened anterior midshaft tibia cortex with radiolucent line. Despite those for a long time, it may be minimally symptomatic. This type of stress fractures has been suggested to benefit from intramedullary fixation (Fig. 5.4). *Proximal medial condylar* stress fractures occur very rarely in elderly patients and typically in distance runner [46, 47].

5.4.1 Diagnostics

Diagnosing of stress fractures requires a detailed medical history and physical examination and always requires a confirmation by an imaging study. Early detection of stress fractures can be difficult. The majority of the cases is detected in 1–3 months

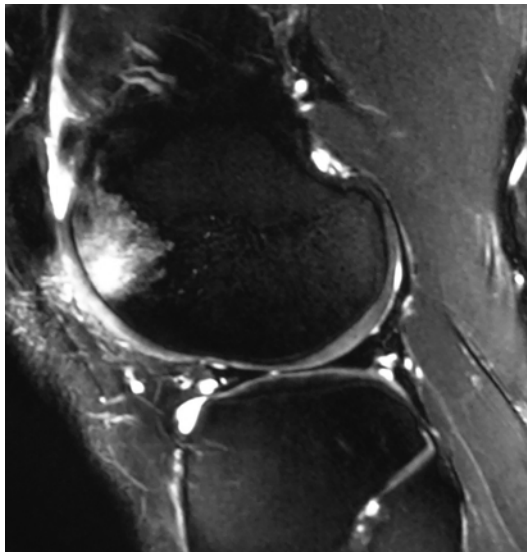

Fig. 5.3 T2-weighted MR image suggestive of lateral femoral condyle "stress reaction" (Image reveals nonspecific edema in basketball player)

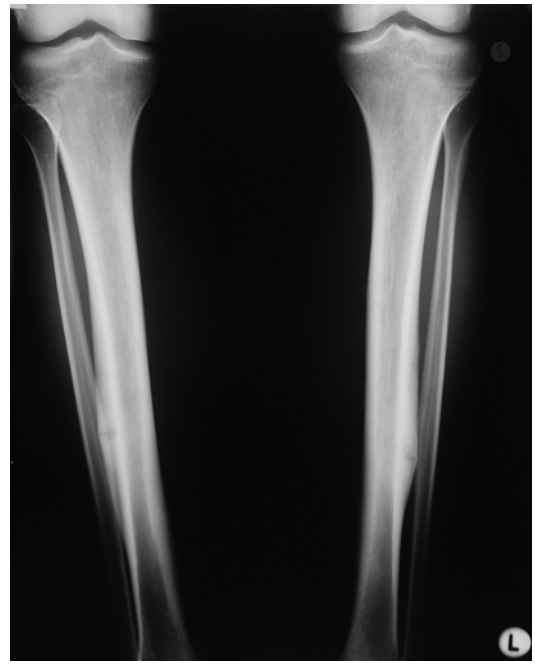

Fig. 5.4 AP X-ray showing bilateral anterior tibial stress fracture in 26-year-old sprinter

after an initial examination. Pain usually starts after the change of usual activity of the athlete, and it is usually nonspecific, insidious in onset, and activity related. The degree of pain may limit or completely suspend the athlete's activity. Swelling of thigh or shin may or may not be present. In cases of femoral stress fractures, the point of maximal tenderness is difficult to localize than in tibia and metatarsals that are subcutaneous. Pains at passive motion of the hip or knee, antalgic gait, and pain at straight leg raise are other signs of proximal femur stress fractures. When bending, twisting, and indirect pressure on the femur or tibia causes pain, it may also be suspected that athlete sustained femoral or tibia shaft SF. In the femoral or tibial condylar stress reactions or fractures, we can find the tenderness of medial joint line and condyle itself. Usually, it is present with effusion, and it seems that the athlete sustained medial meniscus injury or pes anserinus bursitis. The hop test could be used to exacerbate pain in region of the stress fractures. Laboratory tests (e.g., complete blood cell count, alkaline phosphatase, calcium, phosphorus, sedimentation rate, and CRP) are usually not helpful in diagnosing stress fractures. They are only helpful in determining of insufficiency or pathologic fractures. Most stress fractures require imaging studies to confirm the diagnosis. Whatever, plain radiographs, bone scans, and MRI are imaging modalities which are commonly used. Unfortunately, plain radiographs are negative in the early stage of injury, which means at least 2–3 weeks after the onset of the symptoms. On radiographs also we first notice late changes of bone remodeling as a periosteal or endosteal bone formation, thickening of the involved cortical bone, and rarely radiolucent fracture line (Fig. 5.4). Some cases have reported no radiographic changes of stress fractures even after 4 months have elapsed since the onset of symptoms. Technetium bone scan was gold standard for the identification of stress fracture within 72 h, and increase uptake on all three phases of bone scan is diagnostic for stress fractures. But bone scan is not useful tool to monitor the healing process, and it could not distinguish between other conditions such as infection or neoplasm. MRI has emerged as an excellent diagnostic modality for stress fractures. It has higher specificity and may be useful in grading lesions and guiding treatment options. So it not only confirms stress bone reaction or stress fractures but also shows the extent of bony involvement and severity of the pathology (Fig. 5.1). For the identification of early bone marrow edema as an initial sign of bone stress fat-suppression imaging is used. Fat bone marrow is suppressed and the fracture appears as a high signal intensity. As the process advanced, T-1 and T-2 weighted images become positive and identify areas of SF (Fig. 5.5) [47, 48].

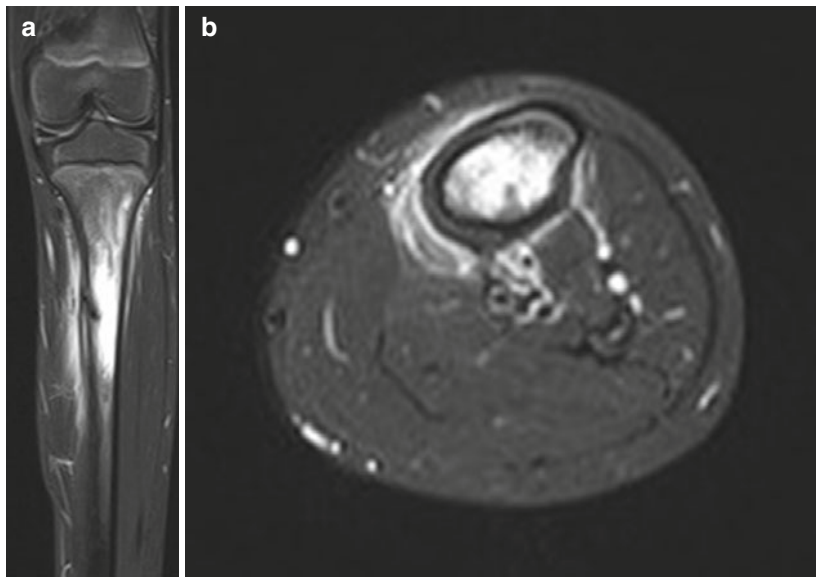

Fig. 5.5 T-2 weighted MR images showing diffuse marrow edema in frontal (**a**) and axial view in a 12-year-old boy (**b**)

5.4.1.1 Differential Diagnosis

However, it is necessary to exclude other disorders that may occur in different cities of the lower limbs before deciding to treat stress fractures. Vascular, inflammatory, infectious, and neoplastic conditions and other overuse injuries could be considered in the differential diagnosis. These conditions include femoral head or condyle avascular necrosis, transient osteoporosis, infection (septic arthritis, osteomyelitis), bursitis, tendonitis, synovitis, impingement hip syndromes, muscle and tendon injuries, and bone sarcoma (osteosarcoma, Ewing sarcoma).

5.4.2 Management

Management of stress fractures includes prevention, conservative treatment, and surgical intervention. Prevention involves educations of athletes, coaches, and parents to recognize the risk factors and understand the impact of excessive physical activity in the relation to the development of all overuse injuries. Most stress fractures are treated *nonoperatively* with excellent results. These patients need a period of rest, which allows the process of bone repair to dominate over resorption. Patient's diet must ensure adequate caloric intake and appropriate quantity of proteins, minerals, and vitamins. For athlete rehabilitation, the correction of training errors that lead initially to SF must be carried out crucially. The use of crutches may be appropriate to decrease the stress in femoral or tibial stress fractures. Unloading braces are used for treatment of femoral or tibial condyle stress fractures. Generally in low-risk stress fractures (e.g., tibial anteromedial stress fractures), the healing process takes at least 6–8 weeks with progressive return to activities. Athletes could be allowed to continue some condition exercises and low-impact activities such as swimming or cycling during the rest of their injured femur or tibia. If the site continues to be asymptomatic, then higher impact activities may gradually be reintroduced. This process can take several months. But on femoral or tibial condylar SF, depending on the amount of bone marrow involvement, cessation of running may be advised for up to 6 months. Repeated X-ray in follow-up is necessary to control the bone healing process [2, 8].

Operative treatment for stress fractures of femur or tibia is considered after failure of nonoperative management, prophylactic stabilization of a fracture at high risk for displacement, tension-side femoral neck stress fractures, any displaced femoral or tibial stress fractures, and malunion or nonunion. Internal fixation in these cases restores the stability of lower extremity and allows an athlete to return as soon as possible to a previous level of activity [2, 8]. Complications are associated with conservative or operative treatment and can result in displacement, malunion, nonunion, avascular necrosis, and arthritic changes. The prognosis for young adults after femoral neck SF is poor. Avascular necrosis develops in 20–86 % of cases [49].

Chronic femoral or tibial stress fractures as indicated by visible fracture line, sclerosis, and cysts on plain radiographs often do not respond to conservative treatment and require surgical intervention [50].

So, some practitioners advocate surgery in high-level athletes to minimize time lost and sooner return to the previous sport's activities. The most popular surgical intervention of choice for this fracture type is intramedullary nailing. Finally, athletes could return to play, when they are asymptomatic at full weight bearing and have no palpable tenderness on the involved area, and imaging studies must show healed fracture [2, 50].

Take-Home Message

Stress fractures in the lower-leg region represent a low incidence but important injury in athletes. Femoral and tibial stress fractures should be suspected on the basis of history and physical examination and confirmed by radiographs, MRI, or bone scans. However, careful assessment of entire involved and contralateral lower extremity as well as the spine is crucial to determine the accurate and early diagnosis. Conservative treatment consists of rest, with gradual resumption of activities after pain which has resolved and in most case

results in excellent outcome. Certain stress fractures (e.g., femoral neck, anterior tibia) will require operative treatment to promote healing and prevent displacement or to reduce a displaced fracture. Complications in athletes with lower leg are rare. Most athletes can expect to return to the previous level of competition and activity.

5.5 Stress Fractures of the Foot and Ankle

Stress fractures in the feet of athletes should be suspected in the presence of insidious pain associated with increased exercise intensity. A thorough history should be obtained for all patients. Physical examination should highlight tenderness on the affected bone. Plain radiography of the site of pain should be requested, with diagnosis in the majority of cases via more sensitive and specific imaging exams (MRI).

The management of stress fractures depends on fracture location, type, and evolution time. Conservative treatment is used in most cases. It consists of rest, not bearing weight, immobilization, and analgesic. Despite the heightened awareness of the diagnosis, the treatment of stress fractures in the foot and ankle continues to be a particularly problematic issue. The long delay in return to play and the risk of delayed union or nonunion favor the surgical treatment. The classification in low- and high-risk fractures helps the decision-making process. Low-risk stress fractures, such as those of the calcaneus cuboid, cuneiform bones, and lateral malleolus, have a better prognosis and can often be diagnosed clinically and treated with activity modification [6, 10, 51, 52]. High-risk fractures, such as the navicular, talus, medial malleolus, proximal fifth metatarsal, and sesamoids, are not prone to spontaneous healing due to various factors such as blood supply, shearing forces across their surface, and location [2, 10, 52–54]. Advanced imaging, strict nonweight bearing, immobilization, and surgery are frequently needed [2, 10, 52].

There are mixed results with bone stimulators [55–60], bisphosphonates [61, 62], hormone replacement [26, 63, 64], and dietary supplementation of calcium and vitamin D [65, 66] for prevention or treatment of stress fractures of the foot and ankle. There are no data to support or refute the use of calcitonin.

Returning to practicing sports should be conducted gradually after consolidation of the fracture, which depends on the grade and location of the fracture, with greater rest time required for high-risk fractures [67, 68].

5.5.1 Management

The *navicular bone* is susceptible to stress fracture based on specific vascular and biomechanical properties. The diagnosis is often delayed, and navicular stress fractures should be suspected in all athletes with foot pain. Physical examination reveals focal dorsal pain on the midportion of the navicular (N-spot tenderness). Advanced imaging should be obtained if initial radiographs are negative. These fractures can heal without surgery, but prolonged immobilization and limitation of activity are required. Aggressive management may be necessary. Operative treatment entails open reduction and internal fixation with or without bone grafting. Displaced fractures may have a higher risk of nonunion and poorer outcomes even with surgical treatment [69].

Stress fractures of the *fifth metatarsal bone* usually occur at the diaphyseal-metaphyseal junction of the fifth metatarsal. These fractures are common in basketball, football, and soccer players. Cavovarus foot or restricted hindfoot eversion is considered a risk factor. Physical examination shows lateral foot pain, tenderness about the fifth metatarsal base, and pain with passive inversion stretch. Because of the high incidence of delayed union and nonunion, a more aggressive management may be considered. If the patient is an elite-level athlete, has persistent unresolved pain, or develops an established pseudarthrosis, then surgical intervention is indicated. Operative treatment using intramedullary malleolar screw and tension band wiring led to good results. Screw placement can be technically challenging while intramedullary fixation can

cause intraoperative fracture of the metatarsal shaft, bicortical penetration, and skin irritation.

The *medial sesamoid* bone is more commonly injured. Stress fractures are common in football players, runners, golfers, and gymnasts. Patient presents pain on palpation and with forced dorsiflexion. Plain radiographs (AP and sesamoid views) and sagittal cuts on CT are used for the diagnosis. Differential diagnosis includes bipartite sesamoid (5–30 % of general population). Nonsurgical management is the standard of care. It includes immobilization, cessation of sport, partial or non-weight bearing, systemic anti-inflammatories, and steroid injections. Operative treatment includes sesamoidectomy [69], partial sesamoidectomy [65], closed reduction and percutaneous screw placement [71], curettage, and bone grafting [72].

5.5.1.1 Future Treatment Options

Foot orthotics is commonly used as aids in the prevention and treatment of foot stress fracture problems. Based on the two broad rationales regarding the design of foot orthotics, (1) "total contact" approach assumes that uniform distribution of the weight on all structures of the foot will limit stresses and therefore improve and protect the foot and (2) "biomechanical" approach postulates that most maladies of the foot and ankle are related to an imbalance in the supporting structures of the foot. Special attention is taken with adjustments to the orthotics along and beneath the affected regions of the foot for adequate pain management and quick recovery to normal sports activities. Requirements for CAD/CAM orthoses' design and manufacturing are specific and give to the patient a possibility for shortening of non-weight-bearing period and rapidly start of training activities upon operation and as a prevention to avoid a possible refracture [73].

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Meniscal Root Tears (ICL 6)

6

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6.1 Anatomy

Matthias J. Feucht

Detailed knowledge about the anatomy of the meniscal roots is crucial when performing root repair, since biomechanical studies have shown that non-anatomic root repair cannot restore native knee joint biomechanics [52, 83]. In addition, meniscal roots are under considerable risk for iatrogenic injuries during different surgical procedures such as meniscal cyst resection, reconstruction of the cruciate ligaments, or intramedullary tibial nailing [24, 55, 56].

Meniscal roots are ligament-like structures that anchor the anterior and posterior meniscal horns to the tibial plateau (Fig. 6.1). Each meniscal root can be divided into three parts: the ligamentous midsubstance ("root ligament"), the transitional zone between the root ligament and meniscal body, and the bony insertion of the root ligament at the tibial plateau [88].

The root ligaments are predominantly oval in shape, with the exception of the anteromedial root ligament, which demonstrates a relatively flat cross-sectional appearance [16]. The mean cross-sectional area of the root ligaments was reported to be 23.2 mm^2 with a mean length of 11.2 mm [34]. However, differences between the

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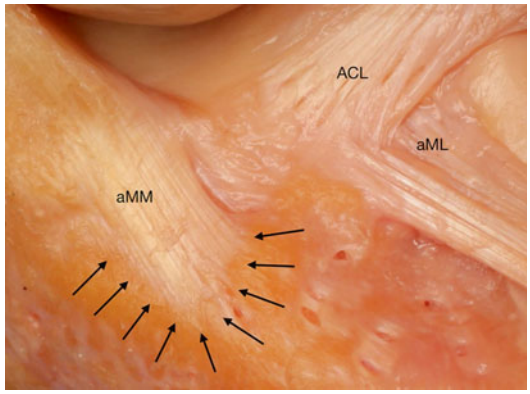

Fig. 6.1 Detailed view of the anteromedial meniscus root (*aMM*). *ACL* anterior cruciate ligament, *aML* anterior root of the lateral meniscus (Reprinted from [86] with kind permission from Springer Science and Business Media)

four roots exist, and the posterior root ligaments are significantly shorter than the anterior ones (Table 6.1).

Histologically, the root ligaments have a microstructure and architecture very similar to that of a "true" ligament with parallel collagen type I fascicles surrounded by membranous septae [88]. The collagen fascicles are continuous between the menisci and the root ligaments [16]. Despite not being considered a "true" ligament by definition, the root ligaments may be considered a ligament that runs through the meniscus with both ends inserting into the tibia [9, 88]. The meniscal roots are well vascularized, comparable to the red-red zone of the menisci [10].

Differences in the collagen arrangement exist between the meniscal body, transitional zone, and root ligament. The collagen arrangement in the root ligament is parallel to the tensile direction of the meniscal attachment, whereas the transitional zone between the meniscus and the root ligament has a rather unorganized structure [30]. The transitional zone between the root ligament and meniscus is considered the weakest link of the meniscal root [30].

The bony insertion of the root ligament is characterized by four different zones: ligamentous zone, uncalcified fibrocartilage, calcified cartilage, and subchondral bone [1, 89]. The topographic anatomy of the meniscal root insertion sites is shown in Fig. 6.2.

Table 6.1 Mean length and mean cross-sectional area of the root ligaments [34]

	Mean length (mm) of the root ligament	Mean cross-sectional area (mm^2) of the root ligament
Anteromedial	13.9	18.7
Anterolateral	13.0	23.2
Posteromedial	7.2	30.7
Posterolateral	9.8	21.7

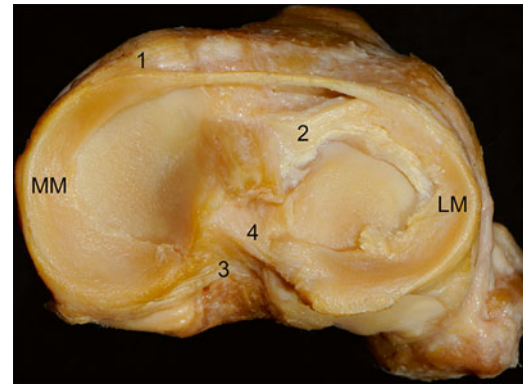

Fig. 6.2 Topographic anatomy of the meniscal root insertion sites. *MM* medial meniscus, *LM* lateral meniscus; *1* anteromedial root; *2* anterolateral root; *3* posteromedial root; *4* posterolateral root

The posterior root of the medial meniscus inserts on the downslope of the posterior intercondylar fossa, posterior to the medial tibial eminence apex, lateral to the articular cartilage margin of the posteromedial tibial plateau, and anteromedial to the tibial insertion of the posterior cruciate ligament [39, 40].

The posterolateral root attachment is located posterior to the lateral tibial spine, medial to the articular margin of the posterolateral tibial plateau, and adjacent to the posterolateral border of the tibial insertion of the anterior cruciate ligament (ACL) [39, 40]. The insertion pattern of the posterolateral root was described as more diverse and complex compared to the posteromedial root [46, 76]. Three different attachment patterns have been described in a recent study [93]: In most cases (76 %), the posterolateral root showed two insertion sites with the major component attaching to the intertubercular area with anterior extension into the medial tubercle and the minor component attaching to the

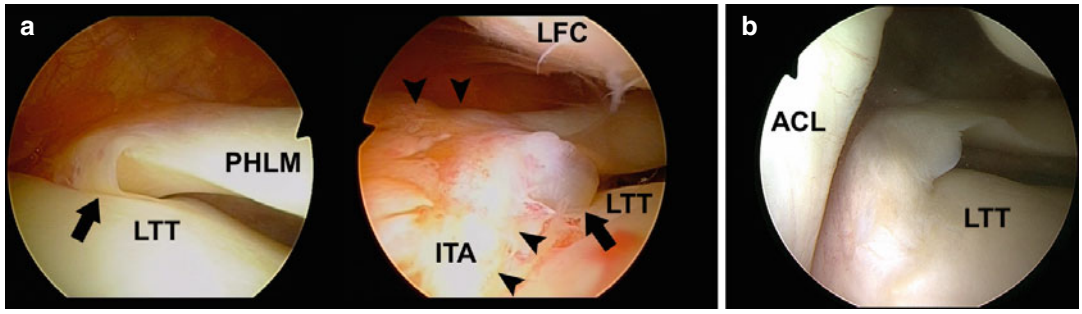

Fig. 6.3 Different attachment patterns of the posterolateral meniscal root. (**a**) Example with two insertion sites: the minor component is attaching to the lateral tibial tubercle (*arrow*), whereas the major component is attaching to the intertubercular area over a broad area (*arrowheads*). (**b**) Example with a single insertion site to the lateral tibial tubercle. *ACL* anterior cruciate ligament, *ITA* intertubercular area, *LFC* lateral femoral condyle, *LTT* lateral tibial tubercle, *PHLM* posterior horn of the lateral meniscus

posterior slope of the lateral tibial tubercle (Fig. 6.3a). In the remaining 24 %, the posterolateral root showed a solitary insertion site to either the intertubercular area or the posterior slope of the lateral tubercle (Fig. 6.3b), respectively.

The insertion of the anteromedial root is located anterior to the apex of the medial tibial eminence, anterolateral to the articular margin of the anteromedial tibial plateau, anteromedial to the anterior border of the ACL, and anteromedial to the center of the anterolateral root [40, 51]. However, several anatomic variants of the anteromedial root attachment have been described [15, 41]. Based on a cadaveric study [12], four different insertion types have been described (Table 6.2).

The anterolateral root attaches anteromedial to the apex of the lateral tibial eminence, anteromedial to the articular margin of the anterolateral tibial plateau, and anterolateral to the center of the ACL insertion [40, 51]. The fibers of the anterolateral root ligament commonly blend with the ACL [16, 76]. Quantitatively, the overlap comprises 63 % of the anterolateral root attachment and 41 % of the tibial footprint of the ACL [51]. This intimate relationship between the anterolateral root and ACL must be taken into account during anatomic ACL reconstruction, since tibial tunnel reaming may significantly decrease the anterolateral root attachment area and ultimate failure strength [55].

The reported mean footprint areas of the meniscal roots vary largely among different studies (Table 6.3). These differences may be attributed to different dissection techniques and an inconsistent definition of the meniscal root attachments. It has been shown that the meniscal roots consist of a dense central portion and a various amount of supplemental fibers [20, 39].

Table 6.2 Different anteromedial meniscal root insertion types [12]

Type	Insertion area	Frequency (%)
I	Flat intercondylar region of the tibial plateau	59
II	Downward slope from the medial articular plateau to the intercondylar region	24
III	Anterior slope of the tibial plateau	15
IV	No firm bony insertion	3

Johannsen et al. described a large posterior-based sheet of supplemental tissue of the posteromedial meniscal root, which they termed the "shiny white fibers" [39]. These supplemental fiber expansions are not considered part of the central root attachment because they are not part of the dense root insertion. However, it has been shown that the supplemental fibers significantly contribute to the biomechanical properties of the native meniscal root [20]. Similarly, supplemental fibers were also observed at the posterolateral and anteromedial meniscal root [20, 39, 51]. These supplemental fibers significantly contribute to the attachment areas of the meniscal roots (Tables 6.4 and 6.5). The shiny white fibers, for example, were shown to account for 31 % of the

Table 6.3 Mean footprint areas of the meniscal root attachment sites (in mm^2) according to different authors [39, 40, 46, 51]

	Johnson 1995 [40]	Kohn 1995 [46]	Johannsen 2012 [39]	LaPrade 2014 [51]
Anteromedial	61.4	139	–	56.3
Anterolateral	44.5	93	–	140.7
Posteromedial	47.3	80	30.4	–
Posterolateral	28.5	115	39.2	–

Table 6.4 Differences of the mean footprint area measured with and without the supplemental fibers [20]

	Mean footprint area (mm^2) with supplemental fibers	Mean footprint area (mm^2) without supplemental fibers	Difference (%)
Anteromedial	101.7	57.0	44.7
Anterolateral	99.5	–[a]	–[a]
Posteromedial	68.0	41.6	26.4
Posterolateral	83.1	57.7	25.5

[a]No supplemental fibers observed

Table 6.5 Schematic overview rehabilitation per phase

	Week 0–6	Week 6–12	Month 3–6
Weightbearing	Non-weight bearing	Partial weight bearing progressing to full weight bearing by 8 weeks	Full weight bearing
Range of motion	0–90	0–130	Full
Exercises	Isometric quadriceps exercises	Isotonic quadriceps strengthening	Continue strengthening
		Closed kinetic chain exercises	Running (first in straight line)

native posteromedial root attachment area [20]. Although the supplemental fibers contribute to the strength of the meniscal roots, it remains unclear if these fibers must be included in root repair procedures [54].

With regard to root repair, available studies on the quantitative arthroscopically pertinent anatomy [39, 51] and quantitative radiographic guidelines [38, 87, 91, 92] may facilitate anatomic root repair. Knowledge about these data is therefore recommended before starting to perform root repair procedures.

The menisci and insertional ligaments comprise a functional unit [65]. Within this context, two further anchoring structures have to be mentioned: the anterior intermeniscal ligament (anterior transverse ligament) and the meniscofemoral ligaments.

The anterior intermeniscal ligament connects the anterior horns of the medial and lateral meniscus. The prevalence has been reported to be 50–94 % [12, 51, 69]. Overall, the anatomical variability of this ligament is substantial, and its functional role remains unclear [65]. Nevertheless, it has been reported to serve as the primary anchor of the anteromedial meniscal horn in some specimens without distinct anteromedial root attachment [12, 69].

Beside its tibial attachment via the posterolateral root, the posterior horn of the lateral meniscus is also anchored to the lateral side of the medial femoral condyle via the meniscofemoral ligaments. One ligament runs anterior to the posterior cruciate ligament (ligament of Humphrey), whereas the other runs posterior to the posterior cruciate ligament (ligament of Wrisberg). The prevalence of at least one meniscofemoral ligament has been reported to be >90 % [32]. Comparable to the posterolateral meniscal roots, these structures play a significant role in stabiliz-

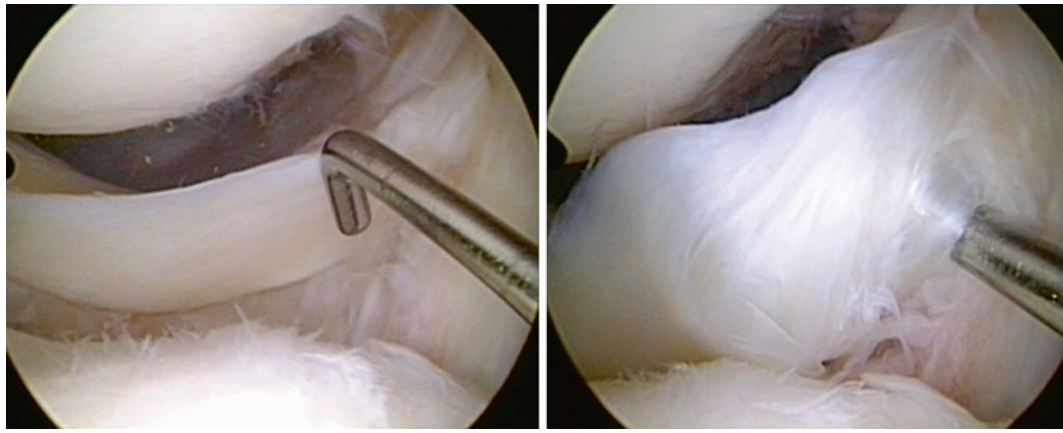

Fig. 6.4 Example of a posterolateral root tear with an intact meniscofemoral ligament (MFL). The posterolateral root is detached from the tibial plateau. Probing reveals a strong MFL (Reprinted from: Feucht et al. [25] with kind permission from Springer Science and Business Media)

ing the lateral meniscus and load transmission of the lateral tibiofemoral compartment [7]. The presence of an intact meniscofemoral ligament may therefore influence the biomechanical consequences of a posterolateral meniscal root tear (Fig. 6.4) [27, 31].

6.2 Biomechanics

Christian Stärke

Intact roots are essential for the knee meniscus to maintain its function in terms of load distribution and stabilization. A key mechanism that depends on the integrity of the meniscal root is the conversion of radial forces into so-called hoop stress. Such radial forces occur, for example, with axial tibiofemoral loads [83]. The wedge shape and ultra low friction between the cartilage and meniscal surface cause a centrifugal translation of the meniscus out of the joint space. However, due to the strong attachments of the meniscus roots to the bone, it behaves like a closed ring structure: a radial expansion of the meniscus causes circumferential tension, the hoop stress. This theory is founded by the fact that strong collagen I bundles as found in tendons and ligaments extend in the circumferential direction of the meniscal tissue [73]. In an intact knee, the shape and size of the menisci correspond closely to the tibiofemoral surfaces, which cause effectively a substantial enlargement of the contact area [36]. A complete radial tear of the meniscus or a root tear leads to the situation that no restraint to the radial forces is given and an extrusion of the meniscus out of the joint space occurs (Fig. 6.5).

No conversion of the axial load into hoop stress takes place anymore in this case, and the tibiofemoral contact area is dramatically reduced. Allaire et al. used sensor arrays to measure the pressure distribution within the medial tibiofemoral compartment and found that a root tear had effects similar to a complete meniscectomy [6]. This was supported by other authors showing similar results [64]. The impact of a root tear on the knee biomechanics has been considerably underrated in earlier years. It is in fact possible that the arthroscopic appearance of the meniscus is largely normal except for the torn root, giving the false impression of minor damage, while a functional meniscectomy results from such lesions (Fig. 6.6).

Most clinical data as well as biomechanical research is about medial meniscal root tears, because these are observed more frequently. There is disagreement as to the effect of root tears in the lateral meniscus. Because of the meniscofemoral ligaments of the lateral meniscus, which are present in the vast majority of

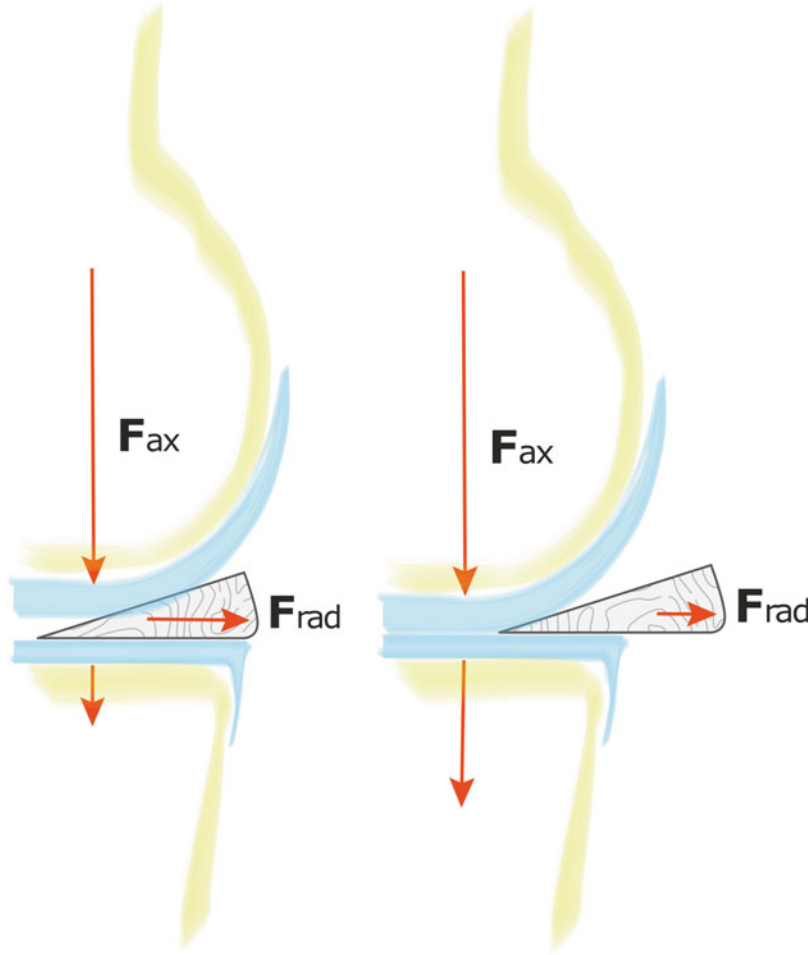

Fig. 6.5 Tibiofemoral loads cause radial forces in the meniscus. With an intact root those are converted into hoop stress (*left*). If the root is torn, this mechanism is broken and the meniscus dislocates from the joint space. Increased tibiofemoral contact stress results (*right*)

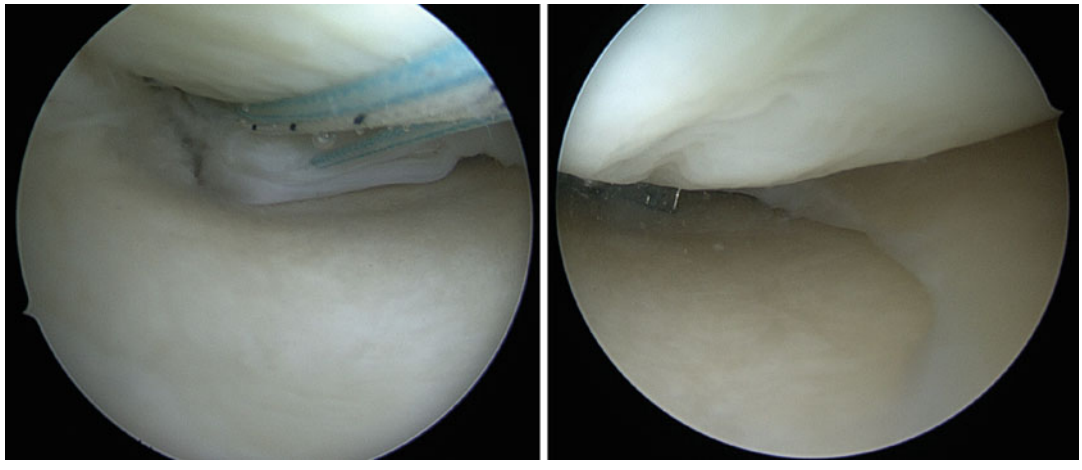

Fig. 6.6 Root tear that has not been recognized on earlier arthroscopy. Appearance of the meniscus body is normal, while a functional meniscectomy results

patients, a tear of the posterior tibial root does not cause a complete disruption of the ring structure. A substantial extrusion seems not to occur in the lateral menisci when only the posterior tibial attachment is involved [75]. Also, no significant effect on the tibiofemoral load distribution was observed as long as the meniscofemoral ligaments remain intact [26]. Are these torn too a functional meniscectomy results similar to a medial meniscal root tear? However, the menisci are not only relevant to increase the tibiofemoral contact area but also to guide knee motion and provide additional stability. Recently, it was shown that lateral meniscal root tears increase the pivoting found with ACL deficiency [80]. Thus, while the impact on the pressure distribution might be minor, lateral root tears could affect knee kinematics. They might not be as harmless as thought earlier, and repair should be considered. Changes in joint kinematics were also found for medial meniscal root tears. In one study the lateral translation of the tibia was significantly increased as was the medial compartment excursion compared to the unaffected contralateral side [63]. Kopf et al. determined the failure load of meniscal roots. Depending on the location, failure occurred between 407 and 692 N on average [48]. The authors assessed also the stability of different suture techniques and found that all were substantially inferior to the failure load of the native root.

Repairing a torn root can theoretically restore normal loading patterns in the tibiofemoral compartments as shown in a biomechanical study [64]. It is important to realize that an anatomic repair of the root is essential. Repairing the root too tight causes undue circumferential tension in the meniscus, while a loose repair leads to a loss of function [52, 83]. So far it is unclear which method of fixation yields the best results in a biomechanical sense. A transtibial pull-out suture is probably the method of choice for most surgeons, but anchor repair of torn roots has been described as well. The load to failure is similar for both methods, but elongation and stiffness are reduced with the anchor technique [22]. The forces acting on repaired medial meniscal root tears have been found to depend mainly on the tibiofemoral load and rotation. For example, internal rotation of the femur with the tibia fixed can cause tensile forces that could exceed the failure load of common suture materials [84]. At least for pull-out sutures, it was demonstrated in biomechanical tests that the initial reduction of the avulsed root is not maintained under cyclic load and the suture loosens out [77]. This affects also cartilage loading that thus increases over time (Fig. 6.7). Therefore, a slight over-tightening of the suture might be justified or strict unloading necessary. Also the suture technique affects the stability of the repair. A modified Kessler stitch or Mason-Allen suture should be considered [21, 48].

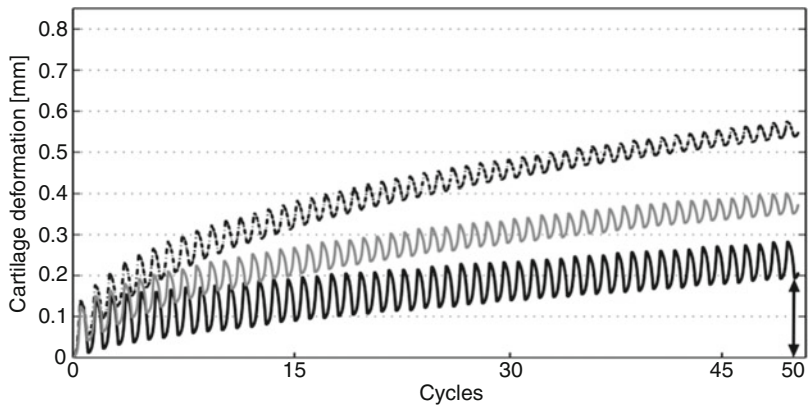

Fig. 6.7 Cartilage deformation under cyclic tibiofemoral load measured with the posterior medial meniscal root intact (*lower curve*), detached (*upper curve*) and repaired (*middle curve*). The detachment of the meniscal root increases cartilage stress significantly which is not fully normalized after the repair (With kind permission from Springer Science + Business Media: Röpke et al. [77])

Ellman et al. demonstrated that the meniscal roots have also supplemental fibers, for example, the "shiny white fibers" in the medial posterior root. In the case of the posterior medial root, those accessory fibers account for about a third of the insertion area and almost 50 % of the failure strength of the root. They are, however, usually not reconstructed with conventional techniques, which could explain that root repair often fails to restore normal biomechanics [20].

6.2.1 Conclusion

Meniscal root tears have profound effects on load distribution and kinematics of the knee. Repair should therefore be attempted from a biomechanical point of view. A mechanically sufficient suture can be challenging, and post-op unloading is usually required.

6.3 History and Clinical Examination

Michael T. Hirschmann

Two entities of meniscus root tears are distinguished: (i) traumatic and (ii) degenerative root tears. *Traumatic* root tears occur mainly in younger patients (up to 40 years) who experienced an adequate trauma. The posterior root of the lateral meniscus is mainly involved, and often patients have associate ligament injuries of the knee. In rare case of an isolated meniscus root tear, patients may report a popping, a locking of the knee, and a joint effusion [11]. It is hard to clearly identify a root tear under these circumstances in an acute setting, as classical meniscus tests cannot be applied. In a chronic setting, classical meniscus test such as described below can be used. However, even then it will be hard to distinguish a meniscal tear of the corpus from a root tear with only the history and the examination. Though, diagnosis relies on MRI or surgery [13].

On the other side, *degenerative* root tears occur mainly in older (>50 years) female obese patients, who often did not experience an adequate trauma. Sometimes they cannot even recall a trauma. Complains and symptoms are very similar to patients with degenerative meniscus lesions of the corpus. Typically, patients describe weight-bearing pain mainly on the affected side – medial or lateral. The pain can be aggravated during rotation of the knee. Squatting is also often painful, and some patients report about temporarily locking. Baker's cyst with its typical symptoms such as swelling in the popliteal fossa and pressure sensation can also occur. Many of the patients have already some degree of OA, which might interfere with the symptoms of the root tear. Thus, swelling, increasing pain over the day and during activity, and exacerbated pain during the first steps after sitting are reported. Generally, clinical examination and tests for meniscal root tears are similar to clinical examination performed in case of other meniscal lesions or OA.

Clinical assessment starts when the patient enters the outpatient clinic. Alignment, gait, and limping should be assessed. Clinical assessment starts with a detailed clinical history. Here, the most important factor is the course of the patients' symptoms and screening for the aforementioned typical findings.

After assessment for swelling, joint effusion, and range of motion, specific meniscus tests should be performed. The surgeon should use a mixture of tests. Just to introduce here are a few of the most commonly used meniscus tests:

The McMurray test is among the most commonly used clinical tests to identify a meniscal tear (Fig. 6.8) [42, 62, 67]. Although it is a relatively specific test (from 77 % to 98 %), the sensitivity of the McMurray test is relatively low (from 16 to 58 %) [19, 29, 37, 50, 67]. The modification of the interpretation of a positive test including reproduction of pain and/or adding varus and valgus components and/or an axial compression seems to be more helpful than the original version increasing the validity of the test [35].

Joint line tenderness is among the most basic maneuvers, yet it often provides more useful information than the provocative maneuvers designed to detect meniscal tears [35, 42, 47, 67].

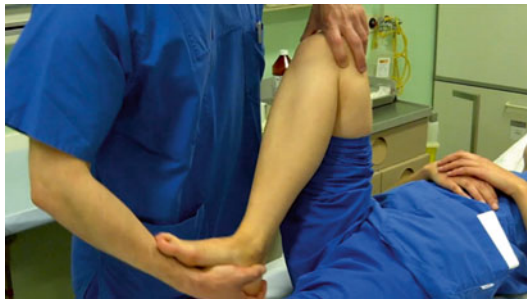

Fig. 6.8 McMurray test of the right knee. The index finger is put at the joint line (without performing pressure). The knee is in maximum flexion and varus stress can be applied. The next step would be to externally rotate the tibia and slowly extend the knee. The test is positive if the examiner feels a click or the patient experiences pain

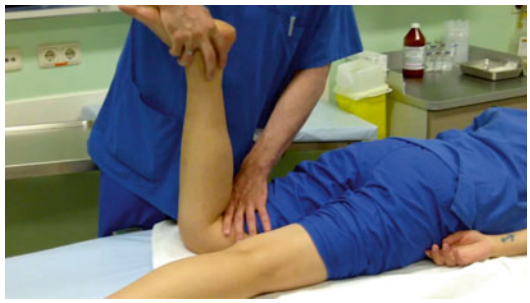

Fig. 6.9 The Apley grinding test is performed with the patients in a prone position with a 90° flexed knee. Pressure is axially applied onto the leg, and the tibia is rotated internally and externally. The test is positive for a medial meniscal (*root*) tear if the patient experiences pain in external rotation of the tibia and the other way around for the lateral meniscal (*root*) tears

Joint line tenderness has a fairly good sensitivity from 55 % to 85 %, but lacks good specificity with values going from 15 to 77 % [29, 37, 50, 67, 82].

The Apley compression test has a poor sensitivity (13–50 %), but is considered to be a specific test (60–90 %) (Fig. 6.9) [29, 42, 50, 67].

In the Apley distraction test, instead of compressing, the examiner distracts the tibia away from the femur while rotating the tibia. The test is considered positive if pain occurs and refers to a joint capsule or ligament lesion and is used to help to differentiate between synovitis and meniscus-related issues. Therefore, a combination of tests is useful.

6.3.1 Conclusion

The traumatic meniscal root tear has to be distinguished from the degenerative meniscal root tears. In traumatic meniscal root tears, diagnosis mainly relies on MRI or arthroscopy. In the degenerative root tears, history and clinical examination including meniscus tests for root tears are similar to other meniscus lesions. OA as a concomitant disease has to be kept in mind in those patients. MRI adds to the final diagnosis.

6.4 Radiologic Diagnostics

Anna Hirschmann

Radiologically meniscal root tears are mainly diagnosed by magnetic resonance imaging (*MRI*). *Radiographs* aid in assessing the degree of osteoarthritis (OA), which often accompanies degenerative meniscal root tears. The degree of OA plays an important role for the treatment decision, e.g., root repair, arthroplasty, etc. Furthermore, upright full-length leg radiographs allow an objective and precise evaluation of the leg axis, which is important for the decision of potential knee osteotomies if a malalignment accompanies a meniscal root tear. Thus far, ultrasound seems to play no relevant role for diagnosis of meniscal root tears.

6.4.1 MRI

In general, the assessment of all four roots is crucial in any MRI evaluation of the knee, whereby the knowledge about the anatomy is essential. Optimal image quality is mandatory and can be achieved by a high spatial resolution. Increase of matrix size, a small field of view (<16 cm), and maximum slice thickness of 3 mm improve the spatial resolution [71]. The signal-to-noise ratio has to be improved by using a dedicated knee coil and highest possible magnetic field strength. The following sequences should be included in an MRI protocol: T1-weighted coronal, intermediate-weighted fat-saturated coronal, sagittal, and axial.

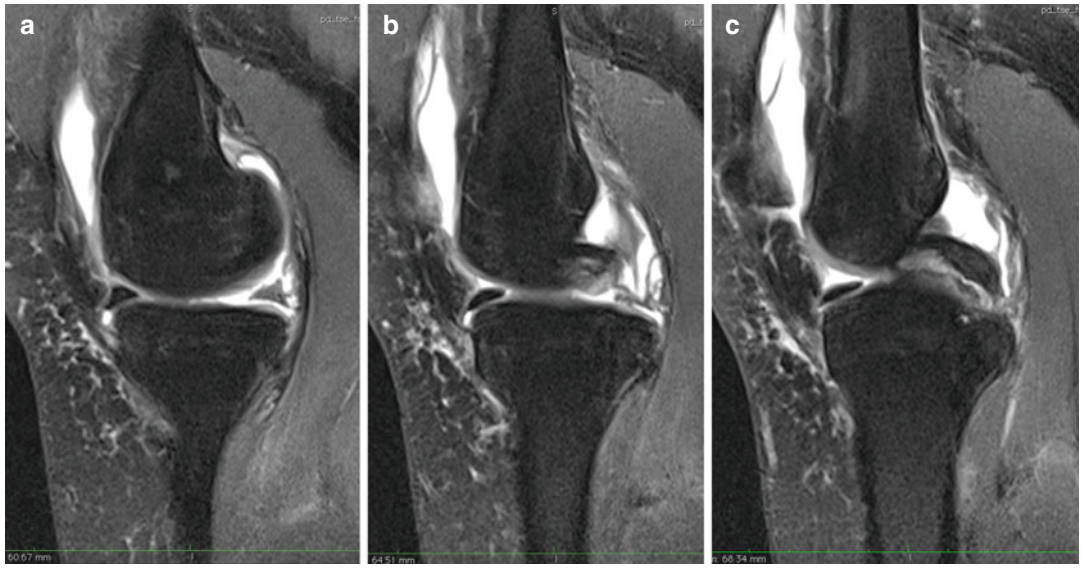

Fig. 6.10 Sagittal intermediate-weighted images showing a posterior root tear of the medial meniscus. Additionally, posterior meniscocapsular separation and partial tearing of the posterior capsule of the knee joint have to be noticed

Alternatively coronal or sagittal intermediate-weighted sequence may be without fat saturation in order to gain a higher resolution. Additionally, a high-resolution 3D sequence may be added allowing multiplanar reformations.

Anatomical pitfalls of the meniscal roots have to be noticed, e.g., the striated appearance of the anterior root of the lateral meniscus [71]. The anterior root of the medial meniscus may insert on the anterior margin of the tibia and may not be mistaken for a meniscal extrusion [45, 71].

All image planes should carefully be assessed for possible meniscal root tears. Meniscal root tears are typically radial tears and can be incomplete or complete (Figs. 6.10, 6.11, and 6.12). The intact posterior meniscal root coursing over the corresponding tibial plateau should be visualized on one coronal image. On sagittal images, the intact medial and lateral posterior meniscal roots should appear on the following medial and lateral image of the posterior cruciate ligament. Paying attention to the meniscal roots on MRI increases the sensitivity and specificity of tears to up to 90 % and 95 %, respectively [81].

In patients with partial or complete tears of the anterior cruciate ligament, careful assessment for posterolateral meniscal root tears is mandatory [45]. Posteromedial root tears can occur in patients with grade 3 medial collateral ligament tears and intact meniscal capsular ligaments [45].

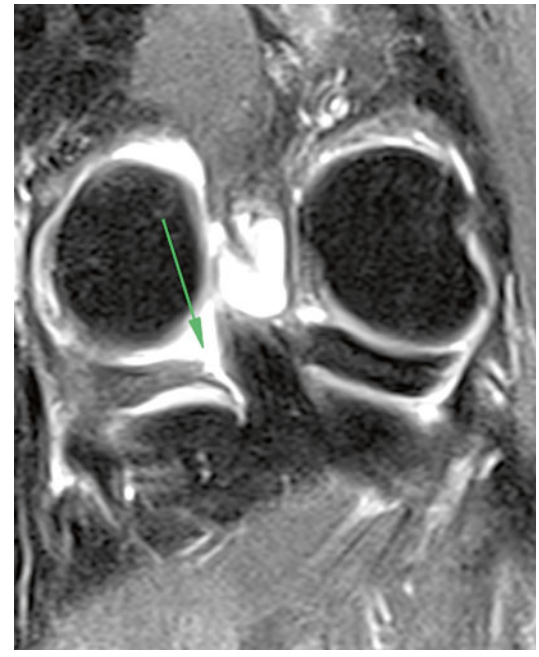

Fig. 6.11 Coronal T2-weighted fat-saturated image shows a posterior root tear of the medial meniscus. Only a tiny remnant of the root is not retracted (*arrow*)

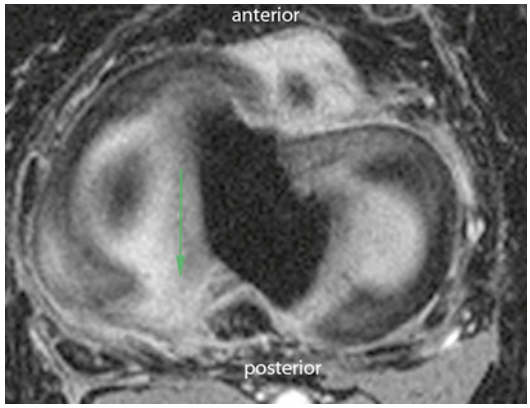

Fig. 6.12 High-grade incomplete radial tear (*arrow*) of the posteromedial meniscal root on this axial image. The corpus of the meniscus is shifted medially

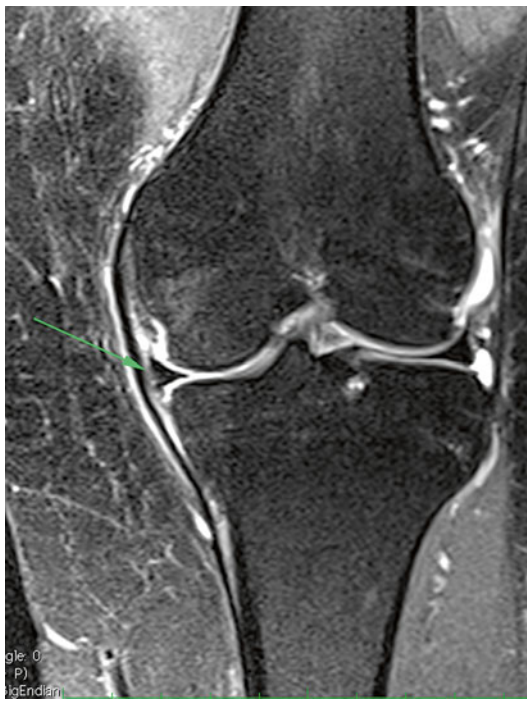

Fig. 6.13 Coronal intermediate-weighted fat-saturated image shows an extruded medial meniscus (*arrow*); careful assessment of the posteromedial meniscal root is mandatory

For acute root tears, concomitant injuries such as ligament tears, especially the meniscofemoral ligaments, play an important role. For degenerative tears, the degree of cartilage lesions is rather important.

A complete meniscal root tear is often associated with a meniscal extrusion (Fig. 6.13). Displacement of the meniscus more than 3 mm over the edge of the tibia is defined as extrusion [71]. The extrusion can also be recognized in horizontal meniscal tears, but in this case the degree of extrusion is less compared to root tears [85]. Meniscal extrusion occurs more often on the medial side. Beside the meniscal roots, the lateral meniscus is stabilized by the meniscofemoral ligaments; thus, an extrusion only happens if these ligaments are torn too.

6.4.2 Radiographs

We recommend upright anteroposterior and lateral X-rays of the knee joint. Additionally, Rosenberg view and full-length radiography can be obtained. The degree of OA can easily be assessed using radiographs. Full-length radiography is needed to evaluate the leg axis and the degree of malalignment for a potential osteotomy.

6.4.3 Conclusion

Best imaging modality in the evaluation of meniscal root tears is MRI. Meniscal extrusion can be a sign for a meniscal root tear. Additional X-rays aid in the assessment of potential osteoarthritis or malalignment.

6.5 Treatment of Traumatic Meniscus Root Tears

Nicolas Pujol

6.5.1 Introduction

The meniscus plays a key part in the shocks absorption, the distribution of the loads in the femorotibial joint, proprioception, and anteroposterior stabilization (secondary brake). Lesions of the meniscal roots, especially if due to a trauma

in active patients, are now better individualized: lesions of the roots can increase the peaks of constraints into the cartilage, comparable to a subtotal meniscectomy [26]. The absence of treatment would support painful knee, meniscal extrusion, joint line narrowing, and therefore degenerative changes [74]. These lesions are mainly related to the posterior root of the lateral or the medial side. Meniscal root lesions can involve true avulsions from the tibial insertion or radial lesions close (<1 cm) to the root, and classifications have been developed [5, 28, 53]. Posterolateral meniscal root tears are commonly associated with tears of the ACL [66]. In a series of 559 knee MRIs with arthroscopic correlation, De Smet et al. [81] reported an overall incidence of 2.9 % for posterolateral meniscal root tears. In patients with ACL tears, the incidence was overall tenfold higher compared with patients without ACL tears (8 % and 0.8 %, respectively).

6.5.2 Indications

There are several treatment options to treat root tears, and it is still a subject of controversy. Nonoperative treatment has been proposed. Shelbourne et al. [79] evaluated the outcomes of 33 patients with posterolateral meniscal root tears left in situ during ACL reconstruction and compared the results with those for matched patients with intact menisci at the time of ACL reconstruction. After a mean follow-up of 10.6 years, no differences in subjective or objective scores were observed between the two groups. However, patients with a posterolateral root tear showed significant lateral joint space narrowing compared with the control group. Anderson [8] et al. suggested that not all posterolateral root tears require repair. If the posterolateral meniscus horn is still attached to the posterior meniscofemoral ligament, root repair may not be necessary. However, the impact of an intact posterior meniscofemoral ligament in the case of posterolateral root tear is not fully understood.

Meniscectomy seems to have detrimental effects in the short term. The most commonly used operative techniques for repair are side-to-side suture techniques or transtibial pull-out suture [57]. Anderson et al. [8] reported that 24 patients after combined ACL reconstruction and lateral meniscal root repair by side-to-side suture ($n=8$) or transtibial pull-out repair ($n=16$) resulted in 92 % of repairs functioning successfully. In this study, nonoperative treatment was compared with operative treatment. The results indicated that patients after operative treatment tend to reach a higher functional score and lower rates of osteoarthritis compared to conservative treatment.

Only one study compared posteromedial meniscal root repair and partial meniscectomy of the medial meniscus retrospectively [43]. This study demonstrated superior clinical scores and less joint space narrowing in patients after pull-out suture repair compared with partial meniscectomy.

Surgery can be proposed to young patients with a traumatic and complete lesion of the roots, mainly concomitant with an ACL reconstruction (Fig. 6.14).

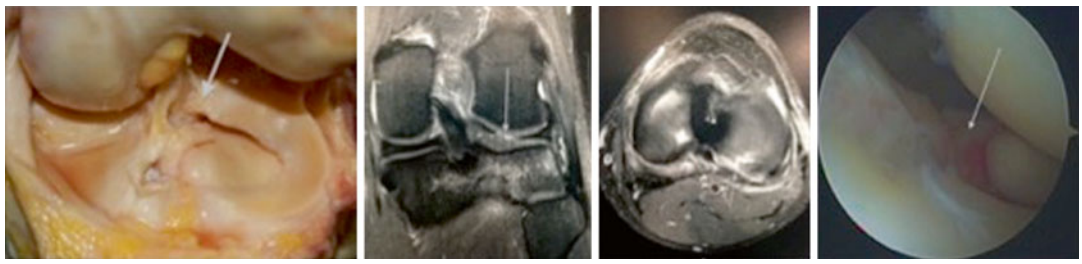

Fig. 6.14 Example of a posterior root tear of the lateral meniscus with anatomic and MRI correlations. *Arrow* showing the root lesion

6.5.3 Surgical Technique

The patient is placed with knee at 90° of knee flexion, with a pneumatic tourniquet. The hardware requirements are:

- 30° and/or 70° arthroscope,
- 4.5 mm shaver
- Tibial anterior cruciate ligament (ACL) drill guide
- Guide pin
- Cannulated reamer (4.5 or 5 mm of diameter)
- Curved hook

Standard anteromedial and anterolateral arthroscopic portals are initially made, followed by one or two posterior portals. Diagnosis is also confirmed under arthroscopy. The associated lesions are also addressed: cruciate ligaments, focal cartilaginous lesions, and other meniscal lesions. Once the diagnosis is carried out, the quality of the meniscal tissue is appreciated (reductibility). Sometimes a debridement of the capsule around the meniscal root is needed before repair. The zone of tibial insertion is abraded with a shaver until subchondral bone. An ancillary tibial drill guide is set up by the most direct way (medial for a medial root tear, lateral for a lateral tear) in the root footprint, by the intercondylar notch. If difficult, this guide can be placed by a posterior portal, especially to reach the footprint of the posterior root of the medial meniscus (Fig. 6.15). Guide pin and 4.5 or 5 mm reamer are also used to make the tibial tunnel. A hook is introduced into the joint in order to pass two sutures into the meniscal root (Figs. 6.16 and 6.17). A lasso loop is then carried out twice with a nonabsorbable suture (decimal 2) (Fig. 6.18). This is important to have a strong repair attachment, so double sutures are advised. These sutures are passed in the tibial tunnel. This tran-

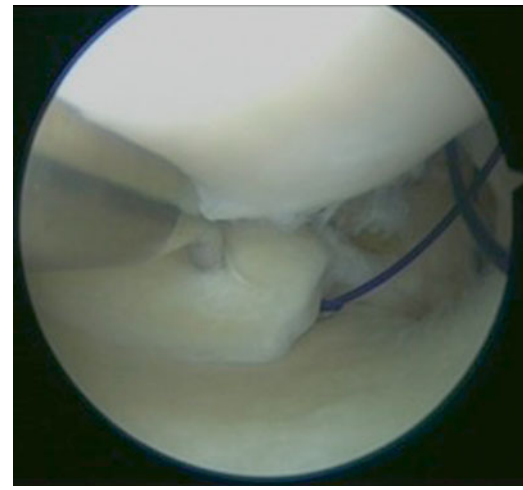

Fig. 6.16 Curved hook to pass sutures

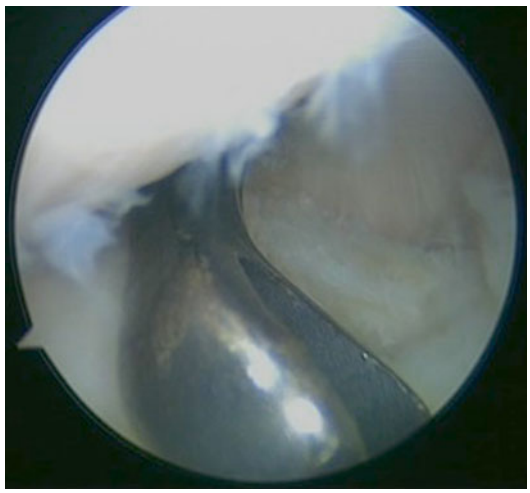

Fig. 6.15 Tibial drill guide, posteromedial portal

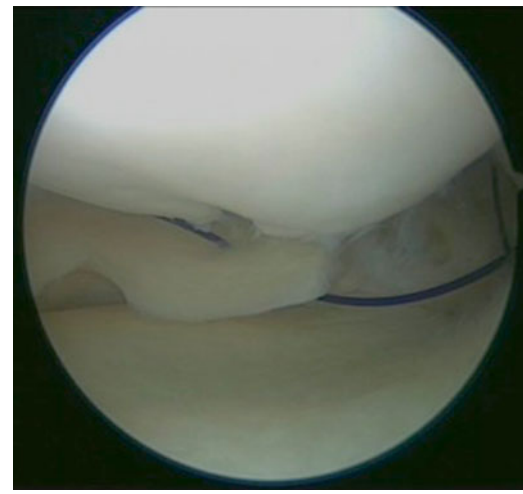

Fig. 6.17 First suture

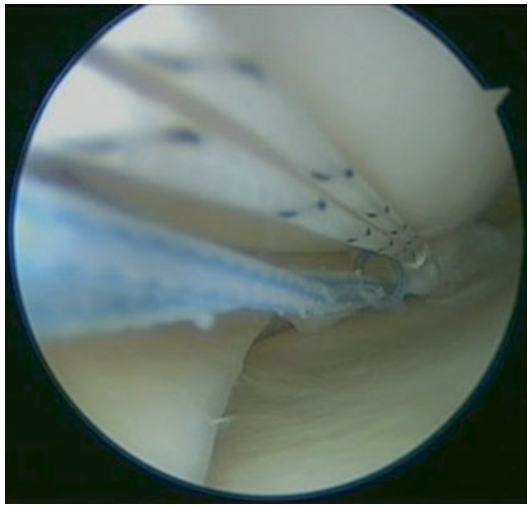

Fig. 6.18 Lasso loop with nonabsorbable sutures

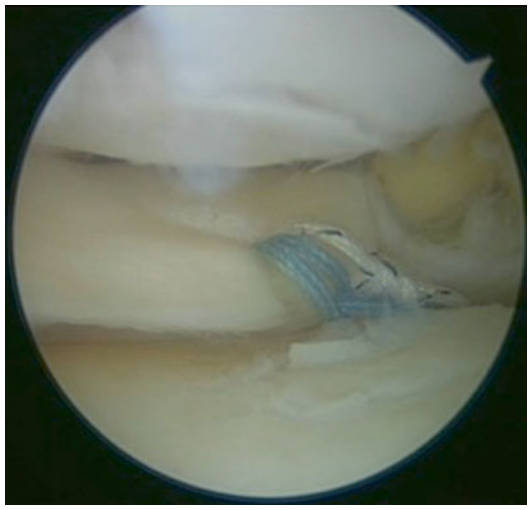

Fig. 6.19 Final aspect

sosseous cortical fixation suture is tightened (Fig. 6.19) and secured by a cortical button (Fig. 6.20). This is a difficult technique, far different from the classical meniscal repairs. Taking into account the high loads into the repaired site, full weight bearing is not recommended by 45 days after surgery. Knee flexion is early begun, with a limit of 90° during the first days. Return to sports will be allowed progressively with swimming and bicycle, running at 90 days, and then a complete resumption pivoting activities after 6 months.

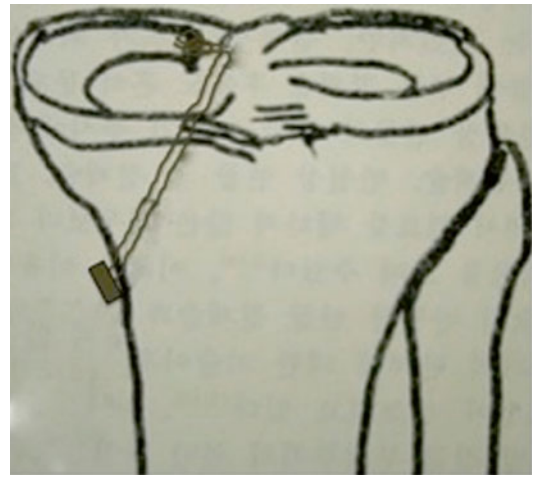

Fig. 6.20 Drawing of surgical technique with pull-out sutures and tibial cortical button

6.5.4 Conclusions

Medial meniscal root tears are rarely traumatic. Lateral meniscal root tears are commonly associated with injuries of the ACL. Patients with acute and traumatic root tears are considered to be the ideal candidates for root repair. But there is limited evidence to state precisely indications, repair techniques, and comparative results in the long term.

6.6 Treatment of Degenerative Meniscal Root Tears

Sebastian Kopf

Degenerative meniscal root tears occur mainly in obese female patients above 50 years without any significant knee trauma [33, 61]. The posteromedial root is more often involved compared to the posterolateral root. The rate of posteromedial root tears of all medial meniscus tears goes up to 30 % in Eastern floor-based lifestyle populations [14, 59]. Patients might report about pain or popping during squatting or a minor twist of the knee with an onset of pain. However, often they cannot remember any trauma and just report about an increasing knee pain over time with locking sensations. Attention to meniscal root tears has increased over the last years tremendously and

thus the development of treatment techniques. Before this recent increase in interest, they were often undiagnosed, or if detected, degenerative meniscal root tears especially in the older patients with higher grades of cartilage lesions were neglected. These patients were treated conservatively, or with a partial resection, seldom a horizontal suture was used. The conservative treatment including NSAIDs and physiotherapy can improve patients' symptoms for up to 3 years, but osteoarthritis (OA) progresses especially in patients with higher BMI [70].

Surgical treatment varies from partial meniscal resection to remove instable tissue, to horizontal meniscal repairs, to transtibial pull-out sutures or suture anchor root refixation. Partial meniscal resection is superior to conservative treatment based on the Lysholm score, but there is still a prompt progression in OA [72]. The horizontal suture repair is only indicated in the rare circumstances of tear at the meniscus-root junction and sufficient tissue quality (Fig. 6.21). Clinical data are not available thus far.

For the transtibial pull-out suture technique – one of the most advocated techniques for root tears over the last years – the torn root has to be fixed with one or two sutures (different knots were described) and the ends of the suture(s) are pulled through a transtibial tunnel, which in general ends at the anteromedial cortex to the tibia (Fig. 6.22). At this aperture the suture ends are fixed with a button or over a short bony bridge. The intra-articular aperture should be as anatomically as possible, because even some millimeter of misplacement can tremendously change meniscal function [83]. This technique has shown in small comparative studies its superiority compared to partial resection of the torn roots using the Lysholm, International Knee Documentation Committee (IKDC), and the Hospital for Special Surgery (HSS) score as well

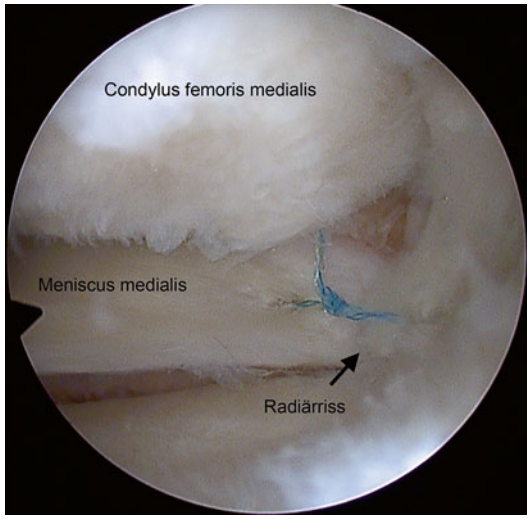

Fig. 6.21 Horizontal suture of a rare posteromedial meniscus root tear at the meniscus – root junction (Picture is from Kopf et al. [49] with kind permission from Springer Science and Business Media)

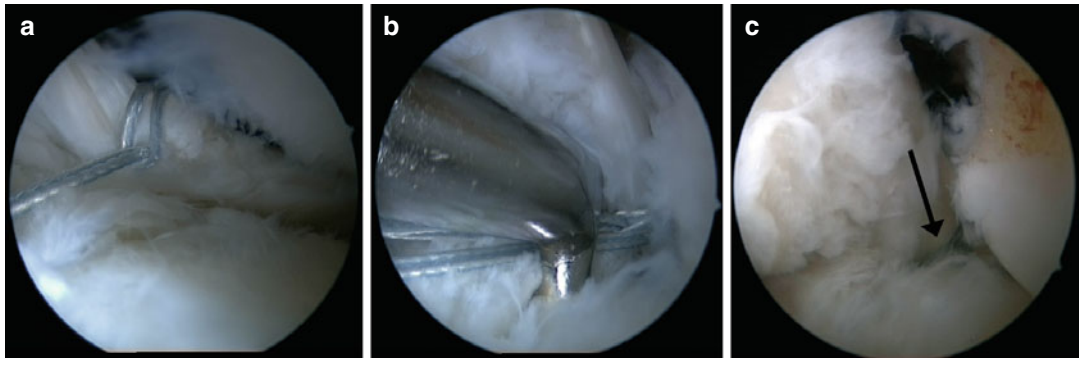

Fig. 6.22 Transtibial pull-out suture technique. (**a**) Using a suture lasso, a suture (or two) is passed through the torn root. (**b**) The transtibial tunnel to pass the sutures is in general drilled using an ACL drill guide. (**c**) The refixed meniscal root after fixation of the sutures ends at the anteromedial tibial cortex (Picture is from Kopf et al. [49] with kind permission from Springer Science and Business Media)

as the progression of OA. The progression of OA was reported to be between 10 % and 33 % after 33 and 49 months, respectively [18, 43]. Using MRI, reported healing rates are high varying with up to 100 % after 32 months [43, 61]. Even MRI is widely used to evaluate healing of meniscus roots; the gold standard is re-arthroscopy. In a study of 11 patients that underwent re-arthroscopy 14 months after posteromedial root fixation using the transtibial pull-out suture technique, no *complete* healing was seen. Five patients showed a lax healing, four patients had scar tissue, and in two patients the fixation was not healed at all (one with complaints and one without complaints) [78].

For the suture anchor technique, a suture anchor is placed through a posterior (posteromedial or posterolateral) portal as close as possible to the location of the root tear, and the root is fixed there. The suture anchor technique seems to be biomechanically slightly superior to the pull-out suture technique. The suture anchor technique is stiffer and does not elongate as much. Regarding maximum load to failure, both techniques are equal [22]. On the other side, surgeons often argue that the transtibial pull-out suture technique opens the medullary cavity and thus creates an influx of progenitor cells into the joint that might improve the healing of the root onto the tunnel aperture. However, a clinical study comparing both techniques did not show any significant differences [43]. In general, risk factors for an inferior outcome of meniscus root treatments are advanced OA and varus knees of more than 5° [68].

In conclusion, surgical treatment especially root fixation seems to be superior compared to conservative treatment and partial resection. However, one has to keep in mind that this statement is based on small case series or small comparative studies with short follow-ups. Thus, clear indications have to be still developed, e.g., in case if OA, osteonecrosis, or leg malalignment. In these cases, different treatment options such as knee arthroplasty (uni- or bicondylar), osteotomies, or even Kinespring® might be favorable instead of a root repair or as an adjunct.

6.7 Conservative Treatment and Rehabilitation

Alli Gokeler

6.7.1 Conservative Treatment of Meniscal Root Tears

From a clinical perspective, there are two groups of patients who suffer meniscal root tears. A relatively large group is made up of athletes in their 20s to 40s who sustain combined ligamentous and meniscus lesions. The injury has typically a traumatic onset resulting in an injury to the ACL, PCL, and other associated ligament combinations. The meniscal root is commonly torn along with the ligament, and it is recommended to perform a concurrent meniscal root repair. It is assumed that repair of the meniscus may prevent onset of and protect a concurrent ACL or PCL graft.

The second group of patients is compromised in their 50s and 60s who have an underlying degenerative process that ultimately results in a tear. The meniscal root tear can occur with daily activities such as squatting and other low load activities. Unfortunately, it is in this age group that rapid development of osteoarthritis can occur.

6.7.1.1 Degenerative Root Tears

In a case series evaluating the effect of conservative treatment for medial meniscal root tears, results were presented for conservative treatment in 37 patients with tears verified by MRI and osteoarthritis grades 1–2 (Kellgren-Lawrence) [70]. The average age was 55.8 years (range 50–62) with an average follow-up of 35 months (range 26–49). Patients received analgesics daily for up to 6 weeks and then as required during follow-up and in addition a 12-week supervised exercise program followed by a home exercise program. The program consisted of range of motion (ROM), stationary cycling, and muscle strengthening progressing from single leg raises to mini-squats (<80° knee flexion). For the first 6 weeks, patients exercised three times a week

under supervision of a physiotherapist and then at least twice a week for a further 6 weeks. On other days, they performed a home program that consisted of strengthening and stretching exercises with three to ten repetitions once a day. After 12 weeks of supervised therapy, patients were encouraged to continue with their home program. The training dosage was determined to perform exercises with some strain but almost pain-free and without having any negative influence in the affected knee the following day. In case the patient tolerated the training dosage without adverse effects, they were instructed to perform the exercises with increasing weights. Outcome determined with the Lysholm Knee Scoring Scale, Tegner Activity Scale, and visual analog scale (VAS) showed significant improvement in Lysholm score, Tegner, and VAS, which reached maximum in 6 months but later was accompanied by a decline. There was a progression in osteoarthritis as per Kellgren and Lawrence radiographic classification from median 1 pre-intervention to median 2 at the final follow-up.

In a retrospective study, 38 patients, 25 patients were operatively treated (pull-out repair group – transtibial) and the remaining 13 patients (conservative treatment group) underwent conservative management [4]. Those 13 patients refused to undergo the operation or had complex root tears considered to be irreparable and were treated conservatively with pain control and physiotherapy. However, the details of the conservative treatment were not reported. The pull-out repair group had statistically significant and clinically relevant better IKDC subjective scores ($p < 0.001$), Tegner and Lysholm activity scale ($p = 0.017$).

6.7.2 Debridement

Postoperative treatment should initially focus on reduction of pain and swelling. Rapid reduction of pain and swelling is therefore an essential goal during the first postoperative weeks, because strengthening of the muscles surrounding the knee cannot be initiated until reflex inhibition is resolved. Immediate weight bearing is allowed as tolerated by the patient. Crutches are advised after surgery and can be abandoned when the patient is able to place full weight on the involved leg without pain and has good control over the quadriceps muscle. Advantages of partial meniscectomy over repair (in chronic tears with concomitant grade III–IV osteoarthritides) include decreased operative time, a less stringent postoperative rehabilitation protocol with no weight-bearing restrictions, and faster return to activities and sports [13].

6.7.3 Repair

When the meniscal root tear is repaired, a period of restricted knee range of motion, especially during weight bearing, is mandatory to allow healing and to protect the repair site. The rehabilitation guidelines presented are a combined time- and criterion-based progression. Specific time frames, restrictions, and precautions are given to protect healing tissues and the surgical repair/reconstruction. General time frames are also given for reference to the average individual. It needs to be recognized that individual patients will progress at different rates depending on the nature of the injury (acute vs. degenerative), their age, associated injuries, pre-injury health status, rehabilitation compliance, and injury severity. In this section, a brief review of important factors is presented that need to be taken into consideration during rehabilitation.

6.7.3.1 Biomechanical Factors

Weight Bearing

In a biomechanical study on cadaveric specimens for 24.3 years (range, 12–35 years), knees were preconditioned for 10 cycles between 1 and 10 N at 0.1 Hz and cyclically tensioned for 1,000 cycles between 10 and 30 N at 0.5 Hz [58]. Based on findings from another study [84], the tests were conducted under neutral rotation, range of motion from 0 to 90° of knee flexion, and 500 N of tibiofemoral load, which are representative of the range of motion and toe-touch weight-bearing protocols during a standard post-

operative rehabilitation program after meniscal root repair. Results showed that a considerable amount of displacement occurred. Given that 3 mm of non-anatomic displacement of a meniscal root has been reported to compromise the ability of the meniscus to distribute tibiofemoral loads in a porcine model, displacement approaching this threshold is worrisome after a transtibial pull-out meniscal root repair [84]. This study presents important clinical relevant data given the young age of cadavers (mean 24 years), an age group in whom meniscal root repair is often performed.

Another biomechanical study evaluated the effects of weight bearing on six human cadaver knees with mean age of 55 years (range, 41–61) [2]. Specimens were tested at various flexion angles representative of the load of the meniscus during gait. Knee joints were consistently compressed to two times body weight at various knee flexion angles for 20 min. Ramp pressure was defined as the pressure when two times body weight was reached, and equilibrium pressure was recorded at the end of the hold period. During the experiment, the medial posterior attachment was subjected to greater ramp pressure than the medial anterior ($p = 0.002$) and greater equilibrium pressure than all other root attachment sites ($p < 0.001$). Interestingly, recorded meniscal pressure was highest at full extension. These results obtained from biomechanical data suggest that weight bearing should be prohibited after repair of meniscal root tears until a sufficient strength can be assumed [2, 84].

6.7.3.2 Clinical Studies

Evidence regarding rehabilitation is sparse and is based predominantly on level III–IV studies as was recently summarized in a systematic review [23].

Weight Bearing

For the first 6 weeks, three studies used a postoperative protocol that kept patient non-weight bearing [17, 43, 61]. In four studies, partial weight bearing was allowed that progressed to full weight bearing at 6 weeks [44, 60, 68, 78]. In three studies full weight bearing was delayed until 8 weeks postoperative [17, 43, 61]. Full squatting was allowed at 3 months [17, 68, 78] or at 6 months [43, 61].

Range of Motion

In the available literature, either a long leg cast or brace was used for the first 2 weeks postoperative [17, 43, 61, 68, 78]. Full flexion was allowed at 3 months [17, 68, 78] or at 6 months [43, 61]. Based on the results of Stärke et al. [84], internal rotation of the femur should be avoided as it generates high tensile forces in the posterior meniscal root (Fig. 6.23). Range-of-motion exercises are less critical when external rotation of the femur relative to the tibia is applied.

Based on both biomechanical and clinical data presented in the sections above, the authors present a three-phase rehabilitation program. Patients who have a meniscal root repair need to be non-weight bearing for 6 weeks after surgery. Physiotherapy is initiated on the first day after surgery. Range of motion is limited to 90° of knee flexion for the first 8 weeks after surgery, and then after this time, they may increase their knee motion. At 6 weeks after surgery, a partial protective weight-bearing program is initiated and patients may slowly wean off crutches when they can ambulate without a limp. The use of a stationary bike may be also started. Patients should avoid impact activities, deep squats, squatting, and lifting for a minimum of 4 months after surgery to protect the meniscal root repair.

Phase 1: 0–6 Weeks

In the immediate postoperative period, a continuous passive motion machine is used for the first 4 weeks (set at 0–90°) [90]. In the first month, physiotherapy consists of straight leg raises, quadriceps sets, heel slides, and calf pumps. Formal, supervised physiotherapy can be started during the second and third months after surgery. In a majority of patients, return to full activity can be achieved by 4 months unless a concomitant ACL reconstruction is performed (in which case the ligament reconstruction dictates the protocol). Bracing is optional and may be useful for the first weeks in the event of a regional block or weak quadriceps strength.

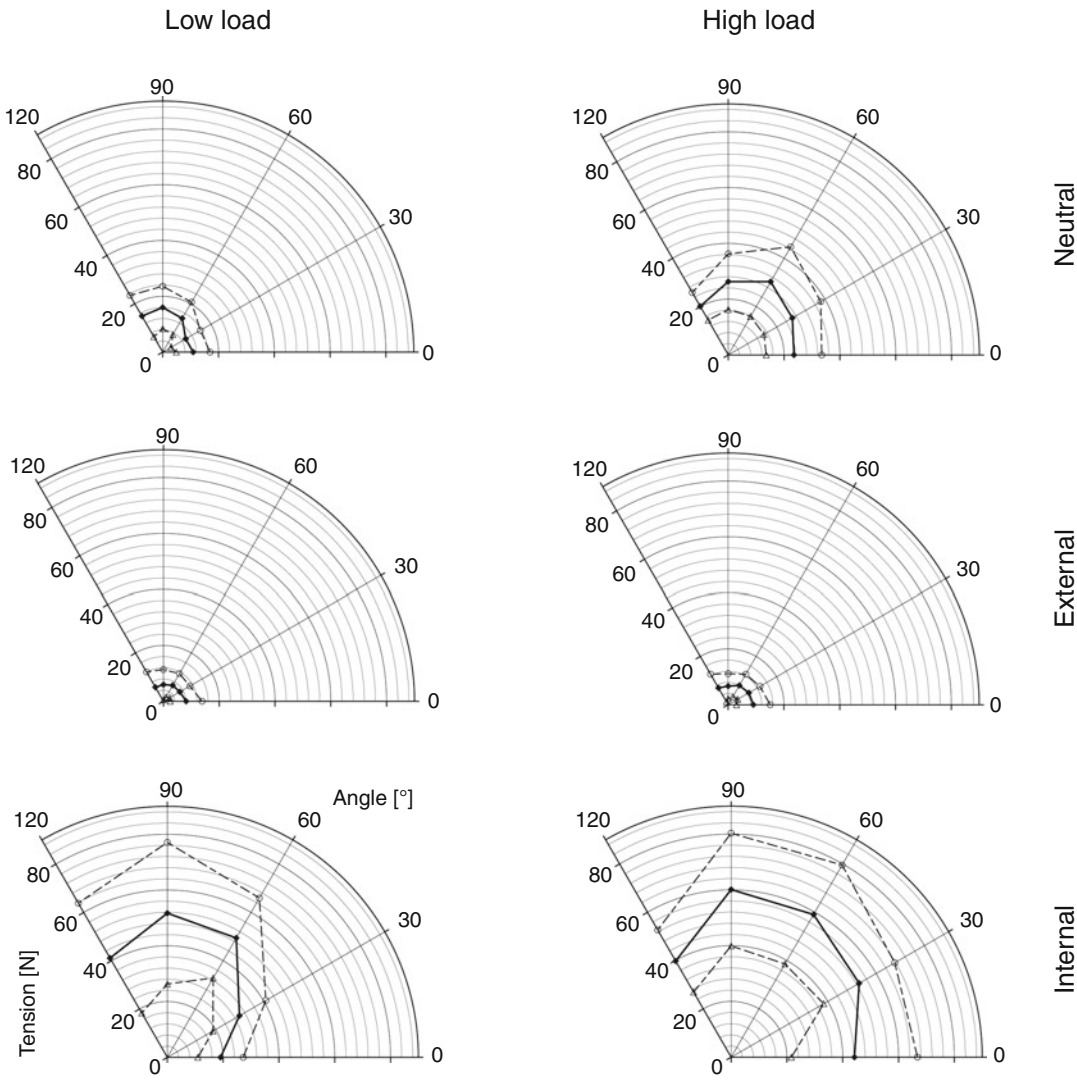

Fig. 6.23 Root tension for each combination of flexion (0°, 30°, 60°, 90°, 120°) and rotation of the femur (no rotation, internal, external) at 100 N and 500 N femorotibial load [84]

Phase 2: 6–12 Weeks

The second postoperative phase following meniscal repair is dedicated to restoring normal ROM to the involved knee and improving muscle strength to the level needed to perform activities of daily living. No forced flexion with passive range of motion with knee flexion or weight-bearing activities that push the knee past 60° of knee flexion.

Phase 3: 3–6 Months

The focus of the final phase of rehabilitation following meniscal repair is directed at optimizing functional capabilities and preparing the patient/athlete for a safe return to sport activities. Return to sports is generally allowed at 6 months; however, we caution to only use time as a guideline. Rehabilitation after meniscal root repair should adhere to biological healing time frames, which may be different from patient to patient. Though time frames have been included to guide the therapist, the patient is required to meet clinical milestones prior to advancing to the next stage, no matter the time frame [3]. In the final phase of rehabilitation, the patient must demonstrate sufficient dynamic neuromuscular control with multiplane

activities that represent the load during work- or sports-related tasks without pain or swelling.

6.7.4 Conclusion

The postoperative program after meniscectomy for degenerative meniscus root tears itself is rather straightforward. On long term, however, rapid development of osteoarthritis may occur. In younger patients, perseverance of meniscus tissue should always be attempted. Rehabilitation after meniscus root repair should adhere to biological healing time frames, which may be different from patient to patient. Though time frames have been included to guide the therapist, the patient is required to meet clinical milestones prior to advancing to the next stage, no matter the time frame (Adams [3]). In addition, therapists should select exercises based on sound knowledge of biomechanical load on meniscal tissue. There is a need for high-quality RCT to determine most effective yet safe rehabilitation protocol after meniscal root repair.

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Ankle Instability (ICL 7)

7

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7.1 Anatomy of the Ankle Joint

Mickey Dalmau Pastor

Repair and reconstruction of the lateral ankle ligaments arthroscopically assisted or as an entirely arthroscopic procedure are gaining popularity over open procedures, due to the fact that combine the repair technique with the inherent advantages of being a minimally invasive arthroscopic procedure [79, 85], while maintaining the strength and efficacy of open repair techniques [28].

In addition, arthroscopic evaluation of the ankle joint is possible, and co-existing problems of the joint (soft tissue impingement, osteochondral lesions, hypertrophic scars, etc.) [23] can be addressed before starting repair of the ligaments.

In order to proceed with these arthroscopic procedures safely, a thorough anatomical knowledge is necessary.

7.1.1 Ligaments Anatomy

The ankle lateral collateral ligament (LCL) complex is formed by three ligaments: anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL).

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In patients with ankle instability, the ATFL and CFL are the primary ankle stabilizers affected; the ATFL is the first ligament to be injured in an ankle sprain, and, if the sprain is severe, it is followed by lesion of the CFL. The PTFL is usually not injured in ankle sprains unless they are very severe or in cases of fracture or luxation of the ankle joint. Thus, anatomy of the ATFL and CFL is very important for surgical procedures that aim to resolve ankle instability.

From an anatomic point of view, ATFL and CFL have a very close origin in the fibula, which are usually connected by arciform fibers [70]. In addition, the distal fascicle of the anterior tibiofibular ligament inserts in the fibula just above the origin of the superior band of the ATFL, and its footprints are also connected by arciform fibers. This lets us believe that these three ligaments function as a unit protecting the ankle from excessive inversion (plantarflexion, adduction, and supination).

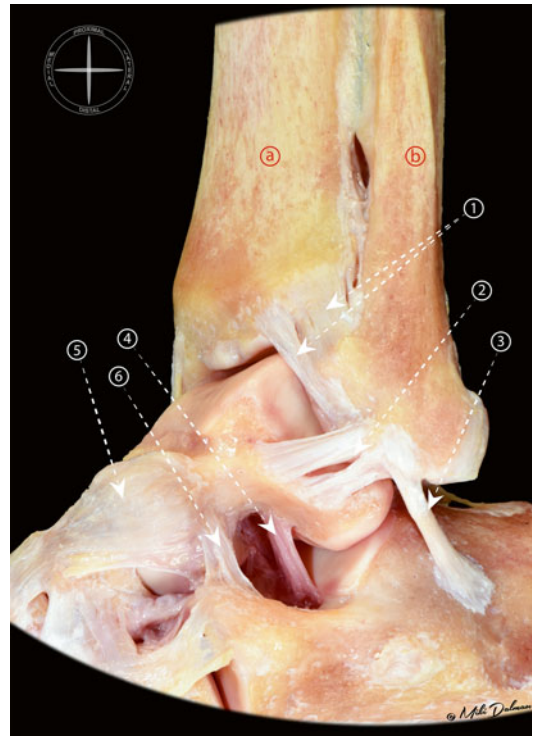

Fig. 7.1 Anterolateral view of an osteoarticular dissection of a left ankle showing the relationship of anterior tibiofibular ligament, anterior talofibular ligament, and calcaneofibular ligament at their fibular attachment. (**a**) Tibia. (**b**) Fibula. *1* Anterior tibiofibular ligament (and distal fascicle). *2* Anterior talofibular ligament. *3* Calcaneofibular ligament. *4* Talocalcaneal interosseous ligament. *5* Talonavicular ligament. *6* Cervical ligament

7.1.2 Anterior Talofibular Ligament

It is the anterior component of the lateral ankle ligament complex and the most frequently injured ligament of the ankle. Although various morphologies have been described [58], this ligament is typically composed by two separated bands, conforming a ligament with an overall quadrilateral morphology that maintains a close relationship with the ankle capsule joint. It is originated at the anterior margin of the lateral malleolus and, directing anteromedially, inserts on the talar body, in the area just anterior to the joint surface occupied by the lateral malleolus (Fig. 7.1). Of the two bands of the ATFL, the inferior band is tensed during dorsiflexion and the superior band during plantarflexion, thus being this superior band the most frequently injured [31].

The ATFL prevents anterior displacement of the talus from the mortise and excessive inversion and internal rotation of the talus on the tibia [12, 75]. Cadaveric studies have demonstrated that after rupture of the ATFL, the amount of transverse plane motion (internal rotation) of the rearfoot increases substantially, which augments stress in the intact remaining ligaments (CFL and PTFL) [48], in what is called rotational instability [37].

In these cases of instability, ATFL is seen by most surgeons to be ruptured near its fibular insertion during ankle arthroscopy. Anatomic and histologic investigations explain this fact. Kumai et al. found that an area of fibrocartilage exists on the zone where the ligament wraps around the anterolateral surface of the talus [51]. This is the result of a compressive force exerted on the ligament by the talus while the foot is in inverted position and that dissipates stress at the talar insertion in a manner that not occurs at the fibular insertion, reason by which ruptures usually occur at the fibular part of the ligament.

Also greater bone density at the talar insertion of the ligament was found when compared with the fibular insertion [51], providing insight on why avulsion fractures are much more common at the fibular insertion of the ATFL.

7.1.3 Calcaneofibular Ligament

It is a cordonal ligament originated at the anterior edge of the lateral malleolus, just inferior to the origin of the anterior talofibular ligament. Both origins are usually united by arciform fibers [70] (Fig. 7.1). In neutral position of the ankle, the ligament directs posterior, medial, and distally in order to insert in a small tubercle just posterior to the peroneal tubercle of the calcaneus. It is superficially crossed by the peroneal tendons, which can leave a concavity over the ligament. It has a relation with the talocalcaneal ligament, from which is separated by adipose tissue, although occasionally some of its fibers are continuous [9].

It is the only component of the LCL that controls two joints (ankle and subtalar joints) and is tensed throughout its entire arc of motion, restricting excessive supination of both joints. In vitro experiments have demonstrated that the CFL restricts excessive inversion and internal rotation of the rearfoot and is most tense when the ankle is dorsiflexed [47]. However, the ligament is relaxed in varus position and tensed in valgus. It is the second most-often component injured of the LCL [67].

7.1.4 Posterior Talofibular Ligament

It originates from the malleolar fossa and directs medial with almost a horizontal orientation to insert in the posterior surface of the talus and in the lateral talar process (or os trigonum if present). A group of fibers of this ligament fuse with the intermalleolar ligament, a ligament that must be considered constant [29].

Structures at risk during arthroscopic repair or reconstruction of the lateral ankle ligament complex:

In order to avoid complications during these procedures, knowledge of the main structures at risk is necessary.

Arthroscopic Brostrom procedure [1, 13, 14, 57, 87], all-inside arthroscopic anatomic repair [79, 85], and arthroscopic anatomic reconstruction [33] are all relatively new techniques described to treat ankle instability, and as any surgical technique, attention must be paid to avoid complications. As in any arthroscopic procedure, damage of the superficial peroneal nerve during placement of the anterolateral portal is a primary concern; lesion of the anterior tibial artery is possible when working with the instruments anteriorly directed; damage to the sural nerve will be important in those procedures that use a modified portal more lateral than normal, and when passing sutures; prominent anchors are a complication mostly of knot anchors in reconstruction procedures; finally, bone tunnels may be a source of complications if large diameter tunnels are used (mainly in reconstruction procedures where a graft is used). If tunnel is placed too distal or too lateral in the fibula, the risk of fracture is augmented, especially if using complete tunnels; caution is advised when tunnels are performed through a lateral portal due to the close proximity of the soft tissues and the drill.

7.1.5 Superficial Peroneal Nerve

The superficial peroneal nerve is a branch of the common peroneal nerve that after coursing in the lateral compartment of the leg pierces the crural fascia in the lower third of the leg and divides into the medial and intermediate dorsal cutaneous nerves of the dorsum of the foot [70]. The point of perforation of the fascia is at 12–13 cm proximal to the ankle joint [3, 75]. Perforation of the fascia usually occurs prior to division of the nerve but may also occur after division, having the peroneal nerve two exit points trough the crural fascia [72] (Fig. 7.2).

The superficial peroneal nerve or if divided the intermediate dorsal cutaneous and the medial dorsal cutaneous nerve are the only nerves in the human body that can be made visible [75].

Extreme caution on the part of the surgeon when creating portals together with a good knowledge of superficial peroneal nerve normal anatomy and anatomical variants is mandatory to reduce neurological complications rates. The "fourth toe flexion sign" [75] has been described to help marking the nerve before portal placement.

Placement of the anterolateral portal is usually preceded by marking of the position of the superficial peroneal nerve, identified with the

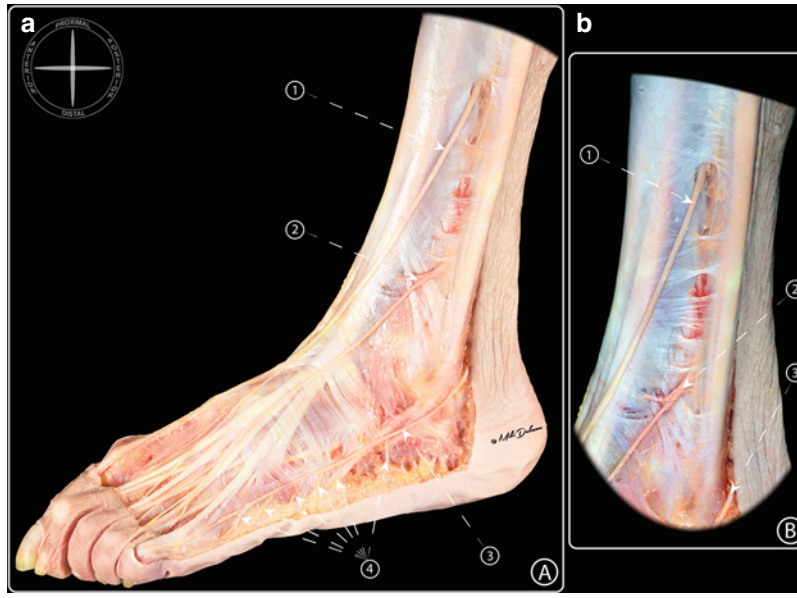

Fig 7.2 (**a**) Superficial dissection of a left leg showing the nerves branches that supply the dorsum of the foot. In this specimen superficial peroneal nerve has two exit points from the crural fascia, and sural nerve has no medial branch. (**b**) Macrophotography showing detail of superficial peroneal nerve exit points from the crural fascia. *1* Medial dorsal cutaneous nerve (branch of superficial peroneal nerve). *2* Intermediate dorsal cutaneous nerve (branch of superficial peroneal nerve). *3* Lateral dorsal cutaneous nerve (branch of sural nerve). *4* Cutaneous branches for the lateral side of the foot (branches of sural nerve)

"fourth toe flexion sign," thus being marked in inversion. However, attention must be paid to the fact that portals are established in neutral or slightly dorsiflexed position [82], and that when the ankle is moved from inversion to dorsiflexion, the superficial peroneal nerve moves laterally, so the marking does not correspond with the real position of the nerve when portal is going to be established. But, if the anterolateral portal is made medial to the marking, injury to the nerve will be prevented.

This changes in cases where the anterolateral portal is modified to a particular technique to allow passing of the suture, in which case the portal is placed lateral to the nerve [13].

7.1.6 Sural Nerve

The sural nerve is formed by the medial sural nerve (branch of the tibial nerve) after receiving the anastomotic peroneal communicating nerve (branch of the common peroneal nerve) [70]. The medial sural nerve runs between the two heads of the gastrocnemius muscle, perforates the fascia, and after receiving the peroneal communicating nerve forms the sural nerve. It courses lateral to the calcaneal tendon together with the small saphenous vein [21] and turns around the posterior border of the lateral malleolus from which is separated by the peroneal tendons. Then it usually divides in a lateral and medial branch that supply the fifth toe and the lateral side of the fourth toe; the medial branch may provide a communicating branch to the superficial peroneal nerve just below to the ankle joint [70, 90]. It also provides a variable number of cutaneous branches to the lateral side of the foot. Variations have sbeen described [50] including the absence of the medial branch (Fig. 7.2).

Attention must be paid to the sural nerve and to its communicating branch to the superficial peroneal nerve to avoid damage, especially if

nonstandard portals are used. If the surgeon is using a modification of the anterolateral portal that makes it more lateral or more distal, there is an increased risk of injury to the sural nerve. Sutures put the sural nerve at high risk during arthroscopic Brostrom procedure [13, 14, 57, 87], and there is lesser risk when using reconstruction or repair procedures [1, 33, 79, 85].

In the beginning of ankle arthroscopy, distraction was routinely used [7, 32], but nowadays it seems that routine distraction is falling into disuse [15, 17, 53, 69, 82, 83, 86, 95].

As in any ankle arthroscopic procedure, during arthroscopic repair or reconstruction of the lateral ligaments, distraction of the joint can be used as surgeon prefers. Thus, some surgeons use noninvasive distraction [13, 14], and others do not use distraction at all, using dorsiflexion instead [57, 79, 85, 87].

There are some well-known anatomic aspects that favor the use of dorsiflexion against distraction, as an enlarged anterior working area [30], protection of the cartilage of the talar dome [83], and a larger distance to the anterior neurovascular bundle [16]. In addition, reported rates of complications are lower when using dorsiflexion than when using distraction of the ankle joint [95]. Dorsiflexion technique also allows better visualization of the origin of the ATFL, key point when performing all-inside repair.

If using distraction, surgeon must be aware that, as more tension is applied to the neurovascular structures, there is an increased risk to lesion these structures with the scalpel. In contrast when working with dorsiflexion, the relaxed soft tissues are less prone to lesion with the scalpel, but this absence of tension makes soft tissues more vulnerable to damage when working with the shaver, so the surgeon must be careful when using this instrument.

Finally, if surgeon is working with distraction, the ankle must be situated in neutral or slightly dorsiflexed position to tense the suture in order to complete either repair or reconstruction of ATFL or CFL.

7.2 Arthroscopic Findings in Ankle Instability

Jordi VegaFernando Peña

Ankle sprain is one of the leading sports injuries in both recreational and professional athletes, accounting for 85 % of ankle injuries [25, 26]. The most common mechanism of injury is an inversion motion of the foot [4, 68], affecting the lateral ligament complex of the ankle. Most patients with this type of injury are successfully treated conservatively. However, residual symptoms after an ankle sprain are reported in 30–40 % of patients [24]. Symptoms include chronic pain, muscular weakness, and recurrent giving-way or instability. Soft tissue impingement or mechanical instability can be the long-term sequela of an ankle sprain [24, 27].

Although, instability of the ankle has been successfully treated by both, open or minimally invasive techniques, including arthroscopic procedures, results can be affected because intra-articular-associated injuries, contributing to pain and dysfunction. Intra-articular pathologies have been observed from 66 % to 95 % of the unstable ankles [23, 38, 39, 49]. Due to these intra-articular conditions, arthroscopic evaluation and treatment of the associated injuries are recommended [10, 23, 38, 39, 49].

Chondral-osteochondral injuries have been observed from 17 % to 95 % of the unstable ankles [20, 38, 78]. Although they can be located at any location of the talus surface, they are mainly located in the medial and lateral area of the talus. Attending the talus grid described by Raikin [66], chondral injuries have been located in zone 4 (56 %) and zone 6 (12 %). Treatment of both chondral injury and ankle instability is necessary to achieve a good result.

Impingement syndrome has been related to chronic instability of the ankle.

Soft tissue impingement has been observed from 44 % to 88 % of the unstable ankles [39, 49, 73]. Fibrotic tissue or synovitis occupying the anterior compartment or the lateral recess is a

common finding in ankle joint instability. On the other hand, injury of the distal portion of the tibiofibular ligament or Bassett's ligament has been observed in 7 % of the patients [39, 73]. Both pain and a chondral injury seem to be related with a greater contact of the ligament with the anterolateral corner of the talus as a consequence of an increased anterior extrusion of the talus resulting from the lateral instability [5, 11, 41].

Bony impingement related to spurs in the anterior rim of the tibia has been observed in 3–27 % of the patients [39, 49, 77]. Attending their origin, two types of osteophytes have been described. Spurs secondary to instability are different to that related to repetitive microtraumatism [81, 84]. Osteophyte along the anterior rim of the tibia is related to chronic ankle instability [36, 74]. However, osteophyte protruding in the most anterior area of the distal rim of the tibia, and/or in the talar neck, is related with repetitive microtraumatism in the anterior area of the ankle [80].

Other alterations have been related with ankle instability. Presence of loose bodies (8–26 %) [20, 39, 49] that must be removed during instability treatment or submalleolar ossicles (10–25 %) can be observed [39, 77].

Finally, ligament tears are observed during arthroscopy of the unstable ankle. The ATFL is the most frequently injured ligament of the ankle, and most of the unstable ankles have an isolated injury of the ATFL [8]. The upper band of this ligament is in close contact with the capsule of the ankle joint [19, 31, 58, 71]. Due to this anatomic characteristic, it is observed during ankle arthroscopy to be located in the floor of the lateral recess of the ankle [85]. When injured, it can be observed during ankle arthroscopy [86].

In addition to the lateral ligament tear, injury of the deltoid ligament has been described from 6 % to 40 % of the unstable ankles [38, 73]. Because of internal talar rotation related with lateral ankle instability, anterior part of the deltoid ligament can be injured and observed during ankle arthroscopy.

Recognition of all these alterations is important for a complete treatment of the ankle instability. Arthroscopic treatment of both ankle instability and concomitant alterations will provide a better result than just treat instability or secondary pathologies.

In summary, it is important to know that secondary pathologies are present in most of the unstable ankles. Both recognizing concomitant injuries and treating them to stabilize the ankle are necessary to achieve a good result.

7.3 Arthroscopic and Minimally Invasive Surgical Treatment of Chronic Ankle Instability: A Systematic Comprehensive Evidence-Based Review of Current Literature

Mark Glazebrook Kentaro Matsui Bernard Burgesson Masato TakaoStephane Guillo ESSKA AFAS Ankle Instability Group

7.3.1 Introduction

There has been a recent advent of published descriptions on minimally invasive surgeries (MIS) for chronic ankle instability (CAI) [1, 2, 6, 13, 14, 18, 22, 33–35, 40, 42–46, 52, 54–57, 60–65, 79, 85, 87, 89, 93, 94]. These MIS encompass two major categories: anatomical repair or reconstruction of ATFL and/or CFL. Both categories embrace arthroscopic or non-arthroscopic minimally invasive techniques and include the following four main categories of the MIS approaches:

1. Arthroscopic repair
2. Non-arthroscopic minimally invasive repair
3. Arthroscopic reconstruction
4. Non-arthroscopic minimally invasive reconstruction

7.3.2 Methods

A systematic review of the current literature was performed using the methods described by Wright et al. [91, 92]. All published and unpublished clinical studies with English translation were included. The comprehensive literature

searches were conducted (September 4, 2015) by the use of PubMed, EMBASE, Cochrane databases, and Web of Science and thorough hand searching of references in narrative and systematic reviews.

7.3.3 Results

Thirty-three of these studies [1, 2, 6, 13, 14, 18, 22, 33–35, 40, 42–46, 52, 54–57, 60–65, 79, 85, 87, 89, 93, 94] met the inclusion criteria. Of the included studies, 21 studies [1, 2, 6, 13, 14, 18, 35, 40, 42–44, 46, 52, 54, 56, 57, 60, 61, 79, 85, 87] were classified into arthroscopic repair category, 6 studies [33, 34, 55, 63–65] were classified into arthroscopic reconstruction category, no papers were classified into non-arthroscopic minimally invasive repair category, and six papers [22, 45, 62, 89, 93, 94] were classified into non-arthroscopic minimally invasive reconstruction category. A summary of the grade of recommendations for or against the current accepted indications for each four minimally invasive surgical category is presented in Table 7.1.

7.3.3.1 Arthroscopic Repair

Twenty-one studies were published on arthroscopic repair [1, 2, 6, 13, 14, 18, 35, 40, 42–44, 46, 52, 54, 56, 57, 60, 61, 79, 85, 87]. Kashuk et al. [43] reported the first arthroscopic repair approach using suture anchor in 1994, and the following 11 studies [1, 2, 13, 14, 42, 46, 52, 57, 60, 79, 85] were published after 2009. Only seven level IV [1, 13, 14, 46, 52, 60, 85] and five level V studies [2, 42, 43, 57, 79] were available, and a variety of surgical techniques were reported in this approach.

Grade of Recommendation: On the basis of the previously mentioned literature of this category, arthroscopic repair approach with suture anchors and thermal shrinkage techniques was given grade C recommendation (poor quality literature to support). The recommendation regarding the other possible arthroscopic repair approach is grade I recommendation due to the lack of published evidence on this surgical approach.

7.3.3.2 Non-arthroscopic Minimally Invasive Repair

We could find no literature regarding this approach.

Grade of Recommendation: The grade of recommendation regarding the non-arthroscopic minimally invasive repair surgery is grade I due to the lack of published evidence on this surgical approach.

7.3.3.3 Arthroscopic Reconstruction

Only one level IV [64] study and five level V [33, 34, 55, 63, 65] studies were available regarding arthroscopic reconstruction category of CAI. One level IV [64] and 1 level V [65] studies reconstructed only ATFL, and other four level V [33, 34, 55] studies reconstructed both ATFL and CFL using arthroscopy.

Grade of Recommendation: On the basis of the previously mentioned literature of this category, arthroscopic reconstruction for CAI

Table 7.1 Summary of current literatures for or against surgical treatment (repair and reconstruction) of ankle instability using minimally invasive surgical approach (arthroscopic and non-arthroscopic)

Surgical technique category	No. of studies	Level I	Level II	Level III	Level IV	Level V	Grade of recommendation	Recommendation
Arthroscopic repair	21	0	0	0	13	8	C	For
Non-arthroscopic[a] repair	0	0	0	0	0	0	I	NA
Arthroscopic reconstruction	6	0	0	0	1	5	I	NA
Non-arthroscopic[a] reconstruction	6	0	0	1	2	3	I	NA

NA not applicable

[a]Non-arthroscopic minimally invasive

would clearly give a grade I recommendation. Further there is no evidence that shows one technique is superior to another for arthroscopic ATFL and CFL reconstruction.

7.3.3.4 Non-arthroscopic Minimally Invasive Reconstruction

Six studies (one in level III [93], two in level IV [89, 94], and three in level V [22, 45, 62]) were found in this review for this category: minimally invasive reconstruction without using arthroscopy. Three to six small incisions were used by the percutnaeous technique for reconstruction of the ATFL and CFL using auto- or allograft.

Grade of Recommendation: On the basis of the previously mentioned literature, non-arthroscopic minimally invasive approaches to reconstruct the ankle instability would be given incomplete (grade I) recommendation due to the lack of enough published evidence. The one level III evidence study compares the different kinds of graft. It did not compare the non-arthroscopic minimally invasive reconstruction technique to other surgical techniques like open procedure or repair to prove the utility or the safety of minimally invasive reconstruction.

7.3.4 Discussion

Our review showed that 33 studies [1, 2, 6, 13, 14, 18, 22, 33–35, 40, 42–46, 52, 54–57, 60–65, 79, 85, 87, 89, 93, 94] have been published on the use of MIS for treatment CAI and most of the studies: 29 studies [1, 2, 6, 13, 14, 18, 22, 33, 34, 40, 44–46, 52, 54–57, 60–63, 65, 79, 85, 87, 89, 93, 94] were reported after 2000. Most of the studies were level of evidence IV or V. There was one level III [91] and 16 level IV [1, 6, 13, 14, 18, 46, 52, 60, 61, 64, 85, 87, 89, 94] studies in this review supporting the use of MIS for treatment of CAI. Most of the studies adopted AOFAS score [13, 14, 46, 52, 60, 85, 89, 93] and followed by stress radiographs [46, 60, 64, 89, 93, 94], patient satisfaction score [13, 64, 89, 94], Karlsson-Peterson score [44, 91], or VAS [14, 52]. Only one study [33] adopted patient activity score or general health score.

The complication rate of arthroscopic repair category was reported in a past review [88], and it was thought to be high. The complication rate of other MIS categories was not obvious in this review because of the lack of reporting. Future studies should include complications to distinguish whether the complication rate of the MIS was higher than that of conventional open technique.

The indication of each MIS was not clear in most studies. The indications for thermal shrinkage were limited to the patient without mechanical instability [6, 64] or mild to moderate ankle instability [56, 61, 87].

7.3.5 Conclusion

A comprehensive review of the literature has provided predominantly level IV and V evidence on minimally invasive surgery for the treatment of chronic ankle instability. There is limited and poor quality evidence that supports the use minimally invasive approaches in treating chronic ankle instability. This may have more to do with lack of evidence than ineffectiveness of these approaches. It is our recommendation that future studies should be done in a prospective manner comparing clinical outcomes and complication rates not only between various MIS techniques but also between MIS and open procedures. This knowledge will assist surgeons in determining the indications for each technique.

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Proximal Hamstring Injuries (ICL 8)

8

Anne D. van der Made, Gustaaf Reurink, Lars Engebretsen, Erik Witvrouw, Gino M. M. J. Kerkhoffs, Johannes L. Tol, Sakari Orava, and Håvard Moksnes

8.1 Introduction

Proximal hamstring injury occurs frequently and ranges from minor muscle injury to complete avulsions which can be potentially career threatening for athletes. Medical care of these challenging injuries requires proper knowledge of hamstring anatomy, function, aetiology and treatment options. Treatment may be conservative and/or operative. After successful primary treatment, secondary prevention is important due to the high incidence of reinjury. These topics are discussed in the following chapter.

8.2 Anatomy of the Proximal Hamstring Muscle Complex

Anne D. van der Made

The hamstring muscle complex comprises the three muscles in the posterior thigh compartment: semitendinosus (ST), semimembranosus (SM) and

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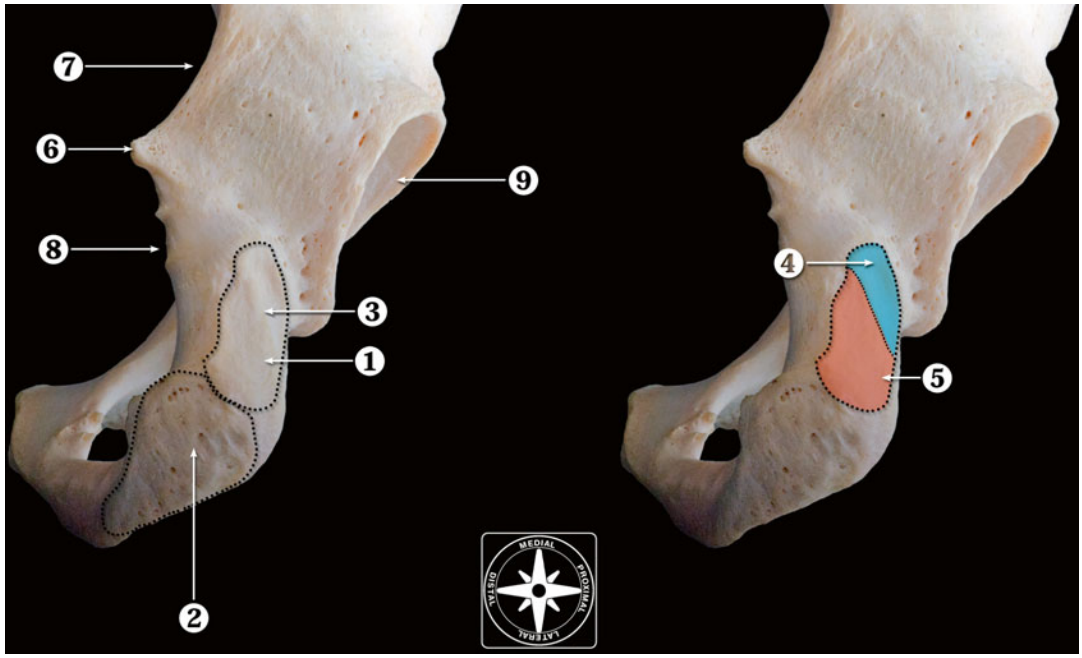

Fig. 8.1 Posterior view of the right coxal bone showing the ischial tuberosity which can be divided into two regions: *1* Upper region. *2* Lower region. *3* Vertical ridge, which divides the upper region in two facets. *4* Lateral facet, for insertion of the tendon of the semimembranosus muscle. *5* Medial facet, for insertion of the conjoint tendon of the long head of biceps femoris and semitendinosus muscle. *6* Sciatic spine. *7* Greater sciatic notch. *8* Lesser sciatic notch. *9* Acetabulum (From van der Made et al. [7]. With permission of Springer Science + Business Media)

biceps femoris which can be divided into a long head (BFLH) and a short head (BFSH) [1–7].

With the exception of the BFSH, these muscles span both the hip and knee joint, thereby acting as both flexors of the knee and extensors of the hip. The BFSH, spanning a single joint, acts only as a knee flexor.

The upper region of the posterior aspect of the ischial tuberosity can be divided into a medial and lateral facet (Fig. 8.1).

The BFLH and ST have a common origin on the medial facet to which the conjoint tendon is attached [1, 3, 5–8]. In addition, a part of the ST has a direct attachment on the ischial tuberosity [1, 4–8]. At the common proximal part, the ST consists mainly of a muscular portion with only a short tendon, whereas the BFLH has a longer tendinous part [1, 3–8] (Fig. 8.2).

The SM runs anterior to this common proximal part and attaches to its origin on the lateral facet (Fig. 8.1, Fig. 8.3a and Fig. 8.3b) [3, 5, 7].

More distally, the BFSH originates on the lateral lip of the linea aspera to join the BFLH [2, 4, 8].

While the proximal tendon of the BFLH is thick and round, the proximal SM tendon has a wide or aponeurotic appearance [7, 8]. The proximal tendons, originating as free tendons to which muscle fibres start to attach when continuing distally, extend along a considerable portion of the length of their respective muscles [7, 8]. In fact, when it comes to total tendon length, proximal and distal tendons are overlapping in the BFLH and SM [7]. Additionally, the ST has a tendinous inscription also referred to as the 'raphe', dividing the ST into two parts (Fig. 8.2) [7, 8] that are innervated by different nerve branches [8].

Anatomical variations of the hamstring muscle complex that have been described are as follows: an accessory SM, hypoplastic/absent SM, a separate proximal BFLH tendon and a separate distal BFSH insertion [2, 3].

The BFLH, ST and SM are innervated by the tibial part of the sciatic nerve, whereas the BFSH is innervated by the common peroneal part of the sciatic nerve [2]. The sciatic nerve passes the proximal hamstring muscle complex on the lat-

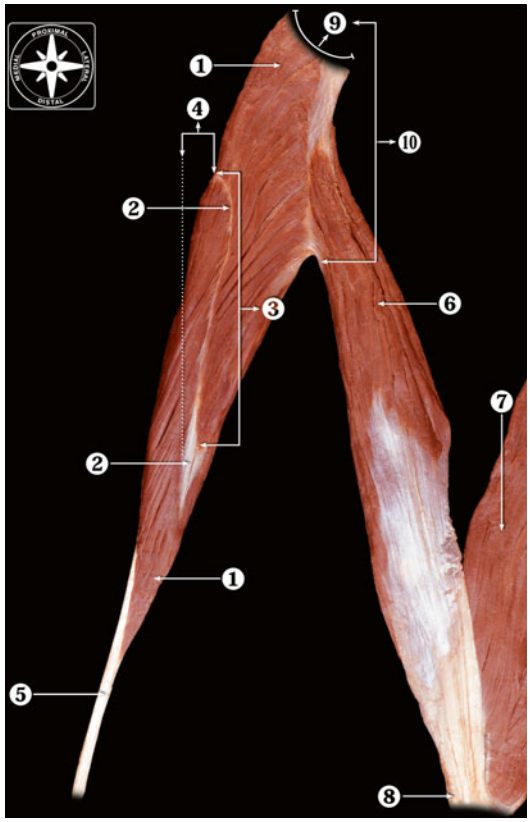

Fig. 8.2 Anatomical dissection showing the muscular characteristics of the biceps femoris and semitendinosus muscle. *1* Semitendinosus muscle. *2* Raphe. *3* Length of the raphe. *4* Width of the raphe. *5* Semitendinosus tendon. *6* Long head of biceps femoris muscle. *7* Short head of biceps femoris muscle. *8* Biceps femoris tendon. *9* Ischial tuberosity. *10* Conjoint tendon (From van der Made et al. [7]. With permission of Springer Science+Business Media)

eral side at a distance of approximately 1 cm from the most lateral aspect [4, 7, 9]. In case surgery is carried out in this region, the proximity of the sciatic nerve to the proximal hamstring muscle complex necessitates a careful approach and protection of the nerve.

8.3 Aetiology

Erik Witvrouw

It has been reported that the majority of hamstring injuries occur while the athlete is running at maximal or close to maximal speeds [10]. Therefore, a complete understanding of the biomechanical function of the hamstrings during sprinting is imperative in order to develop a good rehabilitation programme, targeting the mechanism of the injury.

Several studies have found the hamstrings to be active from mid-swing until terminal stance [11–16]. Looking at the exact timing of the hamstring injury, biomechanical data have identified the terminal swing phase as the period in the stride cycle when the injury most likely occurs [17, 18].

In an interesting paper [19], the different hamstring muscles during running were examined. The authors found the hamstrings as a whole to be lengthening, producing peak force, and absorbing a lot of energy (eccentric muscle work) during sprinting. However, looking at the different muscles within the hamstring group, the BFLH muscle had the largest increase in length (12 %) while the SM muscle produced the highest force and absorbed and generated the most power. The results suggest that the pathomechanics of a BF injury might be different from those of an SM injury, and consequently these injuries might need a different treatment approach. Based upon these results, an injury to the BF might need a treatment with emphasis on lengthening, while a SM muscle injury might be more orientated towards a strengthening approach.

In a recent study Askling et al. [20] compared a rehabilitation programme with hamstring exercises being performed at longer muscle length, mimicking movements occurring simultaneously at both knee and hip with a conventional eccentric and concentric hamstring strengthening programme with no emphasis on lengthening. They found that the protocol emphasising lengthening type of exercises was more effective than a conventional strengthening programme. However, the authors do not mention which type of injury was involved (BF versus SM). Though, since the majority of the hamstring injuries involve BF injuries, this study might confirm the hypothesis that a BF injury rehabilitation programme should be emphasising on lengthening. In addition, it also shows that a rehabilitation programme should attempt to mirror the particular situation and muscle work that lead to the injury.

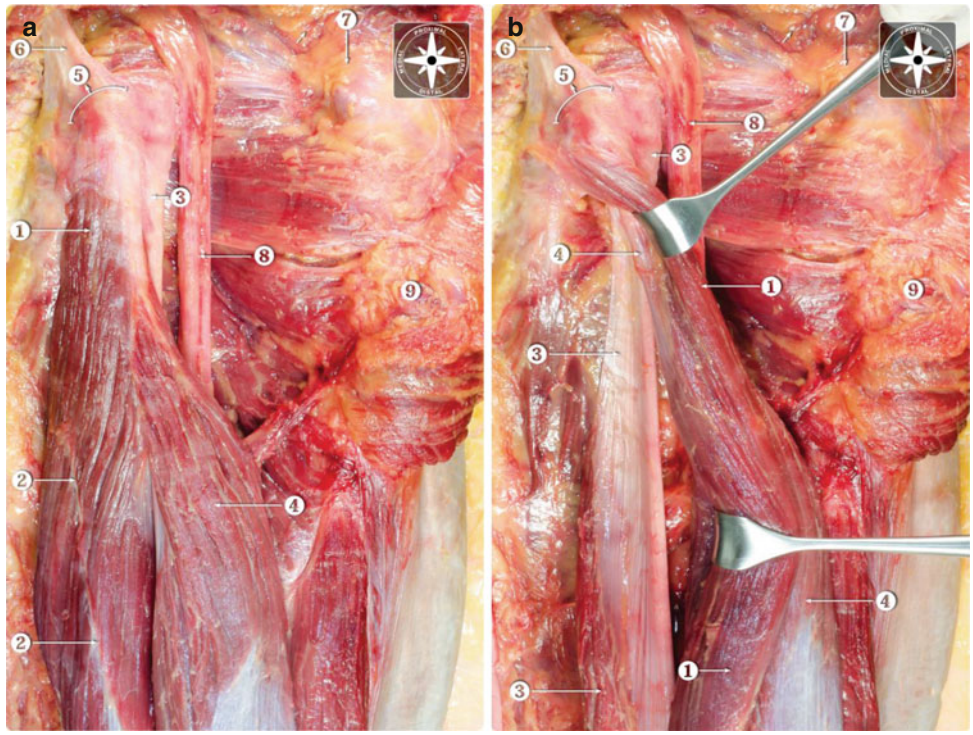

Fig. 8.3 Dissection of the hamstring tendons. (**a**) Normal topographic anatomy. (**b**) The semitendinosus and long head of biceps femoris muscles have been rejected laterally to observe its relationship with the ischial origin of the semimembranosus muscle. *1* Semitendinosus muscle. *2* Raphe of semitendinosus muscle. *3* Semimembranosus muscle. *4* Long head of biceps femoris muscle. *5* Ischial tuberosity. *6* Sacrotuberous ligament. *7* Great trochanter. *8* Sciatic nerve. *9* Gluteus maximus (cut and rejected) (From van der Made et al. [7]. With permission of Springer Science + Business Media)

Increasing the muscle length is traditionally performed by the means of a stretching programme, and research has proven its validity. Yet, if the goal of a rehabilitation programme is to mirror the particular situation and muscle work that lead to the hamstring (BF) injury, stretching alone might not be the treatment of choice. However, there is another way of increasing muscle length. Performing repetitive muscle contractions in elongated positions is found to increase the series compliance of muscles and allow for longer operating lengths [21, 22]. Considering the specificity of hamstring muscle work during sprinting and other high speed movements, eccentric muscle training in elongated positions seems a very good solution. It has been well established that eccentric training in elongated positions can shift the optimal length to longer muscle lengths. The goal of this training programme is therefore not to strengthen the hamstring muscle (although this is an additional and interesting benefit), but rather changing the optimal muscle length. This is in accordance with the results of studies which showed that very low intensity (but in elongated positions) eccentric hamstring exercises gave good treatment results, frequently superior to high intense eccentric exercises in non-elongated conditions. Therefore, hamstring exercises performed at longer muscle-tendon length, preferably mimicking movements occurring simultaneously at both the knee and the hip, could be a key strategy in the management of hamstring injuries [19, 23].

As the pelvis is the origin of the hamstring muscles, pelvic position plays an important role in the total hamstring length over the hip and knee joint. Sufficient neuromuscular control of the lumbopelvic region, including anterior and posterior tilt, is needed to create optimal function of the hamstrings during sprinting and other high-speed skilled movements. Changes in pelvic position could lead to changes in length-tension relationships. The concept of that trunk stabilisation and neuromuscular control exercises should be included into the rehabilitation. Indeed, studies have shown that a progressive agility and trunk stabilisation programme gave as good, or better, results compared to a progressive running and eccentric training programme following acute hamstring injury [24, 25].

A recent study demonstrated significantly more symmetrical activation patterns between the BF, ST and SM in an injury group compared to a control group [26]. The prominent role of the ST was evident in both groups. However, in the injury group, the activity of the ST was partly traded in for more involvement of its synergists. The ST seems to be activated most during the prone leg curling exercise. Previous research reported that the ST had the highest muscle activity and was recruited more than both the BF and the SM in strength exercises and in locomotion [27].

This activation pattern appears to be the result of a sophisticated, complex neuromuscular coordination within the hamstring muscle complex, which possibly provides the most efficient muscle functioning and economic force production. They also demonstrated that the ST has the highest levels of muscle activity during the terminal swing phase (whereas the BF is predominantly active from the middle to late swing phase), where the hamstring muscle group has to withstand the highest levels of muscle tendon stretch and negative work. This supports the hypothesis and suggests that under high loading conditions, the ST has a prominent role in producing and controlling the torques around both hip and knee joints.

8.4 Surgical Treatment of Acute Proximal Hamstring Injuries

Gino M.M.J. Kerkhoffs

There is no consensus on the indication for surgical treatment of acute proximal hamstring injury. Surgery is mainly reserved for avulsion fractures of the ischial tuberosity and hamstring avulsions; complete rupture of a hamstring tendon from its origin [28, 29]. The choice for surgical repair of proximal hamstring avulsions is made based on the number of ruptured tendons and/or amount of retraction, but these criteria are not consistently applied in current literature [28]. In our hospital, the choice for a surgical or conservative approach is made by shared decision-making.

Evidence on clinical outcomes following repair of proximal hamstring avulsions is limited to studies of low methodological quality [28]. Surgical repair is reported to lead to high patient satisfaction (88–100 %) and a return to sports rate of 76–100%. However, decreased hamstring strength (78–101 %), residual pain (8–61 %) and decreased activity level (55–100 % returned to pre-injury activity level) have been reported by a relevant number of patients [28].

Despite a very small number of conservatively managed published cases and lack of a quality assessment of the included studies, a recent systematic review [29] concluded that surgical repair yields significantly better subjective outcomes, rate of return to pre-injury level of sport and greater strength/endurance compared to conservative treatment.

The same review concluded that acute repair (≤4 weeks) leads to significantly better patient satisfaction, subjective outcomes, pain relief, strength/endurance and higher rate of return to pre-injury level of sport than delayed repair (>4 weeks). This difference has not been confirmed by a second systematic review, which found no to minimal differences between acute and delayed repair [28]. Note that 4 weeks is an arbitrary limit, reflecting the development of scar tissue at the avulsion site. Furthermore, there is moderate evidence that clinical outcome is less

favourable if the (complete) avulsion is treated later than 6–12 weeks [30, 31]. Moreover, delayed repairs are considered technically more challenging due to development of scar tissue [28].

Both systematic reviews did not differentiate between results of partial (1- or 2-tendon) avulsions and complete (3-tendon) avulsions. According to a study that compared outcome of surgical repair of partial and complete ruptures, no significant differences in return to pre-injury sporting level and patient satisfaction were found [32].

Surgical repair comprises reinsertion of the ruptured tendons to their correct anatomic position. The patient is typically placed in prone position. The type of incision is chosen based on the expected difficulty of the repair (i.e. amount of retraction, adhesions). For more exposure a longitudinal incision can be used, while a transverse incision in the gluteal crease is used for improved cosmetic results. Also, a combination of both may be used. The tendons are then cleared of scar tissue and mobilised. It is very important to identify and protect the sciatic nerve to prevent iatrogenic injury. Once the tendons are mobilised and the sciatic nerve is protected, suture anchors are placed in a debrided ischial tuberosity to which the tendons are tightly secured [28]. A recent (in vitro) biomechanical analysis demonstrated that size of the anchors did not affect the strength of the repair, but that the number of anchors (5 versus 2) used significantly affects the strength [33].

Alternatively, the repair may be augmented in cases where there is too much tension on the repair, or if retraction prevents re-approximation of the rupture tendon. This occurs mainly in delayed repairs. An auto- or allograft may be used to bridge this defect, such as an iliotibial tract autograft or an Achilles tendon allograft reconstruction [28, 30]. Endoscopic techniques have also been described [28].

Postoperatively, the entire leg may be placed in a cast or brace. Intraoperatively, tension on the repair is assessed, and the knee is placed in an angle that prevents the repair from being at risk of rerupture. Over the coming weeks, the cast is changed and eventually replaced with a brace and knee extension/hamstring lengthening is gradually increased. If no tension in the tendon is felt after the repair, bracing may not be needed. A phased rehabilitation programme is started.

8.5 Chronic Proximal Hamstring Injury: Tendinopathy

Sakari Orava

Proximal hamstring tendinopathy (PHT) is a disabling disease often causing underperformance in athletes.

The main symptom of PHT is lower gluteal pain, especially during running or prolonged sitting. Typically, it starts without any sudden trauma and gradually becomes worse with continued loading of the hamstrings. Palpation reveals tenderness over the ischial tuberosity, with pain on resisted knee flexion. Pain is often provoked at this site by active hamstring stretching. Sensorimotor functions are intact.

Imaging by means of ultrasound or MRI is used to confirm the diagnosis and to assess the extent of the injury. MRI of PHT will reveal increased signal intensity on T1- and T2-weigthed images with thickened tendons and peritendinous/bone marrow oedema. Note that these changes can also be seen in asymptomatic patients.

Common consensus and high-level evidence on the optimal conservative treatment are lacking. Conservative treatment may include an initial phase of relative rest and icing to relieve symptoms followed by a rehabilitation programme focusing on (eccentric) hamstring strength and core stability. Use of nonsteroidal anti-inflammatory drugs (NSAIDs), trigger point dry needling, PRP or corticosteroid injections, electric muscle stimulation, proprioceptive training and soft tissue mobilisation have also been described. Time to full recovery is usually between one to three months.

Surgical treatment aims at improving symptoms in cases that do not respond well to a conservative approach and comprises a transverse tenotomy of the thickened semimembranosus

tendon. This approach appears to lead to mainly good results with a low complication rate.

PHT is a considerable challenge for treating health-care professionals. As a tendinopathic pathology, it is an overload type injury. As with other chronic tendon overuse injuries, current treatment strategies are unspecific with uncertain outcomes due to the unknown aetiology of the tendon degeneration [34].

8.6 Rehabilitation of Incomplete Proximal Stretch-Type Hamstring Injuries: Worst Case Scenario?

Håvard Moksnes

Acute hamstring strains are common in sports, and various demands on the hamstring complex in different sports are reflected by variations in injury mechanisms and injury sites [29, 35]. Over the past decade consensus has been established that differentiation between sprinting type and stretching type injuries is of importance because different treatment algorithms should be applied, and prolonged recovery time can be expected with stretching-type injuries [36]. Stretch-type hamstring injuries occur with combined excessive hip flexion and knee extension and are most likely to result in a proximal injury that affect one, two or all three of the hamstring tendons. Proximal stretch-type hamstring injuries are frequently associated with prolonged morbidities consisting of impaired lower extremity function due to deficits in muscle strength and long-standing pain following either surgical or conservative management [29, 37–39]. Evidence-based rehabilitation protocols are lacking in the literature, although some level IV studies are available [40–42].

Accurate anatomical and functional diagnosis is of great importance when rehabilitation is initiated as the different muscle bellies must be targeted with different exercises [40, 43]. Proximal hamstring injuries affecting one of the two medial tendons are usually considered to have a favourable prognosis following conservative treatment due to the agonist function of the semitendinosus (SM) and semimembranosus (ST) muscles. Conversely, an avulsion of both medial tendons or the long head of the biceps femoris tendon (BFLH) is less likely to result in a favourable outcome following conservative treatment – in particular if the athlete is participating in a sport with high demands for high-speed running. Additionally, the sciatic nerve passes in close proximity to the hamstring tendons and muscles which makes it vulnerable when a stretching type injury occurs. Reduced function of the peroneal branch may occur after a stretch-type injury and may result in weakness of the short head of the biceps femoris muscle and also possibly affect the function of ankle dorsiflexion.

Worst-case scenarios after an incomplete stretch-type hamstring injury resulting in chronic functional impairments and pain occur in the following circumstances: (1) a large avulsion (BFLH or SM + ST) is missed and treated conservatively or left untreated, (2) specific exercises are not provided during rehabilitation, (3) pain is ignored during rehabilitation and (4) nervous tissue involvement. Rehabilitation algorithms, clinical application and functional progression models to avoid the worst-case scenarios will be discussed at the ESSKA 2016 ICL.

8.7 PRP for Acute and Chronic Proximal Hamstring Injuries

Gustaaf Reurink

There is a growing interest in sports medicine and athletic communities for using endogenous growth factors directly into the injury site to facilitate healing after injury [44, 45]. The most popular is the injection of platelet-rich plasma (PRP). Platelets release various growth factors upon activation that are assumed to provide regenerative benefits. Basic science studies have shown that myoblasts and tenocytes can be proliferated by growth factors like platelet-derived

growth factor (PDGF), insulin-like growth factor (IGF-1), basic fibroblast growth factor (bFGF-2) and nerve growth factor (NGF) [46, 47]. In deliberately injured animal muscles, these growth factors increase regeneration [46, 47].

8.7.1 Acute (Proximal) Hamstring Injuries

Despite the promising results from basic research, and apparent widespread clinical use, a recent meta-analysis with pooled data of three randomised controlled trials (RCTs) [48–50] showed no superiority of PRP in treating acute hamstring muscle injuries on the time to return to play and the re-injury rate [51]. As these RCTs excluded all complete hamstring ruptures (grade III), and the lack of clinical studies available on the use of PRP in proximal hamstring avulsions, it remains unknown to what extent these result can be generalised to complete proximal hamstring injuries. Despite this unknown generalisability, we do not expect that PRP injections in complete muscle ruptures would show different efficacy than in partial ruptures. Therefore, we discourage the use of PRP injections in acute proximal hamstring injuries.

8.7.2 Chronic Proximal Hamstring Tendinopathy

PRP is widely used for treatment of chronic tendinopathy, including proximal hamstring tendinopathy. Nonetheless, the scientific evidence for its effectiveness in proximal hamstring tendinopathy is limited to one RCT comparing PRP and whole blood injections [52] and three low quality case series (level IV evidence) [53–55]. There are currently no studies that compare PRP treatment with a control group without injections or placebo. High-quality systematic reviews on other chronic tendinopathic conditions, such as lateral epicondylitis and Achilles and rotator cuff tendinopathy, show no benefit of PRP over placebo treatment on pain and function [56, 57].

As there is no high-level evidence to support its use in proximal hamstring tendinopathy, and the strong evidence against a therapeutic benefit in other tendinopathies, we also do not recommend PRP injections in proximal hamstring tendinopathy.

8.7.3 PRP: Many Unanswered Questions

Our current scientific knowledge about PRP remains at a basic science level, and there are many unanswered questions regarding its use in muscle injury [46]. These include some very basic questions, such as what concentrations and ratio of growth factors are required for optimal muscle healing? Which specific growth factors are active? Is timing and number of injections important? Does the injected PRP remain at the injection site? Is the presence of leucocytes in the PRP beneficial or detrimental for tendon and muscle healing? In addition to these unanswered basic questions, currently no proven scientific mechanism is available for a therapeutic effect of PRP in tendon and muscle injury.

Conclusion

As there is no high-quality evidence that justifies the use of PRP in proximal hamstring injuries, we do not recommend PRP injections in both acute and chronic injuries.

Take Home Message

- Different injury mechanisms lead to distinct injuries in different hamstring muscles with different prognoses.
- A rehabilitation programme should aim at mimicking the particular situation and muscle work that lead to the injury.
- Surgical repair of proximal hamstring avulsions comprises reinsertion at the correct anatomical site and should ideally be performed within 6–12 weeks. Chronic total tears may be reconstructed with an auto- or allograft.

- Proximal hamstring tendinopathy (PHT) is a disabling disease often causing underperformance in athletes.
- High-quality evidence to support the use of PRP is lacking and its use in proximal hamstring injury is therefore not recommended.

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9 Posterolateral Corner Reconstruction: Approach to Treatment Including Mini-open and Arthroscopic Techniques (ICL 10)

Ivan Saenz, Xavier Pelfort, Robert F. LaPrade, Brett A. Fritsch, Pablo E. Gelber, and Karl-Heinz Frosch

9.1 Introduction

The posterolateral corner of the knee is an anatomically complex region. Successful treatment of injuries to this part of the knee requires a detailed understanding of its anatomy and biomechanics. Injuries are graded based upon the structures involved and the resulting patterns of instability, and there are multiple different reconstruction techniques described, all of which differ in their ability to recreate the biomechanics of this region. The approaches for performing these reconstructions run the gamut from total open, to minimally invasive, through to arthroscopically assisted techniques.

This chapter aims to give a brief overview of the most surgically relevant anatomy of the posterolateral corner, the biomechanical consequences

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of different reconstructions, and a guide to choosing the reconstruction based upon the degree of injury. We will discuss the evolution toward minimally invasive techniques for open reconstruction and the future direction of surgery of this region including arthroscopic reconstruction of some of its elements.

9.2 Anatomy of the Posterolateral Corner (PLC) of the Knee

9.2.1 Anatomy and Its Relationship to Injury

The posterolateral corner (PLC) is a complex functional unit consisting of multiple anatomic structures which are responsible for posterolateral stabilization of the knee. These elements prevent varus angulation, posterior shift, and excessive external rotation of the knee [34]. The complexity of the anatomic structures constituting this area and the confused nomenclature of the ligaments and capsular thickenings have concentrated the interest of many researchers [5, 7, 17, 27]. While these authors have identified many distinct components of the posterolateral corner, there are three consistent structures that provide the majority of the functional mechanics of the region, particularly from a surgical reconstruction perspective: the fibular collateral ligament (FCL), the popliteus tendon (PLT), and the popliteofibular ligament (PFL).

Injury to the posterolateral corner occurs when a direct force is applied to the anteromedial tibia with the knee at or near full extension. It can also occur with combined hyperextension and external rotation, severe varus stress, or severe tibial external rotation torque. When using MRI to make the diagnosis, posterolateral knee injuries occurred in approximately 15 % of all patients who have suffered an acute ligament injury of the knee. Between them, more than half involves more than one of these three critical ligaments, and the most common injury combination is FCL + PFL [19].

9.2.1.1 Fibular Collateral Ligament (FCL)

The fibular collateral ligament (FCL), also known as the lateral collateral ligament, is one of the three main structures of the posterolateral corner of the knee. The FCL prevents varus angulation and limits internal rotation of the knee. The FCL is typically 4–5 mm in width and attaches proximally in a fanlike manner on the femur. Its proximal attachment is slightly proximal (1.4 mm) and posterior (3.1 mm) to the lateral epicondyle [16]. The fibular insertion is on the anterolateral aspect of the fibular head, slightly anterior and distal to the styloid process, with a fan-shaped morphology and blended with the attachment of the biceps femoris tendon [26] (Fig. 9.1). The static stability of the PLC is mainly provided by the fibular collateral ligament (FCL) and the popliteofibular ligament (PFL). The FCL is the primary static stabilizer of the varus opening [16].

9.2.1.2 Popliteus Tendon (PLT) Muscle

The popliteus complex is a very important posterolateral rotatory stabilizer to the knee. It has both a static and a dynamic function. The main

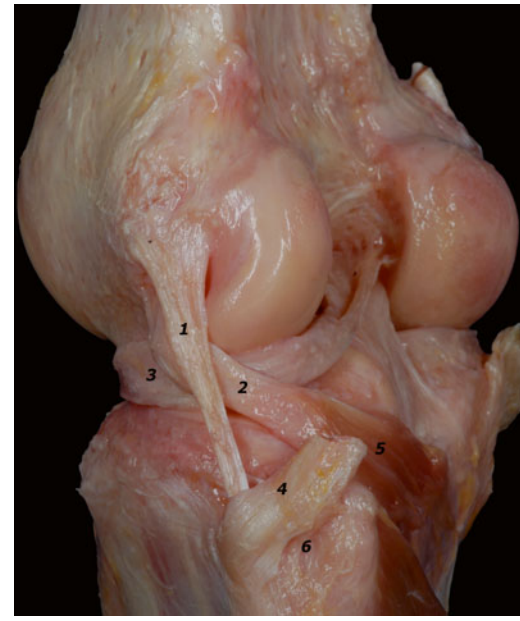

Fig. 9.1 Posterolateral view of FCL in extension knee. *1* FCL, *2* PT, *3* lateral meniscus, *4* biceps tendon, *5* PM, and *6* fibular head

tendinous attachment of the PLT is at the top fifth of the popliteal sulcus of the femur. At this location, the center of the popliteus tendon attachment is 18.5 mm anterior and distal to the center of the LCL attachment on the femur. The tendon continues down through the popliteal hiatus, deep in relation to the fabellofibular and arcuate ligaments, and at the level of the popliteus musculotendinous junction the popliteofibular ligament courses from the popliteus tendon down to the posteromedial aspect of the fibular styloid [16]. The muscle unit of the popliteus itself then continues down to its insertion on the posteromedial tibia.

9.2.1.3 Popliteofibular Ligament (PFL)

The presence of the fibular attachment of the popliteus was first mentioned by Higgins in 1894, and later by Taylor and Bonney, but then was largely ignored. This belies its importance. A study by Shahane et al. [29] identified the PFL in all of their knees, and it was identified in 98 % of the knees studied by Sudasna et al. [6]. In a study of 115 cadaveric knees, Watanabe et al. identified the PFL in 94 % of knees [36]. The PFL courses from the PT down to the posteromedial aspect of the fibular styloid. The mean angle of its course has been reported by different authors as between 38 and 51° in a distolateral direction from the popliteus tendon to the posteromedial fibula. Morphological variations include a single bundle, a double ligament, or an inverted Y-shaped structure. A separate anterior and posterior bundle was found in 26.7 % specimens and a Y-shaped ligament in 13.3 % specimens. Sixty percent of specimens had a single anterior or posterior ligament. The function of the popliteofibular ligament is as a static stabilizer of the lateral and posterolateral knee, resisting varus, external rotation, and posterior tibial translation [18, 21] (Fig. 9.2). The PFL and PLT are the primary stabilizers of external rotation [15].

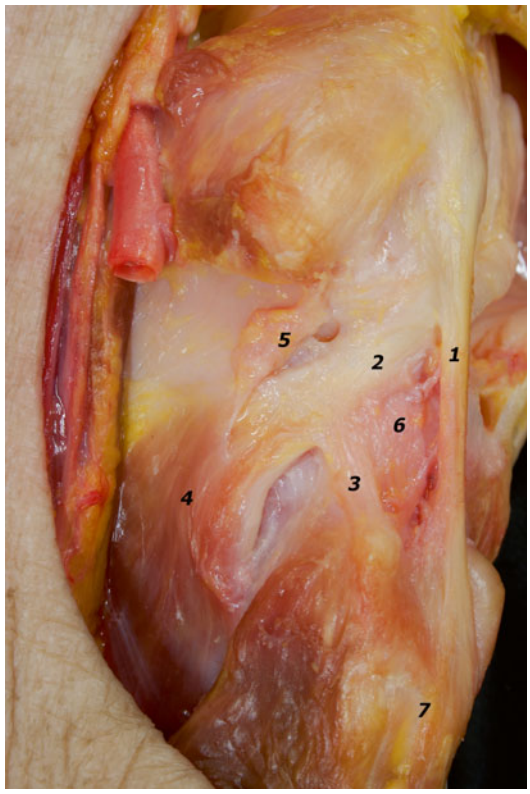

Fig. 9.2 Anatomic dissection of PFL and popliteus tendon and muscle. *1* LCL, *2* PT, *3* PFL, *4* PM, *5*AL, *6* lateral meniscus, and *7* fibular head

9.2.2 Summary of Biomechanics

The main static stabilizers of the posterolateral corner (PLC) of the knee are the fibular (lateral) collateral ligament (FCL), the popliteus tendon (PLT), and the popliteofibular ligament (PFL). Together, these three structures function as essential stabilizers for the PLC of the knee by limiting varus, external rotation, and coupled posterolateral translation. The FCL is the primary restraint to varus stress; however biomechanical cadaveric studies have shown that sectioning the other PLC structures leads to increased varus laxity. In addition to providing secondary restraint against varus force, the PFL and PLT are the primary stabilizers of external rotation [15].

9.3 Biomechanics of Different Reconstruction Techniques

The purpose of PLC reconstruction surgery is to attempt to restore varus and external rotary static stability to the knee with significant and symptomatic posterolateral rotatory instability. While a variety of reconstruction techniques have been

described, few have been biomechanically evaluated. This discussion will focus on those that have been biomechanically studied. This approach also gives some feel to the evolution of reconstruction techniques.

9.3.1 Biceps Tenodesis

Clancy [3] described a repair of the PLC using tenodesis of the biceps femoris tendon. The tenodesis is designed to reconstruct the FCL and to reinforce the posterolateral capsule by tightening the attachments of the biceps tendon to the arcuate complex [3, 22, 35]. In 1993, Wascher et al. biomechanically tested the effects of biceps tenodesis to restore stability in a PLC deficient knee. They found that biceps tenodesis using a femoral fixation point 1 cm anterior to the FCL insertion was effective in restoring external rotation and varus laxity, but actually overconstrained both external rotation at all flexion angles, as well as varus angulation at 60 and 90° of knee flexion. On the contrary, biceps tenodesis using a fixation point one centimeter proximal to the femoral FCL insertion did not adequately restore external rotation and varus laxity at 60 and 90° of knee flexion [35].

9.3.2 Fibular Sling

Numerous reports have described the use of a fibular sling technique to reconstruct the FCL with the use of one or two femoral tunnels [8, 13, 28, 37, 39]. In 2007, Coobs et al. biomechanically tested an isolated FCL reconstruction using an autogenous semitendinosus graft (Fig. 9.3: Anatomic reconstruction of the FCL). In cases of isolated fibular collateral ligament injury, they found that this technique restored varus, external, and internal rotation to near-normal stability [4].

9.3.3 Fibular Sling with PLT and PFL Reconstruction (4-Strand Technique)

In addition to the fibular sling, the popliteus tendon and popliteofibular ligament can be reconstructed with a second graft that attaches to the femoral popliteus tendon insertion. The graft passes from posterior to anterior through the same fibular tunnel as the sling and is then passed anterior to posterior through a tibial tunnel [13]. In 2011, Miyatake et al. compared the biomechanics of the fibular sling technique to Jakobsen's 4-strand technique and found that rotational knee laxity in response to external rotation and posterior translation load was significantly reduced after the 4-strand PLC reconstruction but found no significant difference regarding varus laxity [24].

9.3.4 Effect of Isolated PLT Reconstruction

A biomechanical analysis of the PLT in 2010 by LaPrade et al. demonstrated the importance of the PLT as a primary static stabilizer to external rotation. Anatomic reconstruction of the PLT was shown to significantly reduce external rotation in PLT deficient cadaveric knees (Fig. 9.4: Anatomic reconstruction of the PLT) [20].

9.3.5 Anatomic Reconstruction of the FCL, PLT, and PFL with Two Grafts

In 2004, LaPrade et al. described an anatomic reconstruction technique of the PLC based on a biomechanical study which quantitatively assessed the anatomic attachments of the FCL, PLT, and PFL [15, 16]. This was the first technique to recreate the anatomic attachments of the three main static stabilizers of the PLC. This technique uses two grafts and four tunnels to reconstruct the FCL, PLT, and PFL (Fig. 9.5: Anatomic reconstruction of the FCL, PLT, and PFL).

In 2004, LaPrade et al. demonstrated that the two-graft technique to anatomically reconstruct the primary static stabilizers of the posterolateral knee restored static stability, as measured by joint translation in response to varus loading and external rotation torque. There were no significant differences in varus translation between the intact and reconstructed knees at 0, 60, and 90° of knee flexion. Additionally, there was no significant difference in external rotation between the intact and

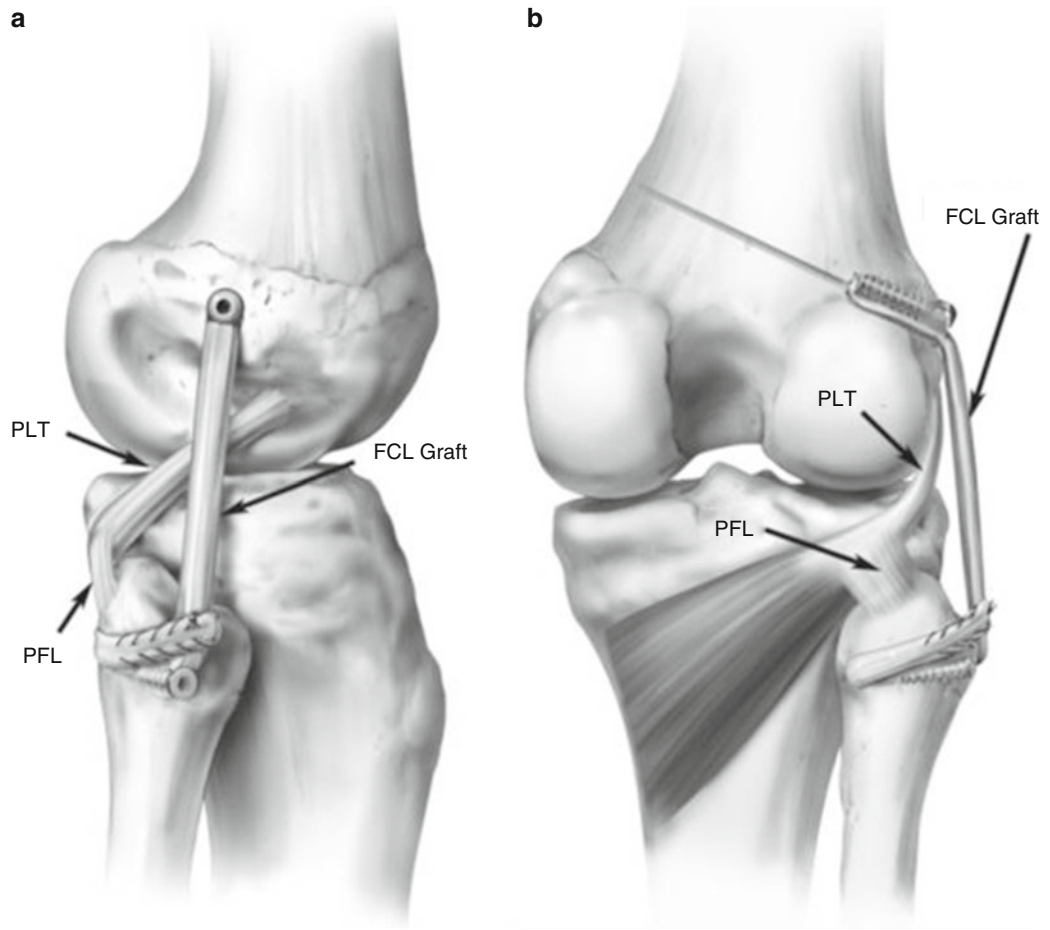

Fig. 9.3 (**a**) Lateral view (*right knee*) and (**b**) posterior view (*right knee*) of an isolated anatomic FCL reconstruction using a semitendinosus graft. Also shown are an intact PLT and PFL. Note that the tunnel exiting the posteromedial margin of the fibular head is distal to the fibular attachment of the PFL. FCL graft, fibular collateral ligament reconstruction with an autogenous semitendinosus graft; *PLT* popliteus tendon, *PFL* popliteofibular ligament (Coobs [4], Reproduced with permission)

reconstructed posterolateral knees at any flexion angle [15]. Furthermore, a follow-up study by McCarthy et al. [23] validated that anatomic reconstruction of the PFL is necessary to restore knee stability for this anatomic PLC reconstruction technique and did not overconstrain the knee [23].

9.3.6 Summary

Assessment of these techniques, based upon their ability to restore normal biomechanics, gives some idea of the variety of techniques available to the treating surgeon. Unfortunately, there has been a paucity of in vitro biomechanical studies for most posterolateral reconstructions. More biomechanical studies are needed, particularly direct comparison studies. In order to restore stability of the knee, particularly varus stability and to limit posterolateral translation in patients with posterolateral knee stability, we believe it is important to reconstruct the FCL, PLT, and PFL [14, 29, 31, 33].

9.4 Minimally Invasive Posterolateral Corner Reconstruction

After determining the exact anatomic structures disrupted in a given injury and deciding on the reconstruction technique which best restores the biomechanics which have been disturbed, the

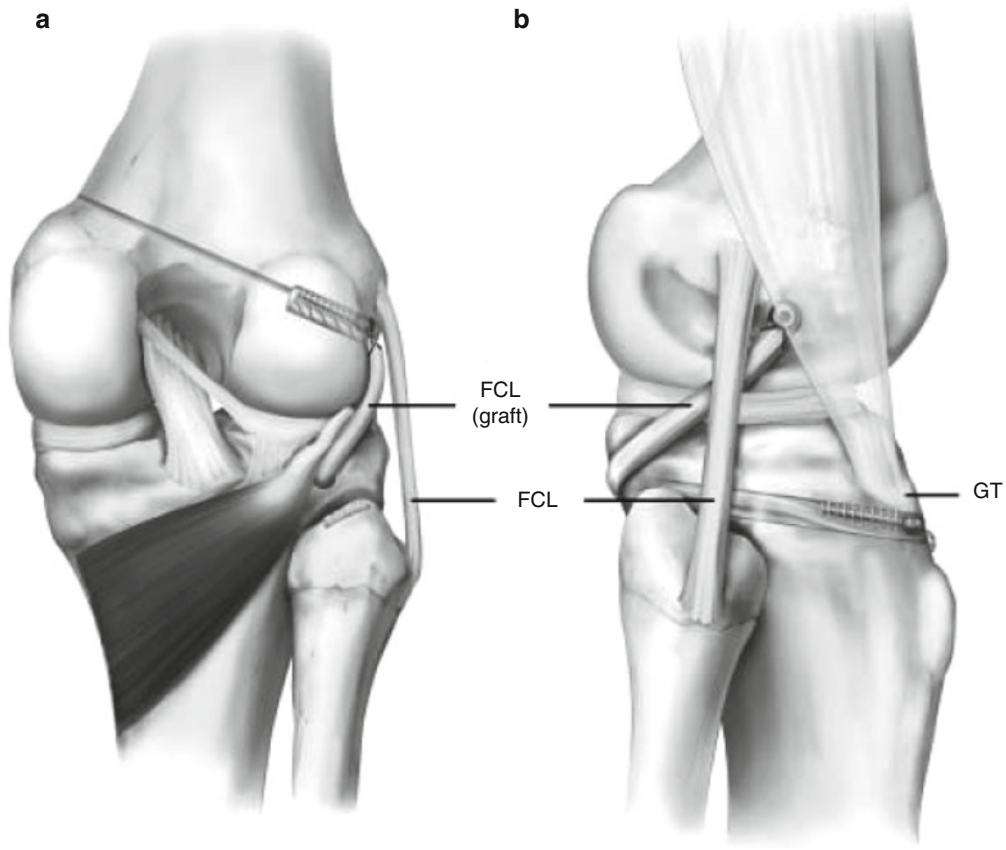

Fig. 9.4 (**a**) Posterior view (*right knee*) and (**b**) lateral view (*right knee*) of an isolated anatomic PLT reconstruction using a semitendinosus graft. Important landmarks for the tibial tunnel include the musculotendinous junction of the popliteus tendon on the posterior tibia and the flat area on the anterior tibia just distal and medial to Gerdy's tubercle (*GT*). The femoral attachment site of the PLT is located at the proximal portion of the anterior fifth of the popliteal sulcus. *PLT* popliteus tendon reconstruction graft, *FCL* fibular collateral ligament (LaPrade [20], Reproduced with permission)

next decision for the treating surgeon is the surgical approach to the reconstruction. The traditional approach has been to perform a wide dissection, in order to fully expose the anatomy and allow for a clear view of all structures that may be repaired, and visualize the reconstruction being used. Standard open techniques begin with a long skin incision and creation skin flaps to expose the subcutaneous layers (Fig. 9.6).

Several authors have described different approaches to the deeper structures via the creation of fascial "windows." Laprade et al. described a three-window approach with the first being made posterior to the long head of biceps to allow exposure of the common peroneal nerve and safe exposure of the posterior aspect of the fibula head, the second between the posterior fibers of the ITB and anterior to the short head of the biceps revealing access to the posterior aspect of the lateral tibial plateau and visualization of popliteal bypass grafts, and the third a longitudinal split in the ITB itself to expose the femoral insertions of the LCL and popliteus [32]. Other authors have described slight variations on this theme, with the exact locations of these deeper windows depending on which structures and planes require exposer for the planned reconstruction [1]. The critical point is that fascial win-

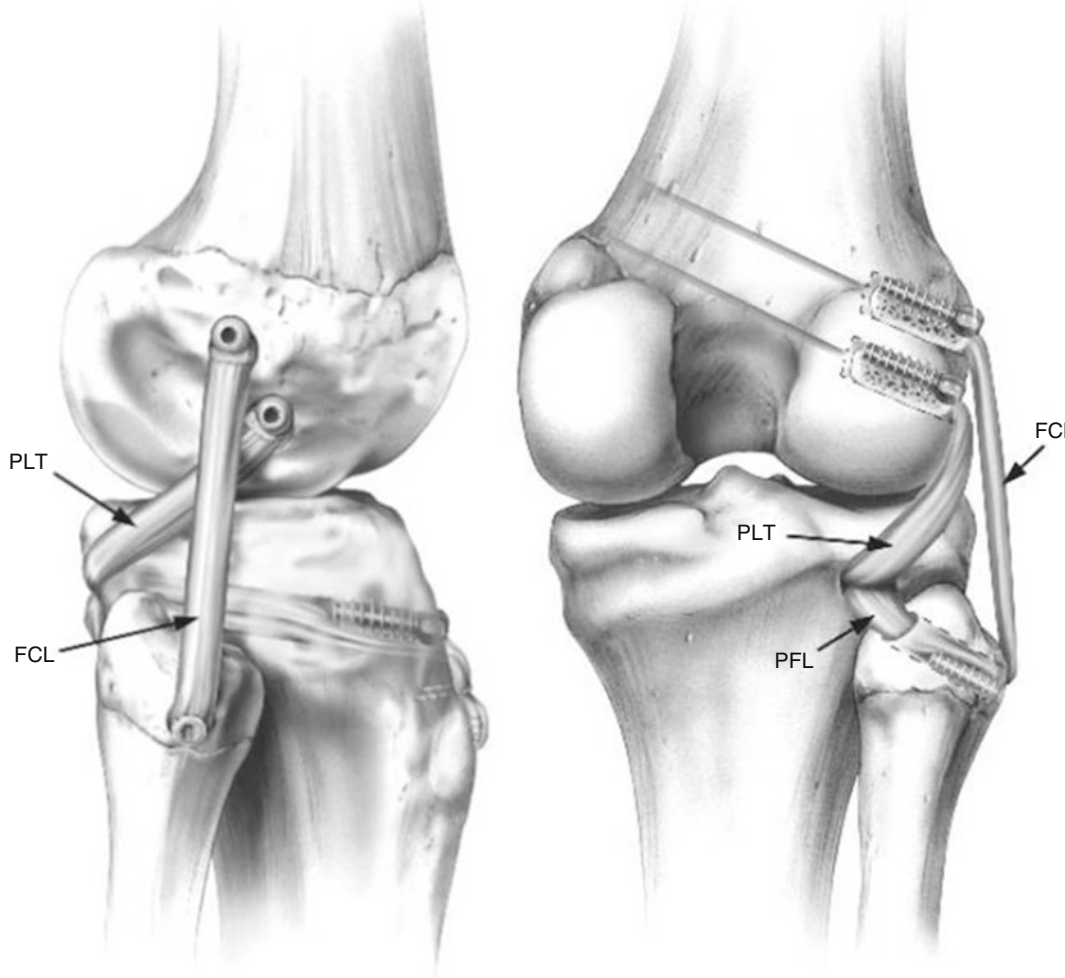

Fig. 9.5 Anatomic reconstruction of the FCL, PLT, and PFL with two grafts. (**a**) Lateral view, *right knee*, and (**b**) posterior view, *right knee. PLT* popliteus tendon, *FCL* fibular collateral ligament, *PFL* popliteofibular ligament (LaPrade et al. [15], Reproduced with permission)

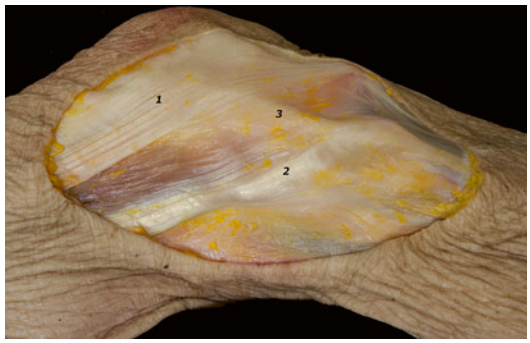

Fig. 9.6 Traditional "open" approach to the PLC. Incision runs along the line of the ITB, curving to finish midway between Gerdy's tubercle and the fibula head. Anterior and posterior skin flaps are created. *1* ITB. *2* Biceps femoris. *3* LCL (under tension)

dows are made based on the need to access the underlying anatomic landmarks and tissue planes.

This concept of making limited windows in the deep fascial layers in order to access the critical landmarks, planes, and structures that lie deeper still can easily be extended one layer more superficial. Rather than starting the approach with a large skin incision and creation of skin flaps followed by more limited incisions in the fascial layers, several small incisions in the skin can be made in the same location as the planned fascial windows that will lie deep to them. By reversing the thinking about the approach from an "outside working in" concept to one of "deep

and working out," a minimally invasive surgical approach can be planned and safely performed.

To plan such a surgical technique, the surgeon must start by visualizing the deepest planes first and extend superficial from those. The critical landmarks that will require exposure in order to pass the grafts through, or into, the bone must make the basis of the incisions. For example, there must be one incision that allows for exposure of the femoral insertion of LCL and popliteus and another for approaching the fibula neck. The next consideration is that there is sufficient exposure to allow for creation of surgical planes for the passage of the grafts from one zone of insertion to another. Finally the incisions should be planned in such a way that they can be extended if needed without the risk of creating narrow skin bridges or particularly unusual incisions should they need to become confluent.

The primary goal is to allow for the same exposure of the fundamental elements of the reconstruction without the need for extensive skin incision and subcutaneous dissection. With a clear understanding of the deepest part of the dissection, and working from there up into the superficial parts of the approach, this can generally be achieved via two or three small incisions (Figs. 9.7 and 9.8).

9.4.1 Indications

This minimally invasive approach is particularly applicable in the chronic posterolateral corner reconstruction. In these cases where there is not the requirement for direct repair of acutely injured in situ anatomic elements, but rather isolated passage of new graft material through well-defined anatomic planes toward fixed bony landmarks, there is less likelihood for the need to extend the small incisions provided they are properly located. In acute cases where there is the potential to not only augment the posterolateral corner with a reconstruction but also to directly repair the native tissue that has been torn or avulsed, there is a greater likelihood for the need to extend the incisions. This does not preclude the use of a minimally invasive technique, but it does require more emphasis on the precise placement and orientation of the skin incisions such that they can be extended if required.

In summary, the goal of any surgical approach is to provide adequate exposure of the anatomy that requires attention. In the case of the postero-

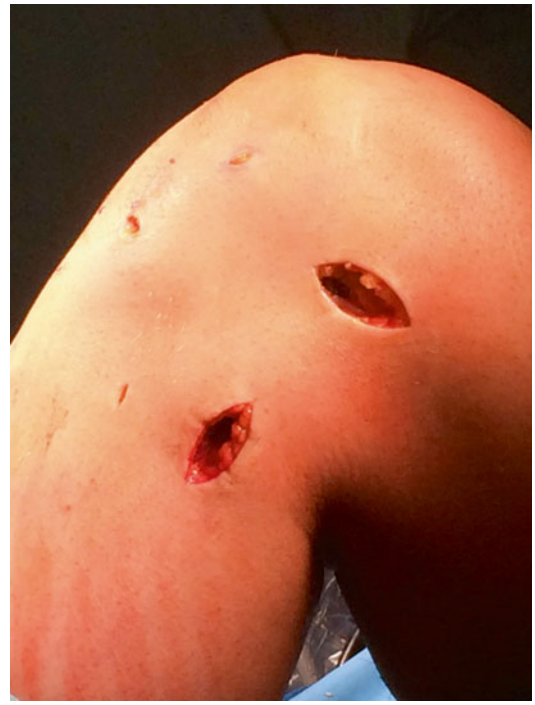

Fig. 9.7 Two incision techniques that allow access to the femoral insertion of the FCL and PLT and the fibula neck. The fibula insertion is mobile to allow access anterior and posterior to the fibula for safe identification of the CPN at the fibula neck and creation of a fibula tunnel for graft passage

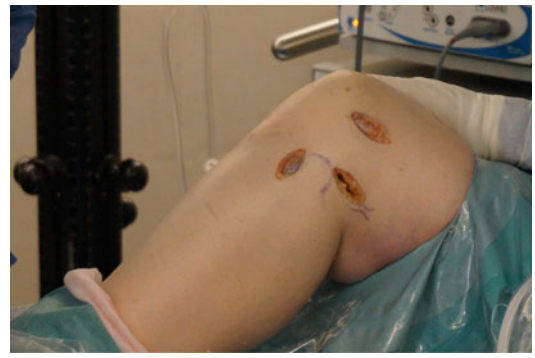

Fig. 9.8 A third incision can be added for easier access to the plane behind the fibula and tibia for the two-graft anatomic reconstruction of LaPrade

lateral corner, this can generally be achieved by two or three minimal skin incisions that are placed in such a way as to allow access to the deep fascial windows that make up the basis for accessing the anatomy critical to the reconstruction, rather than the need for an extensive incision and skin flap creation.

9.5 Surgical Considerations Based on Grading of Injury

There are multiple approaches to surgically reconstructing the posterolateral corner. One approach is to grade the severity of the injury and then tailor the reconstruction to the grade. For a PLC injury's grading system to be considered optimal, it must include assessment of both varus and rotational stability. The grading system described by Fanelli and Larsen [9] fulfills this requisite. It classifies the PLC injuries as types A, B, and C (Table 9.1).

With each increase in Fanelli grade of injury, there is a greater degree of instability and a concordant need for a more robust reconstruction technique. This system can thus be used to guide the reconstruction chosen as follows:

9.5.1 Fanelli A

The PFL is reconstructed following a recently described technique [38]. A standard large lateral incision or three short incisions are made just (1) anterior to the fibular head, (2) proximal to the posterior aspect of the fibular head anterior to the biceps femori (which protects the peroneal nerve), and (3) around the lateral femoral epicondyle. Both ends of a tendon graft are introduced retrograde into two convergent tunnels drilled in the fibular head (Fig. 9.9). The free tails are introduced and fixed in a femoral tunnel drilled in the anterior third of the popliteus sulcus. If an ACL reconstruction is being concomitantly performed, this femoral tunnel must be drilled at 30° axial and 30° coronal angulations [5] to avoid tunnel collision.

Table 9.1 Classification system for PLC injuries as described by Fanelli and Larsen [9]

Fanelli A	Fanelli B	Fanelli C
Increase external rotation	Increase external rotation and mild varus instability	Significant rotational and varus instability
Isolated injury to PFL	Injury to PFL and partial FCL	Complete injury to PFL, FCL, and cruciate ligaments

9.5.2 Fanelli B

The technique described by Arciero [2] specifically addresses the two injured structures: A single graft reconstructs both the FCL as well as the PFL. Again, a standard large lateral incision or, instead, the same three small incisions described in the reconstruction of the PFL are appropriate for exposing the corresponding drilling tunnel places (Fig. 9.10). When an ACL is being concomitantly reconstructed, the femoral tunnel of the PFL is drilled similarly to the previous technique. However, the femoral tunnel of the FCL must be drilled at 30° axial and 0° coronal angulations [12].

9.5.3 Fanelli C

In the most severe cases, a stronger construction should be performed. The well-known Laprade

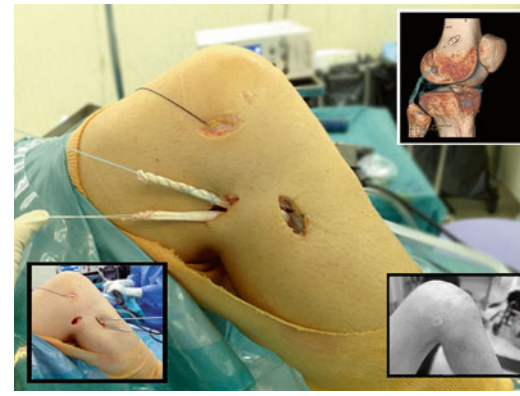

Fig. 9.9 Isolated PFL reconstruction via mini-open technique

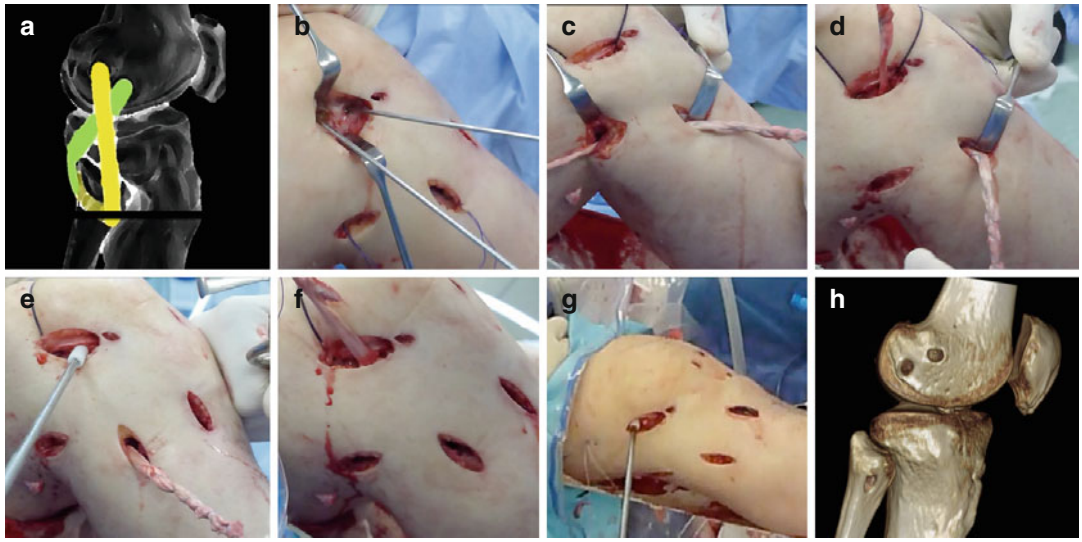

Fig. 9.10 (**a**–**h**) Modified Arciero technique (mini-open)

technique [15] anatomically reconstructs the FCL and also adds a tibial sling graft to fix the PFL as well as the reconstructed popliteus tendon.

9.5.4 Isolated FCL Injury

In the case of the infrequent isolated FCL injuries, a double mini-open incision is sufficient to percutaneously reconstruct this ligament. A bone-tendon graft is recommended, and the Achilles tendon fulfills the requisites of the bone plug and sufficient length of the tendon. The bone plug is fixed in the fibular head. Fluoroscopy is recommended to drill the tunnel in the fibular head. Otherwise, there is a high risk of drilling the tunnel too superficial. The soft tissue end is fixed in a tunnel drilled at the femoral origin of the FCL.

9.5.5 Summary

By grading the injury based upon the exact anatomic disruption and associated pattern of resulting instability, a more standardized approach to its surgical management can be made. It allows for selection of the most appropriate surgical approach to address each individual patient's unique injury.

9.6 Future Directions: Arthroscopic Techniques for Posterolateral Corner Reconstruction

The evolution, from the fully open dissection to minimally invasive techniques, can be extended one further step. Arthroscopic reconstruction of those elements of the posterolateral corner that are intra-articular is already being performed.

9.6.1 Popliteus Bypass Reconstruction

For patients with Fanelli A posterolateral rotational instabilities, most cases have an intact popliteus tendon according to arthroscopic evaluation [7] but an isolated disruption of the popliteofibular ligament (Fig. 9.11).

This results in an intact, dynamic function of the popliteus tendon with a loss of the static stabilization of the popliteus complex against external rotation and dorsal translation of the tibial head. Werner Müller described the use of a "popliteus bypass graft" to reconstruct this static stabilizing function of the popliteus complex [25, 34]. Biomechanical tests demonstrated that the

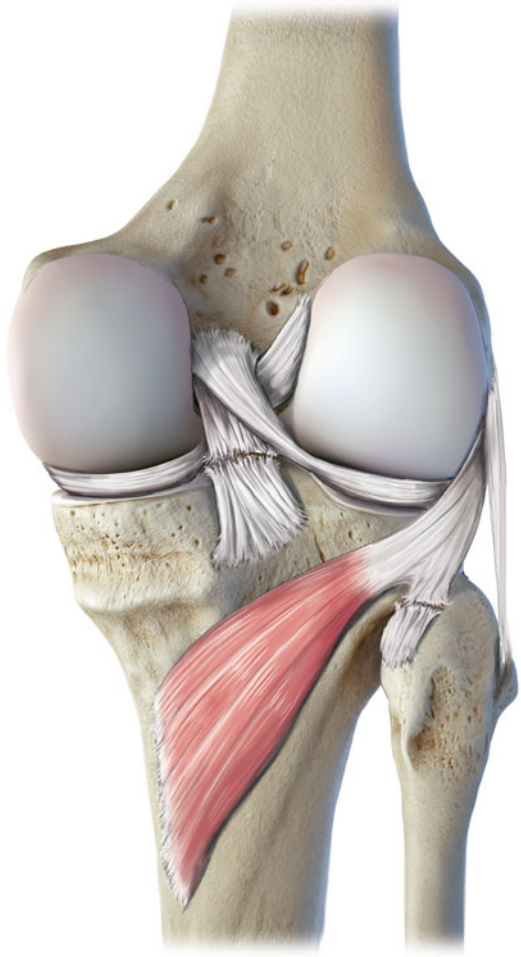

Fig. 9.11 PCL rupture and rupture of the popliteofibular ligament with an intact popliteus tendon and an intact LCL resulting in a posterolateral rotational instability, classified as Fanelli A

bypass procedure could effectively correct the abnormal external rotational instability. In the current literature, different arthroscopic procedures for reconstructing the static portion of the popliteus complex have been described [10, 11, 30]. A popliteus bypass graft can be performed with a tibial or fibular tunnel (in the latter case, it is called "popliteofibular ligament reconstruction"). Clinical and biomechanical studies did not reveal any advantages of either method over the other. However, an arthroscopic and anatomic

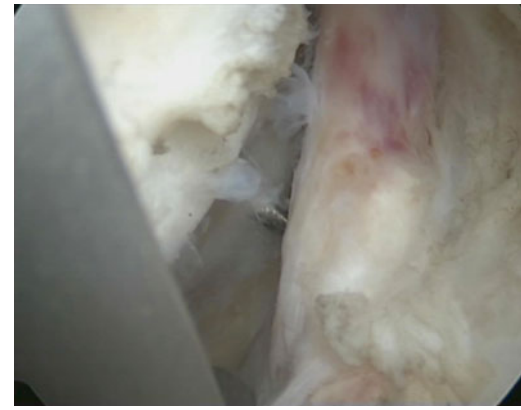

Fig. 9.12 Arthroscopic view from a posteromedial portal in a right knee. At the right edge, the popliteus tendon is retracted out of the sulcus popliteus. In the distal part of the sulcus popliteus, a guide wire was anatomically placed. The tendon itself is intact, but small ligaments are disrupted from the tendon

tibial tunnel is technically easier to create than an arthroscopic fibular tunnel, and the latter has the additional disadvantage of the fibular head bone quality being inferior to that of the tibial metaphysis for graft fixation. Therefore, we prefer using anatomic tibial and femoral tunnels for the popliteus bypass graft guided by arthroscopy.

9.6.2 Surgical Technique

The principles of the operative procedure are:

(i) Clear arthroscopic visualization of the sulcus popliteus
(ii) Insertion of a tibial drill guide ("Tibial Popliteal Marking Hook"), Arthrex, Naples, USA
(iii) Drilling a tibial tunnel located in the middle of the distal part of the sulcus popliteus (Fig. 9.12)
(iv) Femoral exposure of the footprint of the popliteus tendon and anatomic placement of a femoral tunnel under arthroscopic control
(v) Graft passage and fixation

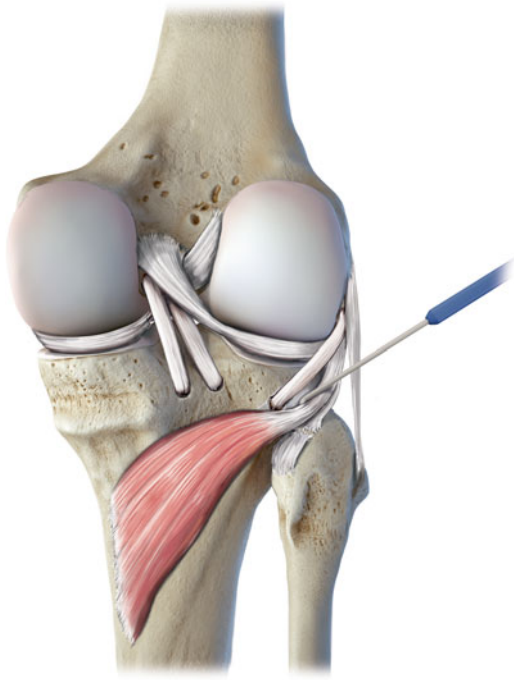

Fig. 9.13 Schematic drawing of an arthroscopic PCL reconstruction (double bundle) combined with an arthroscopic *popliteus bypass graft*

9.6.3 Results

Forty patients, with a combined Fanelli A posterolateral corner injury and PCL disruption, were treated with this technique in combination with a PCL reconstruction (Fig. 9.13).

Fifteen patients have been examined after 1 year of an ongoing study. No technique-related complications were observed. The mean postoperative Lysholm score was 88.6 (±8.7), and the mean side-to-side difference in the posterior drawer test was 2.9 (±2.2) mm (preoperative 13.3 (±1.9) mm).

9.6.4 Summary

More long-term data are needed to support this initial series, but the arthroscopic reconstruction of the static portion of the popliteus complex using a popliteus bypass graft can be performed with a low complication rate and excellent clinical results. It is a technically demanding procedure which requires advanced arthroscopic skills and experience in PCL and PLT surgery, but the advantages of the arthroscopic technique include proper visualization of anatomic landmarks, which is not possible with open techniques and utilization of small incisions with possibility of lower infection rates, lower rates of scar tissue formation, less postoperative pain, faster rehabilitation, and more esthetically acceptable scars.

Conclusion

The posterolateral corner is a complex region of knee anatomy with many components working together to maintain knee stability. Injuries can involve disruption of these different anatomic elements in varying patterns, and an understanding of the anatomy and biomechanics is critical in planning the most appropriate reconstruction of these injuries. The fibular collateral ligament, popliteus tendon, and popliteofibular ligament are the critical elements that must be restored when injured, and the different reconstruction methods aim to restore the biomechanics of these units as closely to normal as possible. By carefully grading each injury, the most appropriate reconstruction can be selected. The techniques to perform the actual reconstructions continue to evolve from the wide-open approach, to minimally invasive open surgery, and even to arthroscopic reconstruction of the intra-articular elements of the posterolateral corner. Much work remains to be done to properly assess the differences in outcomes with different techniques in vivo, but continual refinement in anatomic and biomechanical understanding along with the surgical restoration of these elements is driving ever-improving management of these challenging injuries.

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How to Identify the Optimal Surgical Intervention for Your Osteoarthritic Patient (ICL 11)

10

Michael T. Hirschmann, Nanne Kort, and Roland Becker

10.1 Introduction

What is the optimal treatment for your osteoarthritic patient? How do you decide which surgical treatment to choose? What are the treatment options surgically? When to choose what?

These are a considerable number of questions you could ask yourself in your daily clinical activity. Every day orthopaedic surgeons need to decide how to treat their symptomatic osteoarthritic patients. Ideally, the treatment should be specifically tailored to the type of osteoarthritis (OA), the patient's demands and needs, the patient's comorbidities and the surgeon's capabilities.

There are hardly any guidelines when a patient should undergo which of the following surgeries. What are the diagnostic steps and criteria, which help to decide, whether an osteoarthritic patient should undergo an osteotomy, a unicondylar knee replacement (UKA), a patellofemoral knee replacement (PFJ) or a total knee replacement (TKA)?

This instructional course lecture aims to answer the aforementioned questions and give some guidance in identifying the optimal surgical intervention for each patient.

10.2 Clinical History

The clinical history is one, when not even the important cornerstone of diagnostics. The symptoms guide the orthopaedic surgeon towards the patient's problems and reveal the underlying pathology [3, 8].

10.2.1 Stiffness

Stiffness is one of the first symptoms of OA. The knee feels stiff and swollen, making it difficult to bend and straighten the knee [5, 28].

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10.2.2 Pain

Pain is often the second symptom of OA. Generally, the pain develops gradually over time, although sudden onset is also possible. Pain may cause a feeling of weakness or buckling in the knee. In the first stage of OA, pain and swelling may be worse in the morning or after sitting or resting. In the later stages, the pain is typically activity related and increases over time. Often the patient is able to clearly localise the pain to a distinct part of the knee joint [7, 20].

10.2.3 Locking

Loose fragments of cartilage and other tissue can interfere with the smooth motion of joints. The knee may "lock" or "stick" during movement. It may creak, click, snap or make a grinding noise (crepitus) [16, 24].

10.2.4 Meteorosensitivity

Many people suffering from OA complain about increased knee pain with rainy weather, cold weather or weather changes.

10.2.5 Limitation and Disturbance in Sports and Daily Activities

OA is a progressive disease, which leads to progressive limitation of sports and later daily activities. Depending on the stage of OA and the patient's activity level and sports activity, different surgical options should be recommended (Table 10.1) [6, 19].

For decision-making of optimal treatment age, BMI, activity level, demands and expectations of the patient as well as patient's disturbance and activity limitation need to be considered (Table 10.1) [21].

10.3 Clinical Examination

A detailed but focused clinical examination the orthopaedic surgeon aims to confirm the clinical diagnosis, which was made based on clinical history.

The four pillars of clinical examination are inspection, palpation, ROM and specific clinical tests.

Inspection of the knee starts when the patient enters the room. Alignment, gait and limping should be assessed.

With regard to alignment, a varus or valgus deformity and genu recurvatum should be recognised. In such a knee, osteotomies should be considered [30].

If the deformity is above a certain threshold, partial knee replacement is not recommended [10, 15].

Gait pattern and limping give the treating orthopaedic surgeon additional information. Heel and toe gait should be investigated for thrusting of the knee.

Table 10.1 Indications for high tibial osteotomy (HTO), unicondylar knee arthroplasty (UKA) and total knee arthroplasty (TKA)

	HTO	HTO or UKA	UKA	TKA
Age	<65 years	55–65 years	>55 years	>55 years
Weight (BMI)	<30	<30	<30	Any
Activity	Active	Moderately active	Low demanding	Any
Alignment	5–15°	5–10°	0–5°	Any
ROM	Arc 120°, flexion contracture <5°	Arc 100°, flexion contracture <5°	Arc 90°, flexion contracture <5°	Any
AP instability	Any	<grade I	<grade I	Any
ML instability	<grade II	<grade I	<grade I	Any
No. of knee compartments	1	1	1	2-3
OA severity	KL 1–2	KL 2–3	Any	Any

Thorough palpation of the knee allows localisation of tenderness, warmth, swelling and joint effusion. In particular the location of tender points gives an idea about the extent and location of OA. Furthermore, passive and active range of motion (ROM) need to be assessed. Crepitation behind the knee cap while flexing or extending the knee reflects patellofemoral joint OA.

Laxity of the knee in anterior, posterior, medial and lateral direction needs to be investigated. Also signs of subluxation should be noted. Specific meniscus as well as patellofemoral tests complements the clinical investigation [18].

10.4 Radiographs

Standard weight-bearing radiographs (anterior-posterior, lateral, patellar skyline view) are considered as the primary imaging in patients with OA. These are the working horse of a knee surgeon. In these radiographs osteophyte formation, joint space narrowing, subchondral bone sclerosis and cyst formation are analysed. In addition, subluxation reflects medial-lateral or anterior-posterior instability.

In cases, in which a valgus deformity is seen, a Rosenberg view (45° weight-bearing flexion PA view) could give additional information on the flexion facet.

Long-leg radiographs are necessary for assessment of frontal plane alignment such as varus or valgus deformity.

The grade and severity of OA can be classified with regard to Kellgren-Lawrence [11, 23, 31].

10.5 Additional Diagnostic Imaging (MRI, CT, SPECT/CT)

10.5.1 Magnetic Resonance Imaging (MRI)

MRI is the gold standard in diagnosis of cartilage lesions. It allows grading, sizing and localisation of focal cartilage lesions and generalised OA. It also gives additional information on the state of the meniscus and joint synovitis [22].

10.5.2 Computerised Tomography (CT)

CT gives additional information on bone quality. It also reveals the size and location of osseous cysts, which might be present due to OA changes. In patients with larger bone cysts and low bone quality, UKA is hardly possible [26, 29].

10.5.3 SPECT/CT

SPECT/CT is a hybrid imaging modality, which consists of a 3D scintigraphy (SPECT) and a conventional computerised tomography (CT). The patient is injected with a bone tracer, which is mainly a diphosphonate, targeting active osteoblasts. In numerous studies it has been shown that SPECT/CT is helpful in identifying and localising overloading as well as OA in the knee. This could be particularly helpful in the decision-making process of a partial or total knee replacement.

OA and overloading in only one knee compartment, reflected by increased bone tracer uptake (BTU) SPECT/CT only in the affected knee compartment, are a good indication for a partial knee replacement. Whereas if SPECT/CT shows increased BTU in more than one knee compartment, the patient should be more likely treated with a TKA. Using SPECT/CT even signs of early OA, which are not seen in MRI, could be detected.

10.6 Role of the Physical Therapist and the Patient

The role of the physical therapist cannot be underestimated. During the course of OA, it is the physiotherapist who constantly assesses the functional impairment and symptoms of the patient. Ideally the physiotherapist functions as hinge between the patient and the orthopaedic surgeon.

The patient can be considered as the surgeon's friend. The patient carries all information necessary for guidance of optimal surgical OA treatment. It is the patient's demands, lifestyle, sports and activity profile, which finger point into the direction of optimal treatment decision. The

patient's self-efficacy and compliance are additional key factors for outcomes after OA surgery [9, 25].

10.7 Decision-Making Process – When to Choose What?

10.7.1 Arthroscopy, Lavage and Debridement

Arthroscopic surgery is not an appropriate treatment for knee osteoarthritis unless there is evidence of loose bodies or mechanical symptoms such as locking, giving way or catching. Arthroscopic lavage and debridement can at best provide temporary relief of symptoms; it should be performed as exception only in patients only with normal or nearly normal limb alignment and mild-to-moderate radiographic OA [9, 12, 14, 27].

10.7.2 High Tibial Osteotomy

The ideal candidate for an HTO is a young (less than 60 years old), active patient affected by symptomatic mild-to-moderate varus knee (5–15°) with mild medial compartment involvement (less than grade III, Ahlback classification), intact lateral and patellofemoral compartments, good knee range of motion (knee flexion >120°) and no joint laxity or instability [1, 4].

10.7.3 Unicondylar Knee Replacement

The ideal candidate for UKA is a low demanding, nonobese, over 60-year-old male patient. OA or osteonecrosis should be present in only one knee compartment (medial or lateral). His ROM arc should be over 90° with less than 5° flexion contracture. In addition, the axial malalignment should be within 10° and can be passively corrected to neutral. If the absence of the anterior cruciate is a contraindication, it is still under debate.

A UKA is questionable in the presence of patellofemoral joint arthritis, youth and high activity level, obesity, chondrocalcinosis and crystalline arthropathy [13].

10.7.4 Patellofemoral Joint Replacement and Bicompartmental Joint Replacement

The ideal candidate for a patellofemoral joint replacement is a female nonobese patient >40 years with an OA limited to the patellofemoral knee compartment.

The ideal candidate for a bicompartmental joint replacement is still unclear. The surgical technique, in particular the alignment of the prosthesis, is demanding. In addition, it remains questionable if a patient with bicompartmental OA benefits more from a bicompartmental than a tricompartmental prosthesis [2, 17].

10.7.5 Total Knee Replacement

TKA is the last surgical option to consider. Hence, it should be seen as a last resort.

Take-Home Message

There are a considerable number of treatment options for patients suffering from OA at the knee joint. The most commonly used are arthroscopy, lavage or debridement, high tibial osteotomy, partial knee replacement as well as total knee replacement.

The optimal decision is made as a team approach of patient, physiotherapist and treating orthopaedic surgeon. It is guided by the patient itself, the type and location of OA, the activity level of the patient, the age and several other factors.

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Update in Labral Treatment of the Hip (ICL 12)

11

Christoph Lampert, Marc Tey, Hatem Galal Said, Bent Lund, Michael Dienst, and Ernest Schidlers

11.1 Introduction

Labral tears have been described as a cause of hip pain in young, active patients [1]. It has been shown that those lesions can initiate joint osteoarthritis [2]. Some authors suggest that labral tear is a highly prevalent lesion with up to 90 % of labral detachment in elderly people [3]. On the other side, studies like the one of Wenger et al. [4] conclude that is a rare lesion in the absence of any structural or mechanic evident cause. That means that labral tear treatment is a complex one, because even if we decide a labral debridement, repair, or substitution, biomechanics must be restored, and that means that bony structural abnormalities must be addressed. Acetabular labrum is a complex structure, with an inner part of circumferential fibrocartilage fibers, surrounded by dense connective tissue where we can find nerves and vascular vessels. The shape of that labrum can be different in the different acetabular areas, and some shapes can predispose to labral tears, while different attachment patterns may difficult tear recognition [5]. Thorough knowledge of labral vascularity, geometry and function is important to understand healing patterns of labral detachment and repair [6].

11.2 State of the Art of Treatment

Treatment of acetabular labral tears have been addressed to restore anatomy and preserve its function [7]. Nevertheless, the discussion about the biomechanic role of the acetabular labrum is controversial. Even hip labrum increases the acetabular surface in 28 %, depth in 20 %, and volume in 30 % [8], joint stability achieved by the labrum is smaller than in the shoulder, the other big enarthrosis joint in the human body, where the low bone congruency makes the labrum important to guarantee articular stability. Acetabular labrum is

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important to maintain hip sealing and shock absorption [9]. Several biomechanic works tried to define the function of hip labrum in protecting articular surface from pathologic peak stress. Konrath concluded that resection of hip labrum did not increase the pressure or load in the acetabulum [10]. These authors concluded that excision of the acetabular labrum may not predispose the hip to osteoarthritis. Recent studies using poro-elastic finite element models have demonstrated that the labrum can seal against fluid expression from the joint space. In the absence of this sealing, strains within the matrix of the cartilage were significantly higher. Hadley et al. showed a relationship between peak stress and osteoarthritis development [11]. We performed a dynamic biomechanic study with 6 hip specimens where we observed significant increase in joint peak stress after partial labral tear. It was interesting to note that after complete labral tear (defined as 5 cm longitudinal labral detachment), the acetabular pressure did not significantly increase [12]. That confirms the idea that acetabular labrum guarantees a hip seal, proposed by Ferguson [13] and Philippon [14]. If the joint seal is broken, labral function is gone, and the size of the tear is not an important issue. That concept also explains why in the clinical series the size of the tear is not an important issue on the outcomes. In our biomechanic study, we also could prove how labral reattachment normalized peak stress measured with articular pressure sensors.

As with meniscal injuries, we have realized that restoring the anatomy with acetabular labral repair leads to better future outcomes [15], although partial debridement still leads to quicker good results. Yet there are situations where labral repair is not feasible or indicated. These circumstances mainly include partial labral tears in which a large portion is still stable and calcified or a degenerated labrum, in which the quality of tissues is not suitable for repair or healing, which is sometimes seen in Pincer cases.

Another indication might be elderly patients, in which the demand is less, or in the setting or an arthroscopic management for early OA [16].

There is another key factor, which is surgeon skill. In the early learning curve, performing a labral repair might be difficult, and a debridement might lead to a better outcome than a bad repair, even if it is considered within the context of a two-stage labral reconstruction.

However, labral repair has biomechanically been shown to better restore the labral seal and improve hip stability and pressurization [14, 17].

Surgeons have done labral debridement for many years with still good results reported in the literature [18, 19]. Worse outcomes of repair occur with untreated concomitant pathology as FAI, or dysplasia (DDH) chondral lesions [20].

To the question regarding if there is still a role for labral debridement, the answer is yes. This is true but only in selected cases, where the labrum cannot be repaired as in calcified labrum or if the surgical skill limits a good repair, while addressing the associated pathology of FAI.

In 2011, the Danish Health Authorities determined by law that hip arthroscopies could only be performed in selected centers with more than 30 cases a year. They limited the hospitals allowed to do hip arthroscopies to 11 hospitals, 6 public hospitals, and 5 private clinics. Each hospital was required to report data each year every case and their outcomes. To be able to meet these demands, the Danish Society for Arthroscopy and Sports traumatology funded a National Database for Hip Arthroscopy, and since February 2012, data from 2553 operations have been recorded in this national registry.

Surgeons must report data regarding radiology (CE angle, alpha angle, joint space width among others), use of antibiotics, DVT prophylaxis, and pathology. They also report which specific procedures were undertaken. The patients report preoperative outcome measures, including HAGOS, NRS, EQ5D, HSAS, and others. They also are emailed to answer questionnaires online at 1, 2, and 5 years postoperatively.

From the DHAR, we have extracted the surgical data from the first 2000 patients, and they consist of 56 % females and 44 % males. Mean age was 37.5 years. Mean surgical time was 86.5 min and mean traction time 49.7 min. The most frequent procedure was CAM and Pincer resection and was performed in 86.3 % patients. The most common type of acetabular chondral damage was grade II lesions (wave sign) (41.8 %). Grade III and IV cartilage changes were seen in 41 % of the cases (Becks classification [21]).

Labral damage was found in 1755 patients, and of these, 5 % had a full-thickness resection performed. Eleven percent had a partial resection performed. Eighty-two percent had a labral repair performed with a mean of three suture anchors. Finally, very few labral reconstructions were performed.

The 2-year PROM data from 295 patients revealed that there was a significant improvement in all the scores. Overall HAGOS showed improvement in all the six subscales. Patients over the age of 40 had a significant lower score in all subscales prior to surgery, but at 2 years they improved significantly, and they improved equally to patients under the age of 40. The register showed no difference in outcome between patients with grade II cartilage damage and patients with milder damage to the acetabular cartilage. EQ5D and HSAS scores also showed significant improvement. Interestingly, there was no improvement in the PROM scores from 1 to 2 years. The numbers of patients are still too low to compare labral repair to debridement statistically.

11.3 Future Treatment Options

There is no doubt of acetabular labral importance to achieve a normal biomechanics of the hip. Joint-preserving surgery options goes in the direction of repairing the anatomy. In those cases where labrum is degenerated or pain due to a previous labrectomized joint, reconstruction is proposed as the ideal solution [22]. There is no consensus about the ideal structure to restore labral function, but allogenic labral transplantation [23], allo- or autologous labral plasties [24], and labral substitutions may be the solution for that problem. The surgical technique has been described, but longer follow-up results will give us the answer to that question+

Take-Home Message

1. Acetabular labrum is a complex structure involved in the maintenance of normal biomechanics of hip joint.
2. Biomechanic studies performed in vitro with cadavera specimens and finite elements studies suggest that acetabular labrum must be restored to preserve normal function of the hip.
3. Labral tear options go from debridement to restoration. Good results have been published for each single option. Nevertheless, long-term results advocate for preservation of the structure when possible.
4. Reconstruction can be a good option in case of non-reparable damage of acetabular labrum. Biomechanic and short-term results go in that direction, but there is still a lack of long-term results on labral reconstruction.

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Evaluation and Surgical Decision-Making in Elbow Instability (ICL 13)

12

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Elbow instability is usually the result of an acute major or minor traumatic event, resulting in injury to the ulnar collateral ligament (UCL) or lateral ulnar collateral ligamentous complex (LUCL). This manuscript will focus on the specific salient features of the evaluation and surgical decision-making for injuries to the elbow resulting in medial and lateral (posterolateral) instability.

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12.1 Medial Elbow Instability

Injury to the ulnar collateral ligament often results from a hyperextension or valgus injury, as seen with elbow dislocation or subluxation, from sports such as rugby and wrestling, affecting either the dominant or nondominant elbow [5]. It may also occur as a result of repetitive microtrauma, as seen in throwing sports like baseball, tennis, volleyball, and water polo [5, 6]. This usually affects the dominant arm. Patients may complain of symptoms of instability but may also complain of pain, loss of sports function, weakness, crepitus, locking, stiffness, loss of motion, or numbness or paresthesias [6]. Acute injuries may be associated with a popping sensation in their elbow. High-level throwing athletes may present with vague complaints such as a reduction in pitching velocity or numbness or tingling in the ulnar nerve distribution. Throwers will usually complain of pain in the late cocking or early acceleration phase of the throw. There are several tests to examine valgus stability of the UCL injured elbow. First, palpation of the ligament, distal and posterior to the medial epicondyle, can elicit pain. The classic description for valgus laxity testing involves having the patient seated and the wrist secured between the examiner's forearm and trunk. The elbow is flexed to 20–30° and a valgus stress is applied while palpating for medial joint opening, amount of opening, quality of endpoint, and reproduction of pain as compared to the contralateral extremity. Other tests include the modified milking maneuver, where the patient's shoulder is abducted

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and externally rotated with the elbow in 70 degrees of flexion [6, 7]. The examiner palpates the medial joint with one hand and pulls down on the thumb of the involved arm, introducing a valgus force to the elbow. Again, joint opening, endpoint, and reproduction of pain are evaluated. Another test, the Moving Valgus Stress Test is performed with the patient seated, and the patient's shoulder is placed in an abducted and externally rotated position [29]. The examiner applies a valgus force to the elbow while the elbow is taken through its full range of motion. Pain will be present, in patients with an UCL insufficiency, within a "painful arc" between 80 and 120 degrees of flexion.

Plain radiographs are obtained to rule out other injuries (including avulsion fractures) and to look for signs of elbow degeneration, such as osteophytes or loose bodies. Ultrasound may be useful to assess medial joint opening upon valgus stress and should be compared to the contralateral side. While MRI may demonstrate a UCL injury, MR arthrography is a more sensitive test and may also demonstrate partial UCL injuries and, as such, is often the imaging technique of choice [6, 7].

Surgical indications include an acute tear in a high-level overhead athlete and chronic instability, pain, or inability to return to play, in patients that have failed two good cycles of rehabilitation. For those non-overhead athletes with a UCL tear as a result of an acute traumatic injury, nonoperative treatment is usually adequate, unless there is gross instability of the elbow [7].

Surgical considerations for the UCL injured athletes are [13, 14]:

1. Repair (with or without augmentation) vs. reconstruction
2. Ulnar nerve transposition vs. leave in situ
3. Muscle-splitting approach vs. takedown flexor muscles vs. elevate muscles
4. Connecting tunnels vs. blind ended tunnel
5. Fixation – suture to itself vs. suture anchors vs. tenodesis screws vs. suspensory fixation vs. cortical button
6. Graft type – ipsilateral palmaris longus autograft vs. contralateral palmaris longus autograft vs. gracilis autograft vs. fourth toe extensor autograft vs. strip Achilles autograft vs. various allografts

Postoperatively, the elbow is positioned in brace for 6 weeks and rehabilitative protocols start in 2 weeks. Sport activity progression is initiated at 3–4 months and return to sport is allowed at 6–8 months post-op.

Reported outcomes of UCL surgery are generally favorable, and 85 % of 90 athletes were able to return to a previous or higher level of competition. The most common complications are (often temporary) ulnar nerve dysfunction, medial epicondyle fracture, stiffness, and nonspecific elbow pain.

12.2 Posteromedial Impingement

Posteromedial impingement of the elbow is a rare disorder in the general population [20, 26]. It is usually observed in athletes who overuse their elbow, during overhead throwing or racket sports [15, 16]. This pathology is caused by repetitive hyperextension, valgus, and supination of the elbow and subsequently a mechanical abutment of the olecranon to the bony or soft tissues in the posterior fossa of the elbow [20, 26]. The first stage consists of tissue swelling in the fossa and then formation of osteophytes, and these can break off, with loose bodies as a consequence [15–17]. Possible complaints are pain at the posterior site of the elbow, effusion of the joint, locking complaints, crepitus, and a decrease in range of motion, most notably a lack of extension. Ulnar collateral ligament insufficiency is associated with significant changes in contact area, contact pressure, and valgus laxity during both relative flexion (late cocking/early acceleration phase) and relative extension (deceleration phase) moments [19, 27].

Radiographs, especially an axial view of the ulnohumeral joint, may be helpful to detect osteophytes on the olecranon or on the borders of the posterior fossa and chondromalacia of the posteromedial olecranon. Computed tomography (CT) can also be used to evaluate the posterior compartment for osteophytes. In the first stages of posteromedial impingement, an MRI with intra-articular contrast is more sensitive (the sensitivity for posterior soft tissue or loose bodies is nearly 90 %) [18]. The UCL can also be evaluated with an MRI and helpful in differentiating complete from partial tears of UCL.

Treatment, especially in the first stages, starts with conservative measures such as physiotherapy and nonsteroidal anti-inflammatory drugs, in combination with rest, ice, compression, and elevation. The flexor carpi ulnaris is the primary dynamic stabilizer, and the flexor digitorum superficialis is a secondary stabilizer against valgus torque. Pitching and throwing instructions are important to correct a possible poor technique. Sometimes steroid can be injected to relieve the pain, but one needs to realize that this pathology mostly occurs in young athletes and be aware of the chondrotoxic effect of anesthetics.

If conservative treatment of posteromedial impingement does not lead to symptom relief, arthroscopy of the elbow can be successful. During arthroscopy debridement of the soft tissue can be performed, and loose bodies and osteophytes can be removed [20]. UA insufficiency can be tested by applying valgus stress to the elbow, while the posteromedial ulnohumeral joint space is visualized. Posterior impingement can be associated with medial ligamentous instability of the elbow. The other way around is also possible. It is unclear whether removal of the osteophytes uncovered subtle UCL insufficiency or resulted in increased strain on the UCL, making it more susceptible to rupture when the athlete returned to throwing after rehabilitation [21, 22]. Therefore, it is recommended that only the osteophyte and no native olecranon should be removed [23–25].

12.3 Posterolateral Rotatory Elbow Instability

Injury to the lateral ulnar collateral ligament complex occurs as the sequelae to a fall on an outstretched hand, resulting in subluxation and/or dislocation of the elbow. The diagnosis tends to be subtle and is usually defined as posterolateral rotatory instability. True varus instability due to injury of the radial collateral ligament of the lateral collateral ligament complex (LCLC) is a very infrequent acute isolated instability pattern, because a pure varus stress to the elbow is not commonly generated from routine activities or trauma [8, 9]. A history of acute varus stress to the elbow associated with point tenderness and varus instability on physical examination is diagnostic. Physical examination of the elbow for varus instability is best performed with the elbow flexed to 15–30° with patient's upper arm maximally internally rotated. Loss of a firm endpoint, pain, or increased lateral joint space opening with varus stress is consistent with an attenuated or incompetent radial collateral ligament.

Patients with posterolateral rotatory instability provide a history of prior injury and complain of a popping, catching, or "clunking" as the elbow goes from full extension to flexion. They may state they feel their elbow dislocates. They frequently have complaints when driving and pushing up with their hands when getting out of a chair and/or with push-ups.

The posterolateral rotatory instability test or pivot shift test is performed with the patient supine with the arm overhead, the forearm is fully supinated, and both an axial load and valgus stress are applied to the elbow. With the elbow in the extended position, a dimple is demonstrated laterally, and the radial head becomes prominent [4]. The elbow is flexed while these forces are applied, and it is noted that the elbow usually maximally subluxates at 40° and further flexion may cause a palpable and visible clunk as the elbow reduces [4]. With greater degrees of laxity, greater flexion may be needed to demonstrate the reduction of the radial head. In some instances, the patient simply notices pain with this maneuver without demonstrable pivot being noted, as guarding may make this test difficult to perform in the awake patient. Other functional tests have been described to elicit symptoms, such as pain or giving way while doing push-ups with the forearm in supination and pronation, as well as when trying to lift themselves out of a chair with their hands. The key is the hands are shoulder width apart and the forearms supinated while the elbow is taken through a range of flexion to extension.

Plain radiographs are useful to rule out bony avulsion. The so-called drop sign may be seen on plain radiographs [3]. Stress radiographs can be very useful to demonstrate the dynamic instability; however, this may be difficult in awake patients, who may complain of apprehension but

not allow enough relaxation to demonstrate the instability. MRI can demonstrate injury to the LUCL complex and are helpful.

Accepted surgical indications for a patient with posterolateral rotatory elbow instability are an acute repair of an avulsion injury with significant size of bony fragment, gross elbow instability after reduction of elbow dislocation, or a patient with recurrent instability as a result of injury to the LUCL complex [2, 10–12].

Surgical considerations for the posterolateral elbow instability are (1) repair (with or without augmentation) or reconstruction; (2) connecting tunnels vs. blind ended tunnel; (3) fixation, suture to itself vs. suture anchors vs. tenodesis screws vs. suspensory fixation; and (4) graft type, ipsilateral palmaris longus autograft vs. contralateral palmaris longus autograft vs. slip of triceps vs. gracilis autograft vs. fourth toe extensor autograft vs. strip Achilles autograft vs. various allografts [1].

12.3.1 Treatment of Acute Lateral Instability

A dislocated elbow is best reduced under general anesthesia or a well-placed supraclavicular block. Following the reduction, the elbow is moved from flexion to extension.

If the elbow does not dislocate during range of motion testing, the elbow is placed in a dynamic elbow brace for 6 weeks. Extension is progressively allowed with increments of 30° every 2 weeks, starting with a 60° extension block [28].

Surgery has been suggested if the elbow remains grossly unstable if the elbow is not extended past 30–45° of flexion [29]. Acute lateral ligament repair can be done open or arthroscopically, using a bone anchor in the isometric point at the humeral insertion [31].

The patient is placed in the supine position with the arm on an arm table. Surgery can be performed under general anesthesia or a locoregional block, depending on the preference of the patient. A tourniquet is used. A small lateral incision is made, centered on the lateral epicondyle and the middle of the radial head. In some cases, the extensor tendon mass will be avulsed together with the LCL complex. No further dissection is needed in these cases. An extensor tendon split is used anterior to the LCL if the tendons are still intact. Concomitant injuries, such as a radial head fracture or a type I or II coronoid fracture, can be treated through the same approach. A small bone anchor is drilled into the avulsion site. The exact location of the avulsion can often be identified in acute cases. Both the LCL complex and extensor tendon mass are then repaired to bone using this anchor. A brace is again used for 6 weeks postoperatively, following the same protocol described above [28].

12.3.2 Treatment of Chronic Posterolateral Elbow Instability

Nonoperative management is typically not successful in chronic cases of posterolateral instability. Patients with acute injuries and/or good quality ligamentous tissue are best treated with a repair of the LUCL either open or arthroscopically. Many patients with chronic instability do not have adequate tissue to repair and require an open ligamentous reconstruction using auto- or allograft tissues.

Open repair of the lateral ulnar collateral ligament can be performed through a standard Kocher approach to the lateral elbow. Often an avulsion of the ligament off the humeral origin is identified. The ligament is then repaired by reattaching it to the humeral attachment site though either suture anchors or transosseous sutures.

An arthroscopic evaluation and treatment of posterolateral rotatory instability can be used as a different approach. Pre- and postoperative screening of patients is essential if an arthroscopic technique is contemplated. No comparative data are available on when to imbricate the LCL, when to repair, or when to reconstruct. An adaptation of the original technique that was described by Savoie et al. is used by one of the authors (RvR) [30]. The procedure starts with a standard diagnostic elbow arthroscopy. Some experience in elbow arthroscopy is necessary to perform

advanced elbow arthroscopy safely. The patient is placed in lateral decubitus and we prefer to perform arthroscopic surgery under general anesthesia. A thorough clinical exam is performed before insufflating the joint. An anteromedial portal is made to evaluate the joint and a lateral portal to clear any hemarthrosis or synovitis. If necessary, small coronoid fractures are easily reduced and fixed with threaded pins or cannulated screws at this point. The scope is then brought in the posterior compartment through a posterolateral portal. The posterior compartment is evaluated and a central posterior working portal is made when necessary. Valgus stress testing is done under direct view of the medial ulnohumeral joint space, to evaluate the integrity of the medial collateral ligament complex. The scope is then placed in the radiohumeral gutter, and lateral stability is evaluated by a drive through sign and a pivot maneuver with varus stress. A radial head fracture may be fixed from the soft spot portal at this point, but reduction of the fracture can be challenging through an arthroscopic technique. An anchor is then placed in the lateral epicondyle and the LCL is repaired to the bone using an outside technique. This is a rare procedure in our practice and we have more experience in treating chronic PLRI arthroscopically. In these patients an imbrication of the lateral ligament complex is performed. A no. 2 PDS suture is used to tighten the lateral structures. Thus far, this specific technique has not been used in acute lesions where an anchor is usually used to fix the LCL complex [32]. The postoperative protocol for both techniques is identical to the one described after primary repair in the acute setting.

Ligamentous reconstruction with auto- or allograft is often required in the setting of severe chronic posterolateral rotatory instability. With chronic injuries, the tissue is often of poor quality and repair is not feasible. Typically, the longer the time from injury to repair was predictive of needing a reconstruction. There are different techniques described in the literature with regard to fixation and graft options. Regardless of the technique, identification of the isometric position for the graft is important.

12.3.3 Varus Posteromedial Rotatory Elbow Instability

Varus posteromedial instability consists of the combination of an elbow subluxation with associated fracture of the anteromedial facet of the coronoid. Small coronoid fractures without ulnohumeral subluxation on CT scan and minimal gapping of the radiocapitellar joint on varus stress radiographs may be treated nonoperatively. Rehabilitation involves active assist and active range of motion with the forearm in pronation and avoidance of shoulder abduction, which creates varus stress at the elbow.

Larger fractures (>2–5 mm) O'Driscoll subtypes I, II, and III of the anteromedial facet of the coronoid should be surgically fixated including LCL repair and open reduction, internal fixation of the anteromedial coronoid facet [33]. Medial surgical approach may be done through the split in the flexor carpi ulnaris and/or a more anterior split of the flexor-pronator mass or posterior elevation of the entire flexor-pronator mass. If the anteromedial fragment is not repairable due to significant comminution, the LCL should be repaired, and the rehab protocol involves active range of motion with the elbow in pronation. In the setting of a complete elbow dislocation with a UCL rupture, the UCL should be repaired as well. Anatomic reduction of the coronoid process is not as important as restoration of the anterior buttress and anterior capsular insertion [34]. If, in rare cases, fixation is tenuous and instability persists after LCL repair, a hinged external fixator can be placed. Fixation options for the coronoid process are posteroanterior screws, T plate, or other buttress plate, lasso suture repair. If only one screw will fit in the fragment, it must be supplemented by a lasso suture or buttress plate.

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Peroneal Tendon Disorders (ICL 14)

13

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13.1 Introduction

Peroneal tendon pathologies account for a substantial amount of posterolateral ankle complaints and typically occur after recurrent ankle sprains due to chronic lateral ankle instability or overuse [13, 25, 53, 60]. With an important role in the lateral stabilization of the ankle, more strain is put on the peroneal tendons in cases of chronic instability. During inversion, the peroneus brevis tendon may become impinged between the peroneus longus tendon and the fibula, resulting in hypertrophic tendinopathy and eventually tearing of the tendon [13, 53]. Three primary categories of pathology can be distinguished: (1) tendinopathy (tendinitis, tenosynovitis, tendinosis, and stenosis), (2) subluxation and dislocation, and (3) partial or complete tears [9, 13, 65]. Predisposing factors for peroneal tendinopathies include malalignment of the ankle or hindfoot, psoriatic arthritis, rheumatoid arthritis, hyperparathyroidism, diabetic neuropathy, calcaneal fractures, local steroid injections, and fluoroquinolone use [6, 7, 44, 66, 67, 75].

Although post-traumatic lateral ankle pain presents as a common clinical problem, peroneal tendon disorders are often misdiagnosed [14]. Thorough patient history and physical examination are key in making an accurate diagnosis and choosing an optimal treatment strategy. Since disability and chronic pain complaints associated with peroneal tendon pathologies warrant close attention to diagnosis and management [11, 25, 41, 69], accurate knowledge on the clinical pathways of peroneal tendon pathologies is essential.

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13.2 Anatomy

The peroneal muscles reside in the lateral compartment of the lower leg. The peroneus longus (PL) originates at the lateral condyle of the tibia, the lateral aspect of the proximal fibular head, the intramuscular septa, and the adjacent fascia. The peroneus brevis (PB) originates more distally, at the middle third of the fibular shaft and interosseous membrane. Where the PL becomes completely tendinous 3–4 cm proximal to the distal fibular tip, the PB muscle usually runs more distal. Proximal to the distal fibular tip, the PB is flat and anteromedially located to the PL. After curling around the fibular tip, the PB becomes rounder and crosses the PL. The peroneal tendons are well vascularized by the posterior peroneal artery. Branches run through a common vincula at the whole length of both tendons [37, 53, 59, 71]. The superficial peroneal nerve facilitates innervation of the tendons.

Both peroneal tendons course posterior to the distal fibular tip through the superior peroneal tunnel formed by the retromalleolar groove of the fibula, the distal part of the posterior intramuscular septum of the leg, the fibulotalocalcaneal ligament, and the superior peroneal retinaculum (SPR) [26, 34]. The SPR originates lateral at the posterior aspect of the distal fibula and is extending to its tip. On the medial side, the retinaculum merged with the deep transverse fascia of the posterior compartment of the leg [3]. The SPR forms the lateral border of the tunnel and plays an important role in stabilizing the peroneal tendons posterior to the fibula [26].

Distal to the origin of the PB, approximately 4 cm proximal to the fibular tip, the PL and the PB share a common tendon sheath with synovial fluid. The sheath divides into two separate tendon sheaths at the tip of the distal fibula [55]. A thin, vincula-like structure is located between the PL and PB and is dorsally attached to the dorsolateral aspect of the distal fibula. The distal fibers of the PB muscle belly transform to this membranous layer to end approximately at the tip of the distal fibula [68].

The peroneal tendons are the primary everters and abductors of the foot. They also initiate plantar flexion and stabilize the medial column of the foot while standing. In addition, they play an important role in the stability of the lateral ankle.

13.3 Disorders

13.3.1 Tendinopathy: Tendinitis, Tenosynovitis, Tendinosis, and Stenosis

Tenosynovitis has been reported in 77 % of patients with chronic instability of the ankle [4] and is the most common tendinopathy found in the peroneal tendons [19, 21, 28, 52, 68, 70]. It often results from prolonged or repetitive activity, mostly after a period of relative inactivity [33]. Due to mechanical stress of the tendon, the tendon gets irritated and inflamed, and the tendon sheath gets thickened. If tendinitis is not treated properly, non-inflammatory degeneration of the tendon, better known as tendinosis, may occur due to poor vascularity and primary degenerative changes within the tendon. Tenosynovitis may result in synovial proliferation and fibrosis around the tendon (stenosis), giving rise to obstruction and impingement of the tendons in their tendon sheath. Tendinopathy can occur along the entire length of the peroneal tendon but mostly occurs at the level where the tendon encounters the most stress, i.e., around the lateral malleolus (peroneus brevis tendon) or in the cuboid groove (peroneus longus) [47].

13.3.1.1 Patient History, Physical Examination, and Addition Diagnostics

Peroneal tendinopathies are characterized by a gradual onset of pain over the course of the tendons, mainly during activity, swelling, feeling of weakness, and warmth around the posterolateral ankle. Crepitus and recognizable tenderness are frequently present upon forced eversion against resistance. Passive hindfoot inversion and plantar flexion may also exacerbate pain. A tendinopathy is considered acute when symptoms are present for <2 weeks, subacute when symptoms are

present for 2–6 weeks, and when symptoms persisted for at least 6 weeks, a tendinopathy is considered chronic [33].

While additional diagnostics are not usually needed, magnetic resonance imaging (MRI) and ultrasound (US) may be used to confirm the diagnosis and/or to exclude other pathologies. On MRI, thickening of the tendon or synovial membrane, fluid within the tendon sheath and changes in the surrounding tissue may be seen. US findings include an irregular, thickened, and hypoechoic tendon or synovial membrane and swelling without well-defined defects.

13.3.1.2 Treatment

Peroneal tendinopathies are initially treated in a conservative fashion with rest and immobilization, protected ambulation, activity modification, footwear changes, and anti-inflammatory medication. Physical therapy may be prescribed to strengthen surrounding muscles. Platelet-rich plasma (PRP) is reported as a treatment of peroneal tendinopathies; however, at this time, the formulation requiring to facilitate tendon repair has not been elucidated [12, 23]. Steroids are contraindicated since it stimulates the degenerative process of tendon tissue and eventually may provoke a rupture.

When conservative treatment fails, surgical decompression is offered. The inflamed, degenerated or stenosed tissue is debrided. Additional predisposing factors, such as hypertrophy of the peroneal tubercle, are corrected [8]. Peroneal tendoscopy offers a minimally invasive method of surgical intervention with minimal change of complications, better cosmesis, reduced costs, and earlier recovery than seen in traditional open procedures [19, 21, 28, 52, 68, 72].

13.3.2 Subluxation and Dislocation

Peroneal tendon dislocation occurs mostly in the athletic population, primarily in sports that require cutting movements including skiing [35], soccer, basketball, ice skating, and gymnastics [2] and is reported in 0.3–0.5 % of all traumatic ankle events. Due to frequent misdiagnoses, this may be an underestimation [45]. The typical mechanism of injury is rupturing of the SPR during sudden eccentric contraction of the peroneal muscles on acute dorsiflexion of the foot, with or without inversion, or during forced dorsiflexion of the everted foot. This allows the peroneal tendons to dislocate anteriorly over the lateral malleolus.

13.3.2.1 Patient History, Physical Examination, and Addition Diagnostics

Patients typically report a snapping or popping sensation around the lateral malleolus and complain of significant functional impairment. Pain is often present around the superior peroneal groove or above the joint line [46] and may be provoked by dorsiflexion and eversion of the ankle. Circumduction of the ankle may excite crepitus or snapping sounds, and luxation of the tendons over the lateral malleolus may be visualized. Furthermore, swelling, tenderness, and ecchymosis posterior to the malleolus may be present. A positive anterior drawer or talar tilt test can be used to test the superior peroneal retinaculum [20].

MRI shows the position of the peroneal tendons relative to the distal fibula and may therefore detect dislocation. However, it may not be the best modality to diagnose what may be a dynamic pathology. Real-time dynamic tests, such as US and peroneal tendoscopy, are often preferred. Dynamic US with the foot dorsiflexed can demonstrate luxation of the tendons out of the retromalleolar groove [56]. Peroneal tendoscopy provides accurate visualization of intrasheath subluxation [40].

13.3.2.2 Treatment

The primary indication for treating peroneal tendon dislocation is pain [55]. Conservative treatment may be attempted when acute dislocation is diagnosed. The patient is immobilized in a short leg cast to allow the SPR to heal [55]. However, with a failure rate of 50–76 % [16, 17], surgical procedures have become the preferred treatment, especially in young, active people and athletes [36]. Four main treatment categories can be divided, all with the primary goal to repair the superior peroneal tunnel: (1)

repair or replacement of the SPR [1, 5, 10, 15, 22, 27, 31, 63], (2) groove deepening of the retromalleolar groove [23, 38, 39, 77], (3) bony procedures [32, 76], or (4) rerouting procedures [30, 50, 64]. Associated pathologies and predisposing factors like a concomitant peroneal tendon tear, low-lying muscle belly, and varovalgus hindfoot malalignment should be treated simultaneously.

Most studies utilizing one of these procedures show good to excellent outcomes, high satisfaction, and a high rate of return to sports [23, 38, 39, 50, 64, 77]. However, a combination of a groove deepening and SPR repair provides a significantly higher rate in return to sports when compared to a SPR repair by itself [70].

13.3.3 (Partial) Tears

The prevalence of peroneal tendon tears in the general population remains unknown, but was found in 11–37 % of the specimen in cadaveric studies [57, 58]. Characteristically, a tear occurs following an acute ankle inversion injury or as a result of chronic lateral ankle instability with repetitive sprains [25, 48, 55, 61]. Other provoking factors include peroneal tendon subluxation, anatomic abnormalities, repetitive stress, or overuse [18, 25, 60, 69]. With a vulnerable position between the bony fibular groove and the PL, PB tendon is more likely to tear than the PL [20, 55]. An accessory peroneal quartus muscle or low-lying peroneus brevis muscle belly may also provoke tendon tears, by increasing pressure in the retromalleolar groove [62]. Peroneus brevis tendon tears are usually found within the retromalleolar groove, while tears in the peroneus longus tend to occur at the level of the cuboid [20, 55, 62].

13.3.3.1 Patient History, Physical Examination, and Addition Diagnostics

Patients may present clinically with undefined lateral ankle pain that worsens with activity, swelling over the course of the tendons, instability, and giving way of the lateral ankle. Plantar- and dorsiflexion may exacerbate symptoms, and active eversion is often weakened as compared to the contralateral side. Recognizable pain may be provoked on palpation of the posterior lateral malleolus or along the cuboid bone. Typically, pain is excited on provocation of the peroneal tendons in eversion and on acute loosening of resistance during the provocation test.

MRI is utilized as the standard method for diagnosing peroneal tendon tears [20]. Key findings include chevron-shaped/C-shaped tendon, clefts, defects, irregularity of the tendon contour, and increased signal intensity due to fluid in the tendon sheath [42, 54]. However, fluid within the tendon sheath can also be seen in asymptomatic patients [74]. Furthermore, the so-called magic angle effect may over- or underestimate peroneal tendon disorders [43]. Abnormalities visible on US include tendon thickening, peritendinous fluid within the tendon sheath, and direct visualization of tears. Peroneal tendoscopy offers a great diagnostic tool, since it is highly specific and sensitive and moreover provides easy transition to minimally invasive treatment. Since MRI can be inconclusive, peroneal tendoscopy should be performed when clinical suspicion for a peroneal tear is strong, with or without positive MRI findings [29].

13.3.3.2 Treatment

Initially, peroneal tendon tears are treated conservatively with rest, immobilization, and anti-inflammatory drugs. However, conservative treatment is often not successful, and surgical intervention is required [14, 41, 62]. Depending on the severity of pathology, different surgical treatment options are proposed [25, 41]. If <50 % of the cross-sectional area of the tendon is involved, treatment consists of debridement and tubularization. Over 50 % involvement of the cross-sectional tissue either requires tenodesis to the intact peroneal tendon if one of the peroneal tendons remains functional or grafting when both tendons are nonfunctional [25, 41, 69]. When a tendon is completely ruptured, both ends are sutured together. In symptomatic patients, surgical treatment has been associated with improved return to full activity and improvement in patient-reported outcome scores [11, 41, 51].

13.4 Peroneal Tendoscopy

Peroneal tendoscopy provides opportunities for improvement of both diagnostics and treatment of peroneal tendon disorders. Recently, the procedure has become more and more appreciated [29, 49, 53, 73]. Not only does tendoscopy accommodate an accurate diagnostic tool with high sensitivity and specificity, it is also associated with functional improvements in patients with peroneal tendon pathology.

13.4.1 Surgical Technique

The standard approach for peroneal tendoscopy is a two-portal technique with a skin bridge of >30 mm. Optimal portal access is achieved when the patient is placed in lateral decubitus position. This allows access to the anterior and posterior aspect of the ankle when an open technique is required. When an arthroscopic procedure in conjunction with tendoscopy is considered, a semilateral position can be applied to facilitate access to the medial ankle. Support may be placed under the leg to support free motion in the ankle during surgery. Before placed under anesthesia, the patient is asked to actively evert the foot to visualize the location of the tendons. Both the course of the tendons and the portals are drawn on the patient. Local, regional, epidural, or general anesthesia can be used for the surgery. A tourniquet is then inflated around the proximal thigh of the affected leg to optimize visualization.

The distal portal is made first, 2–3 cm distal to the posterior edge of the lateral malleolus. The skin is incised, and the tendon sheath is carefully penetrated with a 2.7 mm arthroscope with a blunt trocar and inclination angle of 30°. A low pressure, low flow pump of 50–70 mmHg is recommended. While a 4 mm scope is preferred by some surgeons due to increased flow with lower pressure, it may be challenging to pass the larger diameter scope through the retinaculum [49]. Normal saline is used for tendoscopic fluid to maintain hemostasis.

Inspection of the tendons starts approximately 6 cm proximal to the posterior edge of the lateral malleolus. Here, the tendon compartment is split into two separate compartments by a vincula-like structure. More distally, the tendons are back together in one compartment. The second portal is made under guidance of a spinal needle, approximately 2–3 cm proximal to the posterior edge of the lateral malleolus. An overview of both tendons can now be obtained, and the condition of the tendons can be evaluated.

In patients with significant tenosynovitis, complete tenosynovectomy is recommended. This allows better visualization of associated pathologies including tenosynovitis, tears, ruptures, dislocation, and stenosis. When dislocation or subluxation of the peroneal tendons is confirmed, tendoscopic retromalleolar groove deepening can be performed. The peroneal tendons are held out of the way by two Kirschner wires, decreasing the risk of iatrogenic damage. A 3.5 mm burr is used to create a concavity within the retromalleolar groove. Sharp edges are rounded, and the surface of the groove is smoothened, to prevent the tendons from fraying. If the SPR is stripped of, the surface can be tendoscopically roughened with the burr after which two of three suture anchors can be inserted into the fibular ridge and sutured to the SPR. Tears in the peroneal tendons require a mini-open approach. The tendon is brought into the wound, debrided of any remaining degenerative debris, and tubularized using the buried sutures knot and running technique.

After finishing the tendoscopic procedure, the portal incisions are closed by sutures to prevent sinus formation.

13.5 After Treatment

Rehabilitation is an important factor in the clinical success of the treatment of peroneal tendon pathologies and should be tailored to every specific patient. After a tendoscopic procedure, a compressive dressing is recommended for 2 days, followed by full weight bearing and active range of motion as tolerated. When the retinaculum is repaired or an open approach was used, placing a patient in a lower leg splint for 2 days followed by 12 days of a non-weight-bearing lower leg cast is favored. After

2 weeks, patients are either allowed weight bearing in a Walker boot or in a lower leg cast for an additional 4 weeks, followed by physical therapy to regain strength and range of motion. It should be noted that a tailored rehabilitation protocol to every specific patient is advised for an optimal functional recovery and prevention of re-ruptures.

Conclusion

Peroneal tendon pathologies can be frequently diagnosed and account for most posterolateral ankle injuries. To prevent further deterioration of tendon tissue and chronic pain complaints, early identification and appropriate management are essential. While MRI and US can be helpful to locate peroneal tendon pathologies, patient history and physical examination are key items in making an accurate diagnosis and choosing an optimal treatment. Peroneal tendoscopy is a great diagnostic tool to confirm clinical findings and moreover provides an effective treatment technique for a variability of peroneal tendon pathologies.

Case 1

A 17-year-old male, active American football player

Chief complaint:

Left ankle, pain over the posterolateral ankle

HPC:

Posterolateral pain occurred after weight lifting. The patient received conservative treatment including physiotherapy, PRP injection, and shock wave therapy. However, no significant change in symptoms was observed.

Examination:

Foot alignment was normal. There was tenderness over the posterolateral aspect of fibula. Range of motion of ankle and foot looked normal. Clicking and snapping symptoms of the peroneal tendons were unclear. Both the anterior drawer and varus stress test showed a solid endpoint.

MRI:

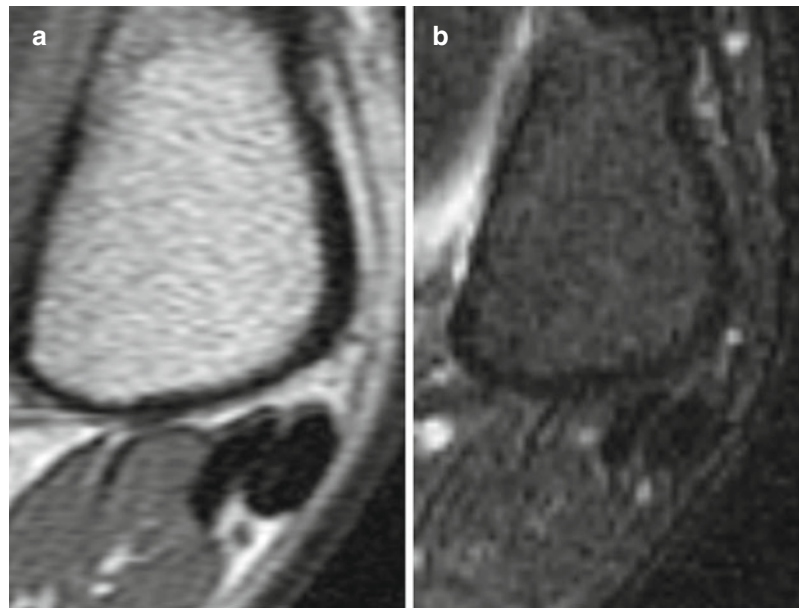

Fig. 13.1 (**a**, **b**) MRI of the left ankle shows no remarkable abnormality

Sonography:

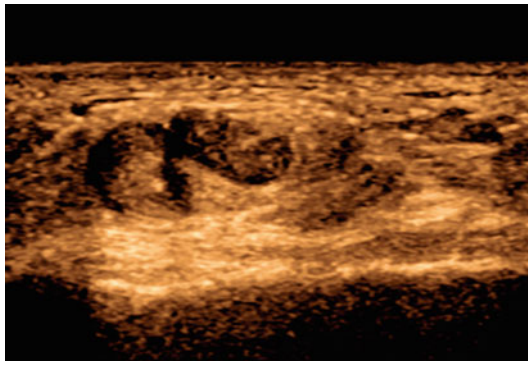

Fig. 13.2 No remarkable tear or subluxation could be visualized using sonography

How would you diagnose the patient? What treatment would you choose?

Case 2

A 44-year-old male

Chief complaint:

Left ankle, pain over the posterolateral ankle following tubularization of a peroneal tendon tear

HPC:

The patient received a reconstruction of the lateral ligaments in the past. Three years ago, he underwent tubularization of a peroneal tendon tear. Although the patient remained pain free after surgery, he sustained an ankle sprain 1 year ago. Ultrasound showed a partial tear, which was treated by PRP injection. However, 8 months after the injection, the patient presented with persistent posterolateral ankle pain.

Examination:

Foot alignment was normal; range of motion of ankle and foot looked normal.

Tenderness existed along the course of the peroneal tendons. On palpation, no tendon was found to be present distal from the fibular groove. Anterior drawer and varus stress test both showed a solid endpoint.

MRI:

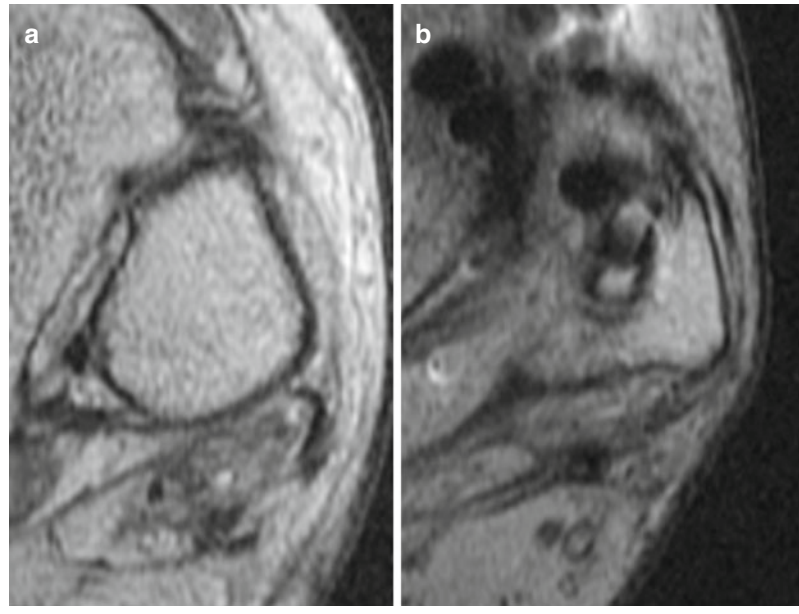

Fig. 13.3 MRI shows complete ruptures of both peroneal tendons

What treatment would you choose?

Case 3

A 20-year-old male, professional soccer player

Chief complaint:

Right ankle, pain over the posterolateral ankle

HPC:

The patient was kicked on the ankle during playing soccer. While the patient had significant pain, he did not take any rest after the injury. Six weeks after injury, he visited at our institution.

Examination:

Foot alignment was normal. There was tenderness and swelling over the posterolateral aspect of fibula. Range of motion of ankle and foot looked normal. Anterior drawer and varus stress test both showed a solid endpoint.

X-ray

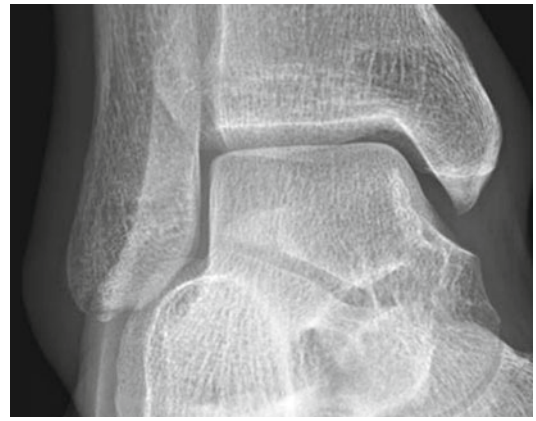

Fig. 13.4 A fracture of the tip of the fibula could be seen on X-ray

CT:

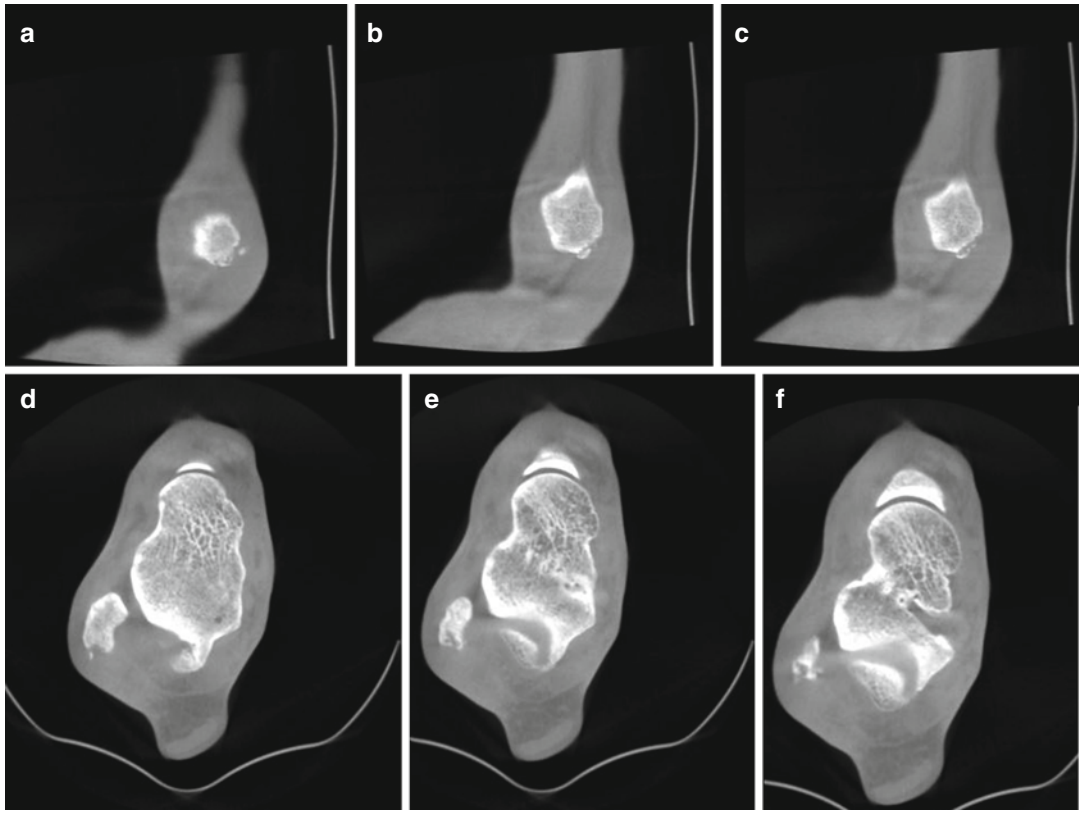

Fig. 13.5 (**a**–**f**) CT shows a fracture of the tip of the fibula

MRI:

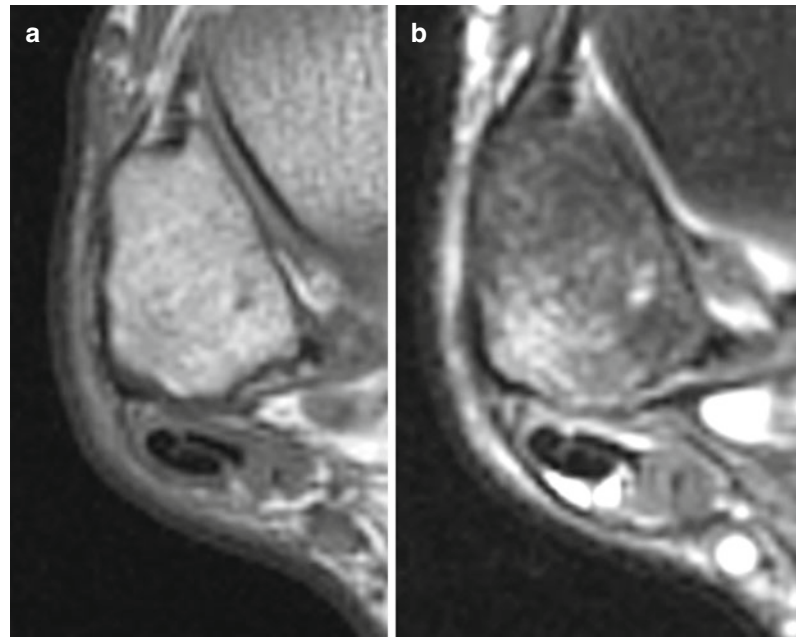

Fig. 13.6 MRI shows signal changes within the peroneal tendon sheath, possible related to a peroneal tendon tear

What treatment would you choose?

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Posterior Shoulder Instability (ICL 15)

14

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14.1 Introduction

Posterior shoulder instability is much less common, more difficult to diagnose, and even more challenging to manage compared to anterior instability. Moreover, true posterior and multidirectional instability can be easily overlooked because the presentation can be confusing and oftentimes they are overlapping entities. A detailed clinical examination and careful imaging evaluation are paramount for the correct diagnosis and indication to treatment. The primary goal of treatment other than pain control and restoration of function is to avoid recurrence of instability and to reduce the risk for posttraumatic osteoarthritis. Nonsurgical treatment is successful in most cases; however, surgical intervention is indicated if conservative treatment fails. For successful surgical treatment, a thorough definition of the instability pattern and a correct evaluation of all soft tissue and bony problems that contribute to instability must be performed. Differently from bony anterior instability, in presence of bone defects, the critical amount of posterior glenoid bone loss has not been defined yet. Moreover, posterior glenoid reconstructive options are limited compared to those available for anterior glenoid bone deficiency. The following chapter will provide an overview on epidemiology, pathomechanics, clinical presentation, imaging findings, and treatment options in posterior shoulder instability.

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14.1.1 Epidemiology

Posterior shoulder instability has been reported to account for only 2–5 % of shoulder instability cases [1]. Patients affected by posterior instability are usually men between the ages of 20 and 30 years, often active and competitive athletes playing overhead or contact sports. It has been recently showed that the prevalence of acute posterior dislocation is 1.1 per 100,000 population per year. Moreover, 67 % of them are caused by a high-energy trauma, such as a fall from height or motor vehicle accident, 31 % by seizures secondary to epilepsy or alcohol or drug withdrawal, and only 2 % by electrocution. Interestingly, only 17.7 % of shoulders developed recurrent instability within the first year after dislocation [2].

Although posterior shoulder instability is still considered rare, with improved understanding of the condition, it is being increasingly recognized. Recent studies reported high rates of posterior instability up to 10 % in young active population [3]. Song et al. [4] recently claimed that incidence of posterior instability is even higher in military population, up to 40 %, if isolated posterior and combined instability are both considered. The authors showed on a consecutive series of 231 patients, who underwent surgical stabilization for instability, which 24.2 % of them were affected by isolated posterior instability and 18.6 % reported combined instability patterns, such as panlabral tears, multidirectional instability, anterior plus posterior instability, and instability with extension of the labral pathology into the superior labrum.

14.1.2 Pathomechanics

Several anatomic risk factors for posterior instability have been identified, such as increased glenoid retroversion, loss of chondrolabral containment, and insufficiency of the posteroinferior capsule [5]. Although increased glenoid retroversion has been claimed as one of the main predisposing factors [6], it is not currently known if it precedes the development of posterior instability or if instability itself affects the bony anatomy. A recent study [7] showed that patients with posterior instability had significantly more glenoid retroversion than patients with anterior instability, and patients with retroversion of more than 16° showed a high incidence of posterior instability of the contralateral shoulder. Moreover, the posterior capsule, which contains the posterior band of the inferior glenohumeral ligament (PIGHL), is not as robust as the anterior capsule; therefore stretch of the capsule and PIGHL beyond the initial resting length is a potential cause of posterior instability. In addition, the middle glenohumeral ligament (MGHL) and superior glenohumeral ligament (SGHL) also play a role in preventing posterior shoulder translation at midrange of abduction and shoulder adduction, respectively. The role of rotator interval in limiting inferior and posterior translation is still questionable. The labrum increases the concavity-compression mechanism. In patients with clinically documented recurrent posterior instability, a loss of chondrolabral containment, incorporating both an increase in bony retroversion as well as a loss of posteroinferior labral height, is a common finding. On the other hand, the role of dynamic stabilizers should also be taken into account. The subscapularis muscle is the primary dynamic stabilizer preventing posterior translation, even if all the rotator cuff muscles are important in providing concavity compression of the shoulder. It is not uncommon in patients affected by posterior instability to find, beside a capsule-labral injury, a concomitant altered scapulo-thoracic kinetics due to inability to optimize rotator cuff strength, particularly with regard to the subscapularis [8].

14.1.3 Classification

Posterior instability can be defined in terms of etiology (traumatic, atraumatic, or microtraumatic), degree (dislocation, subluxation), timing (acute, chronic, or recurrent), and volition. As a matter of fact, approximately half of patients affected by posterior shoulder instability report a discrete injury to the shoulder that initiated the symptoms, albeit a documented previous episode

of posterior dislocation requiring reduction is relatively uncommon.

Traumatic posterior dislocation can be caused by a direct force applied to the anterior shoulder or by an indirect posterior force applied through the arm up to the shoulder, when the arm is in "at-risk" position: adduction, flexion, and internal rotation. Dislocation due to seizure is the result of unbalanced contraction of the shoulder muscles with the arm in a provocative position [9].

Repetitive microtraumas, which lead to the development of recurrent instability, are the most common etiology of posterior shoulder dislocation, especially in certain sporting groups, such as contact or overhead athletes [10]. A frank posterior dislocation from a single traumatic sport injury is relatively uncommon. Athletes usually experience recurrent subluxations due to repetitive posterior load on both the labrum and the capsule, which results in stretch and injury of the PIGHL, as well as labral tears. A typical example in contacts sports, such as football, is an offensive lineman with the arms in the blocking position. Posterior instability secondary to overhead sports is more insidiously to understand. Common provocative activities include the backhand stroke in racket sports, the pull-through phase of swimming, and the follow-through phases in a throwing activity or golf [8].

Atraumatic posterior instability usually reminds to an underlying ligamentous condition, which can be a congenital shoulder laxity or more commonly a generalized ligamentous hyperlaxity. In case of atraumatic instability, a clear distinction between posterior and multidirectional instability is almost impossible.

Voluntary posterior instability should be also taken into account. It may be subdivided as follows: positional, muscular, and habitual (or willful). Positional subluxations occur when the arm is placed in "at-risk" position, and as the arm moves into abduction from this position, the shoulder visibly and audibly relocates. Muscular posterior subluxations occur with selective muscle activation in a resting position (not positional dependent). Habitual instability usually occurs in patients with psychological problems, who are able to subluxate one or both shoulders voluntarily, often with the arm at the side, as a result of unbalanced muscle force couples [1].

14.1.4 Clinical Exam

In general, main complaints of patients affected by posterior instability are pain and weakness along the posterior and inferior side of the shoulder. Sensation of instability usually develops gradually. Patient's history and physical examination are paramount to clarify the presence of multidirectional components. Both shoulders should be evaluated, observing any asymmetry, abnormal motion, muscle atrophy, and scapular winging. Each patient should be asked for voluntary instability. Specific tests confirming the direction of instability and assessing the degree of shoulder hyperlaxity and generalized joint laxity must be performed. Generalized joint laxity is usually evaluated by the Beighton score [11], whereas shoulder hyperlaxity is clinically defined by the presence of adduction-external rotation >85° [12] and a positive Gagey test [13]. These findings are common in patients affected by atraumatic instability but rarely seen in posttraumatic instability.

Specific test for posterior shoulder instability has been described. The jerk test [14] is performed by applying an axial force to the affected arm in 90° of abduction and internal rotation and then the patient's arm is horizontally adducted while axial load is maintained (Fig. 14.1). The test is positive in case of pain or subluxation. To perform the Kim test [15], the arm is abducted to 90° while the patient is sitting; the physician passively elevates the arm an additional 45° while applying a downward and posterior force to the upper arm, with an axial load to the elbow (Fig. 14.2). The test is positive if a posterior and painful subluxation is experienced. For the posterior drawer test [16], the physician stabilizes the shoulder with one hand (between the clavicle and the coracoid and the spine of the scapula) and holds the humeral head with the other hand. The examiner presses the humeral head medially into the center of the glenoid to evaluate the neutral

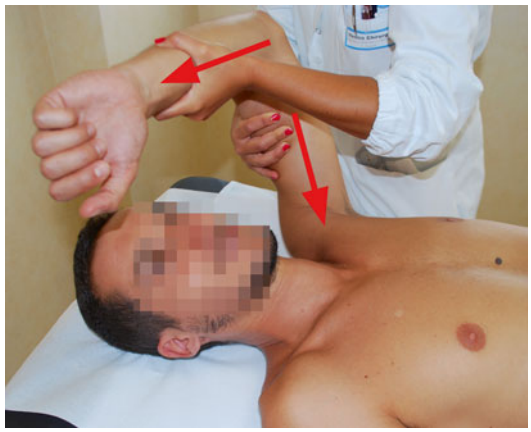

Fig. 14.1 Jerk test: an axial force is applied to the affected arm in 90° of abduction and internal rotation. The arm is horizontally adducted while axial load is maintained

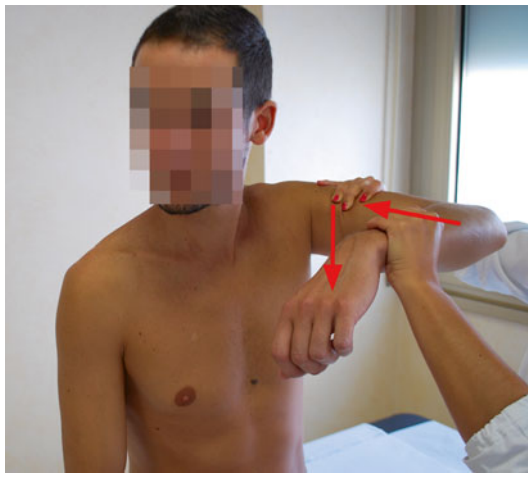

Fig. 14.2 Kim test: the affected arm is placed at 90° of abduction, when the examiner holds the arm and elbow and applies an axial loading force. The arm is then elevated 45° while maintaining axial force that pushes the humeral head posteriorly

position of the joint. Posterior stress is applied and the degree of passive translation determined. Finally to perform the posterior stress test, the physician stabilizes the shoulder with one hand and pushes the 90° flexed, adducted, and internally rotated shoulder posteriorly by the elbow. The test is positive in case of pain or subluxation.

14.1.5 Imaging

Plain radiographs can show normal bony anatomy in atraumatic instability, whereas a reverse Hill-Sachs lesion is the most common finding after a traumatic dislocation [17, 18]. Specific views, such as the west point axillary view can be helpful in the detection of osseous Bankart defects on the posterior glenoid rim. Sometimes a posterior subluxation of the humeral head may be found. Most of the time, bony lesions may not be adequately detected in standard X-ray views. This explains the fact that, despite severity of the injury, acute posterior shoulder dislocations are frequently missed during primary hospital visits. Therefore, computed tomography (CT) and magnetic resonance (MR) imaging, both with or without intra-articular contrast, are extremely helpful for a detailed evaluation of bony and soft tissue anatomy [19]. Glenoid bone defects can be measured best on 3D en face views of the glenoid, and glenoid version can be measured on axial CT images at the level of the mid-glenoid, with a normal retroversion of 2–8° (Fig. 14.3). Moreover, a standardized CT scan measurement method has been recently introduced and proven to be reliable for determining the reverse Hill-Sachs size and location [20]. This is important as a biomechanical study revealed the influence of both the size and location on the likelihood of reverse Hill-Sachs engagement [21]. In the study, it was further shown that the combined measurement of size and location in the axial plane in terms of the so-called gamma angle provides the most reliable estimate of the risk for re-engagement of a reverse Hill-Sachs, with the critical value being a gamma angle above approximately 90°, depending on the individual patient's internal rotation capacity [21] (Fig. 14.4).

In a multicentric study of the German Society of Shoulder and Elbow Surgery (unpublished data), it was observed that reverse Hill-Sachs resulting from a non-locked dislocation typically feature low gamma angle values with low risk for re-engagement, while locked dislocations are associated with higher gamma angles. Accordingly, a new classification for reverse Hill-Sachs lesions has been introduced (Table 14.1).

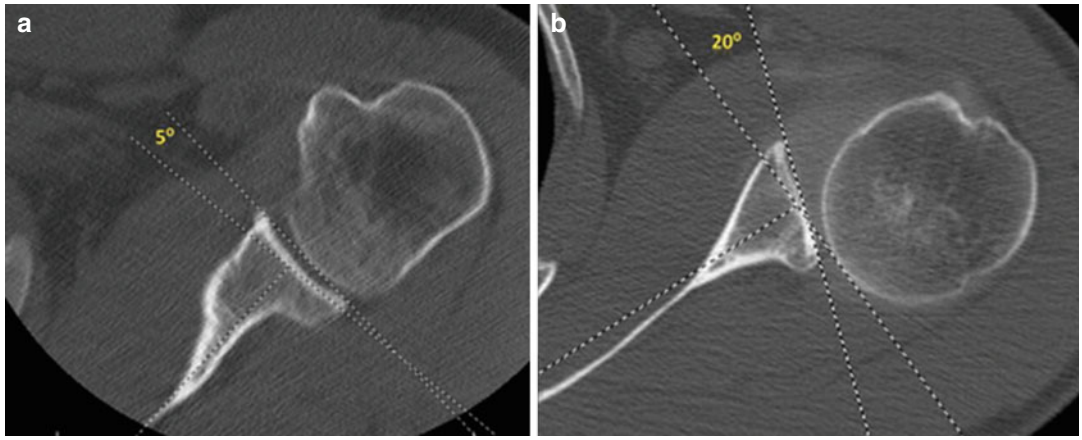

Fig. 14.3 Axial CT images. (**a**) Normal glenoid retroversion. (**b**) Increased glenoid retroversion

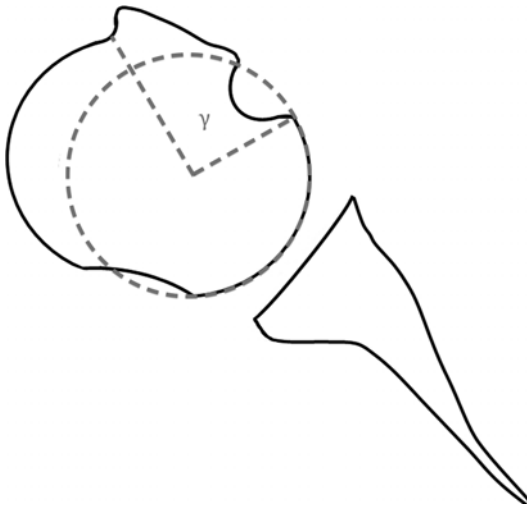

Fig. 14.4 Axial cut. The "gamma angle" results from the combined measurement of size and localization in the axial plane of the reverse Hill-Sachs

Table 14.1 Classification for reverse Hill-Sachs lesions

	Type	Re-engagement risk
Dislocation	1	Low
Locked dislocation	2	Moderate
Chronic locked dislocation	3	High

MR is more sensitive for the evaluation of soft tissue components. Kim et al. [22] proposed to classify labral lesion in four types: (I) incomplete detachment, in which the posteroinferior labrum is separated from the glenoid but not medially displaced, (II) superficial tear between posterior labrum and glenoid articular cartilage without labral detachment (Kim's lesion), (III) chondrolabral erosion, and (IV) degenerative tear of the labrum. MR is 90–94 % [23, 24] accurate for labral pathology when the imaging corresponds to the clinical examination.

14.2 State-of-the-Art Treatment

14.2.1 Acute Traumatic Posterior Shoulder Dislocation

The choice of treatment of acute traumatic posterior shoulder dislocations depends on the presence of osseous defects of the humeral head and glenoid cavity as well as on the functional requests of the patient. According to the new classification by Moroder (unpublished data), type 1 reverse Hill-Sachs with gamma angles below 90° can be treated conservatively by immobilization of the shoulder in neutral rotation for a duration of approximately 4 weeks. Seldomly, type 1 lesions show a gamma angle above 90°, which warrants arthroscopically assisted defect disimpaction and subsequent immobilization (Fig. 14.5). Type 2 lesions with a gamma angle below 90°

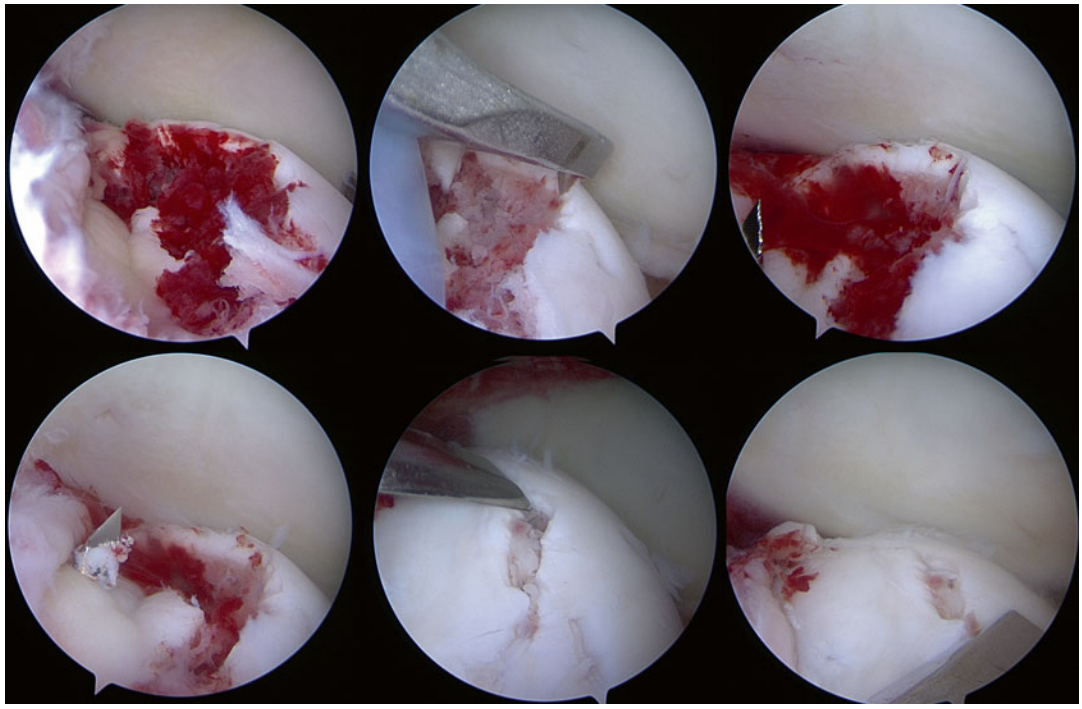

Fig. 14.5 Arthroscopic images showing the technique of disimpaction of a type 1 reverse Hill-Sachs lesion

need to undergo closed or open reduction with subsequent conservative treatment as described above. If the gamma angle exceeds 90° reduction, arthroscopically assisted defect disimpaction and subsequent immobilization are recommended. In general, particular care must be taken to perform the defect elevation as early as possible, since bone healing makes defect disimpaction more difficult to be accomplished. In that case, alternative techniques such as the McLaughlin procedure [25] or grafting techniques [26] may be required. For large defects especially in older patients, hemiarthroplasty might be a viable option [27]. Type 3 lesions result from chronic locked posterior shoulder dislocations and typically exceed the critical gamma angle. In most cases, open reduction and invasive procedures such as arthroplasty, grafting, or rotational osteotomy [28] are required.

Development of arthroscopic techniques allows successful treatment of lesser tuberosity fractures. Cannulated screws or suture anchors can be considered as efficient fixation tool depending on the size and quality of the bony fragment [29]. An efficient way to diminish overtensioning of the bone fragment fixation is an additional suture anchor placed in humeral head with the sutures passed through the subscapularis tendon.

Even though the presence of posterior glenoid bone loss is uncommon in acute traumatic posterior shoulder dislocations, such lesions must be factored into the treatment plan to avoid recurrence of instability. The accurate evaluation of the defect is often challenging in the locked dislocation due to the engaged humeral head masking the posterior glenoid rim. Commonly a posterior glenoid rim fracture can be found after an acute traumatic dislocation. Large fragments should be reduced and stabilized following the rules of intra-articular fracture treatment. Fixation technique depends on the time of surgery, defect size, displacement, and bone quality. Usually, small cannulated cortical and Herbert screws are efficient fixing implants. Suture anchors can also be used for the fixation [30]. It is likely that the presence of a glenoid defect has an effect on the

engagement of a reverse Hill-Sachs; however, the relevance of bipolar bone defects in acute traumatic posterior shoulder dislocations has not been investigated sufficiently to date.

14.2.2 Recurrent Posterior Shoulder Instability

In case of recurrent symptomatic instability, initial treatment is usually non-operative, especially in case of voluntary instability. However, if conservative treatment fails, surgical intervention might be necessary. In most cases, a lesion of the posterior capsulolabral complex occurs [31]. According to the literature, the majority of recurrent posterior instability cases can be treated successfully by arthroscopic repair of the capsule-labral complex with low revision rates and high rates of return to pre-injury sport levels [32, 33]. While there are no prospective randomized trials in literature comparing arthroscopic vs. open capsule-labral repair, also open techniques have shown reliable outcomes with low revision and complication rates in the past [34]. Differently from anterior instability, a state of the art for this rare pathology has not been defined yet. Therefore, choosing between an arthroscopic or open procedure is sometimes based on surgeon's skill and experience. In patients with recurrent posterior shoulder instability and without significant bone loss or increased retroversion, a posterior Bankart repair with capsular shift can be successfully performed either arthroscopically or open (Fig. 14.6) [32, 34]. In cases of large reverse Hill-Sachs lesions, tending to engage, a McLaughlin procedure can be added, either arthroscopically or open (Fig. 14.7) [35, 36]. The advantage of arthroscopy may result from more efficient evaluation of concomitant pathologies, such as the presence of a reverse humeral avulsion of the glenohumeral ligaments (RHAGL). The posterior capsule can be either disrupt or stretched. The repair of this type of lesion is usually performed in the same way as remplissage described by Wolf or by standard reconstruction of partial intra-articular tear of the infraspinatus tendon insertion. When RHAGL is

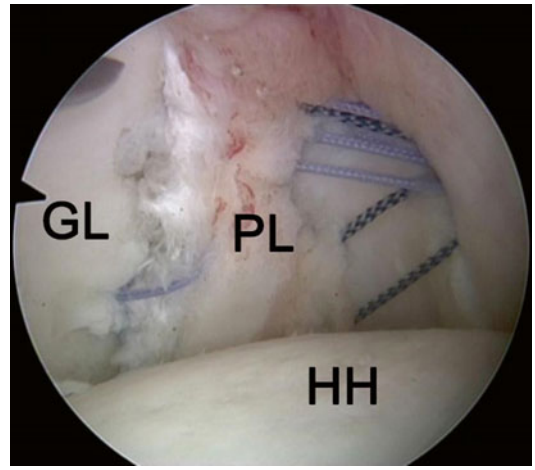

Fig. 14.6 Arthroscopic posterior Bankart repair

associated with posterior Bankart lesion, it is necessary to obtain proper balance in tensioning of posterior structures. The reconstruction of the posterior labrum in situ without capsule plication is a good solution in those cases, allowing to avoid overtensioning of the capsule [37–39]. If no associated lesions are present, arthroscopic posterior capsular plication is also considered an efficient technique in treatment of posterior instability [40, 41]. Lenart et al. [42] reported that posterior capsular plication combined with labral repair improves the outcome and decreases the revision rate. Capsular plications can be performed in two different ways: using simple stitches without bony fixation or by using suture anchors, which provide more favorable results [43]. Provencher et al. [44] proved that absorbable sutures can be insufficient over time and recommend using suture anchors with nonabsorbable sutures.

In case of inveterate fracture of lesser tuberosity, a "sandwich" technique can be used by filling the humeral head bone loss with auto- or allogenic cancellous bone and fixing the lesser tuberosity over it (Fig. 14.8).

Though less common, posterior glenoid bone loss can also occur. In contrast to anterior bone loss, the threshold for bony augmentation of the posterior glenoid rim is unclear. The same applies to the amount of retroversion or dysplasia of the glenoid one can tolerate in posterior instability. While posterior glenoid bone loss of more than

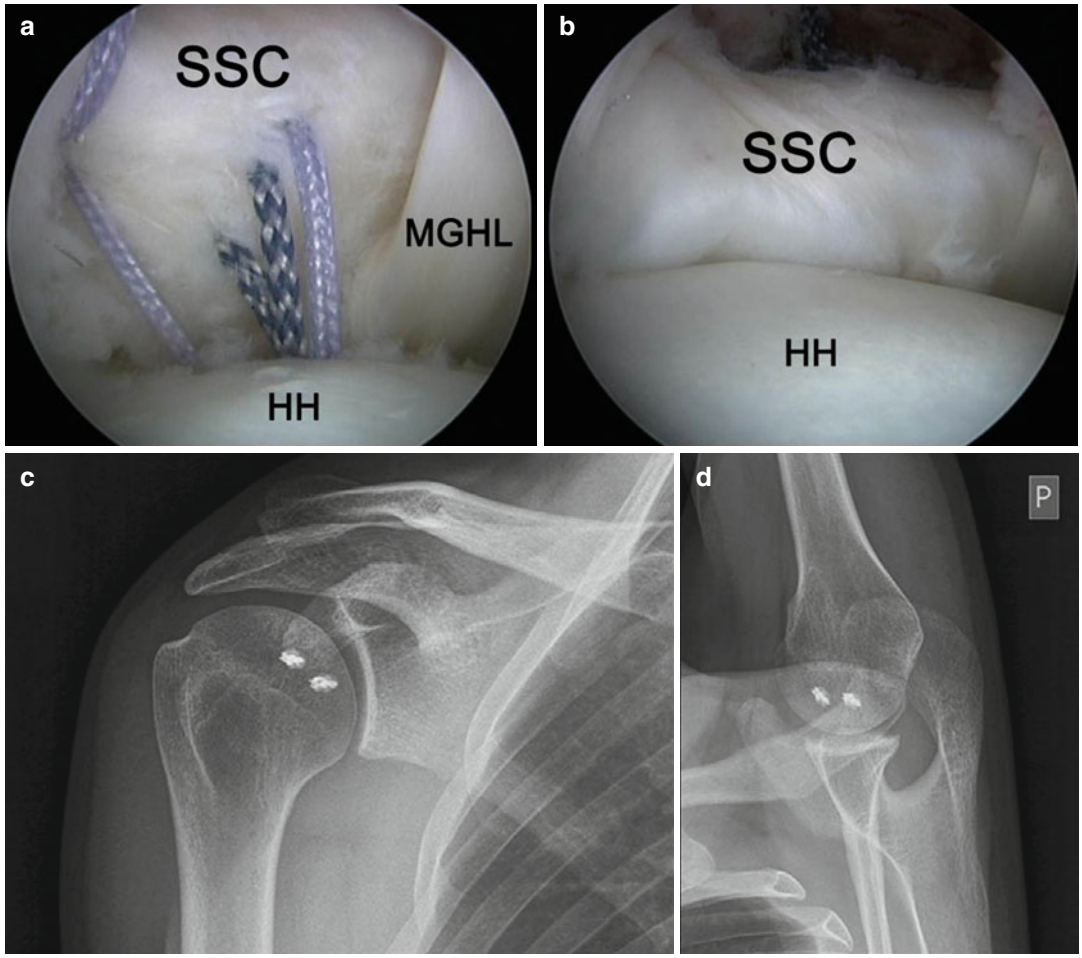

Fig. 14.7 Arthroscopic McLaughlin procedure (**a**, **b**). Postoperative anteroposterior (**c**) and Bernageau (**d**) radiographic views

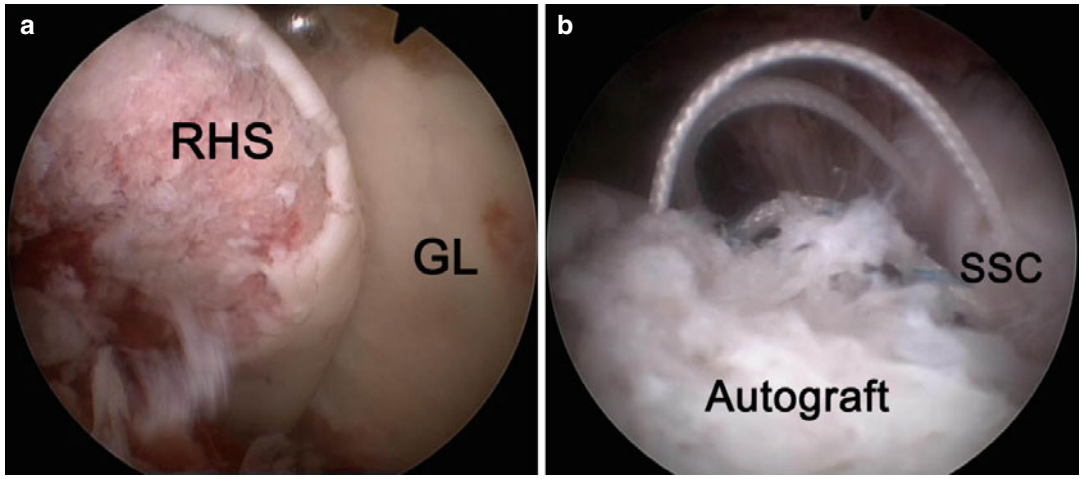

Fig. 14.8 (**a**, **b**) Arthroscopic views of the "sandwich technique" used for the fixation of inveterate fracture of lesser tuberosity

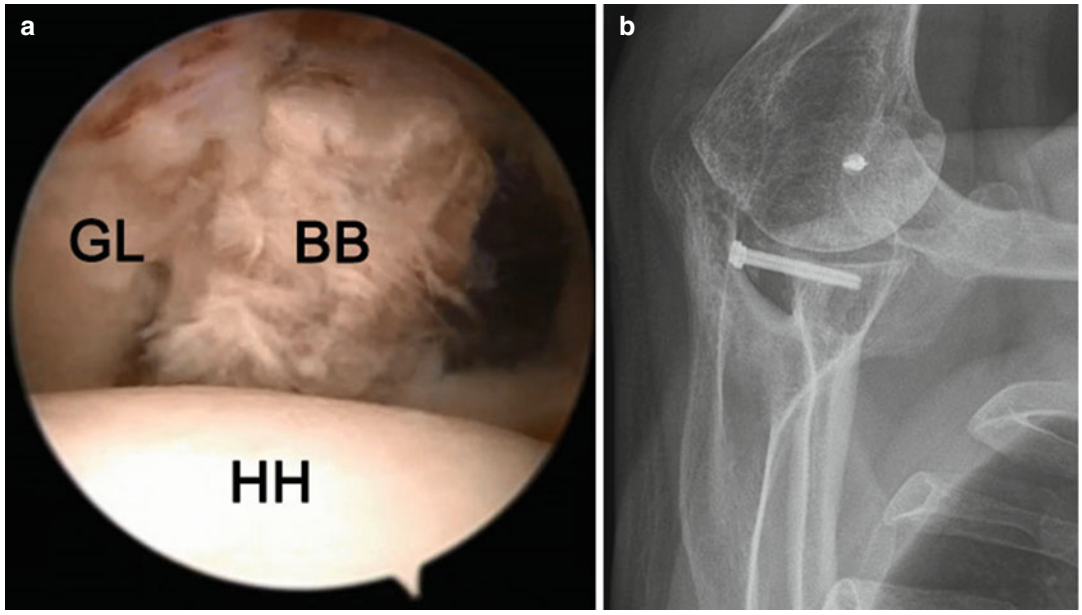

Fig. 14.9 Arthroscopic posterior bone block augmentation (**a**). Postoperative Bernageau radiographic view (**b**)

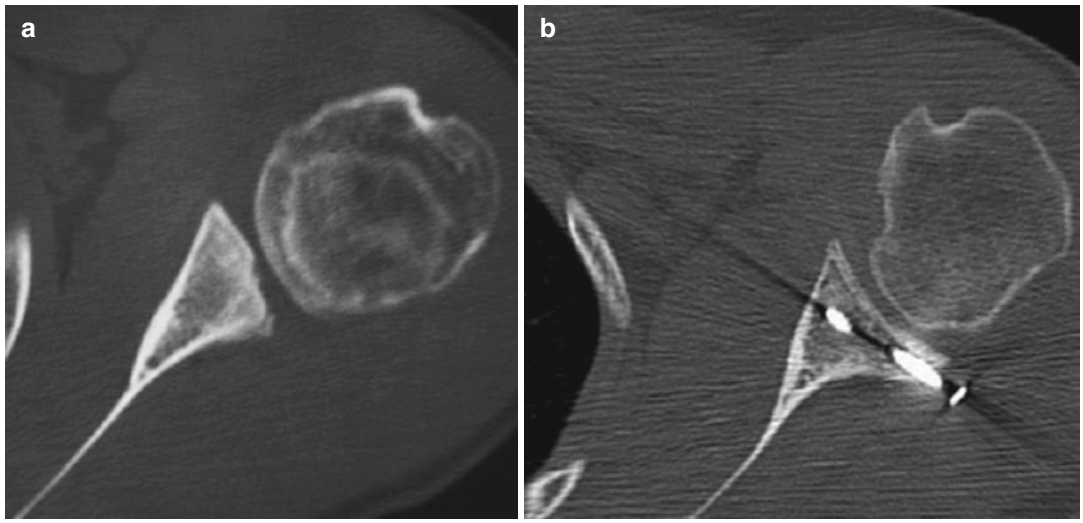

Fig. 14.10 Axial CT images. (**a**) Posterior glenoid bone loss. (**b**) Postoperative image after reconstruction with distal tibia allograft (Reprint with permission; Millett et al. [31])

25 %, Hill-Sachs defects of more than 25 %, and glenoid retroversion of more than 15–20 % are mostly considered to warrant surgical correction, the scientific background supporting this strategy is lacking [45].

For patients with significant posterior glenoid bone loss, a bone block augmentation or bony glenoid reconstruction is indicated. Although it is usually an open approach, arthroscopic techniques, despite being technically demanding, have been also described [46–49] (Fig. 14.9). The glenoid arc can be restored with an anatomic intra-articular bone graft or with an extra-articular graft serving as a buttress for the humeral head.

Since recent literature suggests long-term results of bone block procedures were not as promising, an anatomic bony reconstruction might be more beneficial [50]. The preferred autograft source is the inner table of the iliac crest. The distal tibia has shown to perfectly match the glenoid curvature, if use of an allograft is preferred [51] (Fig. 14.10). It is necessary to keep in mind potential complications such as graft resorption, persistent posterior pain, or abrasion of the infraspinatus muscle.

In cases with severe glenoid dysplasia or retroversion, open correction osteotomy with graft interposition can be indicated. An autologous tricortical bone graft is usually used, harvested from the iliac crest or the scapular spine. The size of the graft is chosen according to the degree of correction and contoured in a wedge fashion. By use of a thin chisel, the osteotomy is made, leaving the anterior cortex of the glenoid neck intact. Once the desired correction has been achieved, the tricortical bone graft is positioned in a press-fit manner. Any capsular insufficiency may then be treated as previously described.

14.3 Future Directions

In the future, arthroscopic procedures will become even more popular for treatment of posterior shoulder instability. Arthroscopic techniques for posterior bone block augmentation are already in use, and instruments and techniques are advancing rapidly. However, the introduced open techniques have shown to provide reliable and good results and remain the gold standard in cases with concomitant bony issues. The value of the arthroscopic techniques will have to be proven in the future.

Take-Home Message

Diagnosis and management of posterior shoulder instability are challenging. Therefore, a thorough clinical examination along with the imaging studies (X-rays, MR, 3D-CT) is mandatory for revealing the correct pathoanatomy, which can be variable and may involve soft-tissue and/or bony elements. If conservative treatment fails, surgery may be indicated. Careful preoperative planning, surgery targeted at the specific pathology, and thoughtful aftercare can maximize the chance for success and minimize the risk of complications. Individuals with hyperlaxity, voluntary or multidirectional instability, or with concomitant bony issues (bone loss, dysplasia, increased retroversion) will require a more careful assessment of the cause for instability. In most cases, a posterior Bankart repair with capsular shift is successful. However, concomitant bony pathologies need to be assessed preoperatively, and in some cases a combined soft-tissue and bony procedure may be needed to restore stability.

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15 Posterior Compartment of the Ankle Joint: A Focus on Arthroscopic Treatment (ICL 17)

Daniel Haverkamp, Niels Bech, Peter de Leeuw, Pieter d'Hooghe, Akos Kynsburg, James Calder, Tahir Ogut, Jorge Batista, and Hélder Pereira

15.1 Introduction

In 1931 Burman found the ankle joint unsuitable for arthroscopy because of its typical anatomy [5]. However as time elapsed and techniques improved, Takagi and later Watanabe made considerable contributions to arthroscopic surgery, and the latter published a series of 28 ankle arthroscopies in 1972 [73]. Since the late 1970s, the number of publications has grown exponentially. Nowadays arthroscopy of the ankle joint has become an important procedure with numerous indications for both anterior as well as posterior pathology and pathology of tendons. Endoscopic surgery offers the possible advantages of direct visualization of structures, improved assessment of articular cartilage, less postoperative morbidity, faster and functional rehabilitation, earlier resumption of sports and outpatient treatment [23, 42, 56]. The value of diagnostic arthroscopy nowadays is considered limited [58, 67, 71]. Posterior ankle problems pose a diagnostic and therapeutic challenge, because of their nature and the deep location of hindfoot structures. This makes direct access more difficult. Historically, the hindfoot was

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Fig. 15.1 Pau Golano: anatomist and researcher

approached by a three-portal technique, i.e. the anteromedial, anterolateral and posterolateral portals, with the patient in the supine position [1, 12, 24]. The traditional posteromedial portal is associated with potential damage to the tibial nerve, the posterior tibial artery and local tendons [13]. A two-portal endoscopic approach with the patient in the prone position was introduced in 2000 [68]. This technique has shown to give excellent access to the posterior ankle compartment, the subtalar joint and extra-articular structures [54, 64, 68].

In this instructional course lecture, we highlight several techniques of the posterior ankle compartment, especially for arthroscopic techniques. This work highlights the specific anatomical structures important for the posterior ankle arthroscopy. A summary from the work of Pau Golano (Fig. 15.1) is provided once some of the authors had the opportunity to closely work together with Pau for several years. Pau Golano was a master in showing the anatomy with his excellent dissections, making it look like a form of art. Anatomical knowledge is an important element for proper surgery and will directly influence the outcome with respect to complication rates. The anatomy also determines the ideal location for the portals.

15.2 State-of-the-Art Treatment

15.2.1 Anatomy (A Tribute to Pau Golano)

Pau was professor of Pathology and Experimental Therapeutics at the University of Barcelona. His exceptional anatomical dissection skills and passion for education were quickly recognized by the orthopaedic surgeons surrounding him. And it did not take long before his skills were recognized worldwide making him the leading expert on orthopaedic anatomy of the last decade. Unfortunately he died way too young in 2014; however, his art lives on. This paragraph shows his work.

> Anatomical knowledge is essential when performing surgery, without a decent roadmap one tends to get lost easily. The problem in anatomy is that not every individual is identical, therefore a thorough knowledge of safe pathways and anomalies that can occur is essential.
>
> Extensive anatomical knowledge can significantly decrease the risk of associated complications by profound familiarity with the anatomy of the region. Adequate knowledge of the anatomy of the joint to be treated should cover not only the most common anatomic configurations but also the possible anatomic variations to avoid confusion and serious technical errors.

The most important structure to define the safe working space in the posterior ankle is the flexor hallucis longus (FHL) tendon. On the medial side of the FHL runs the posterior neurovascular bundle (tibial nerve and posterior tibial artery and veins). To avoid complications the posterior ankle arthroscopy should therefore routinely be performed lateral to the FHL tendon (Fig. 15.2). The first step in approaching the posterior compartment arthroscopically is therefore identifying the FHL first. Plantar flexion of the ankle (letting it hang loosely instead of forced dorsiflexion) results in a better visualization of this tendon of the FHL and avoids damage to the muscle belly [19–21].

When orientating in the posterior compartment, the posterior ankle ligaments are also important. These ligaments include the posterior talofibular ligament; the posterior intermalleolar

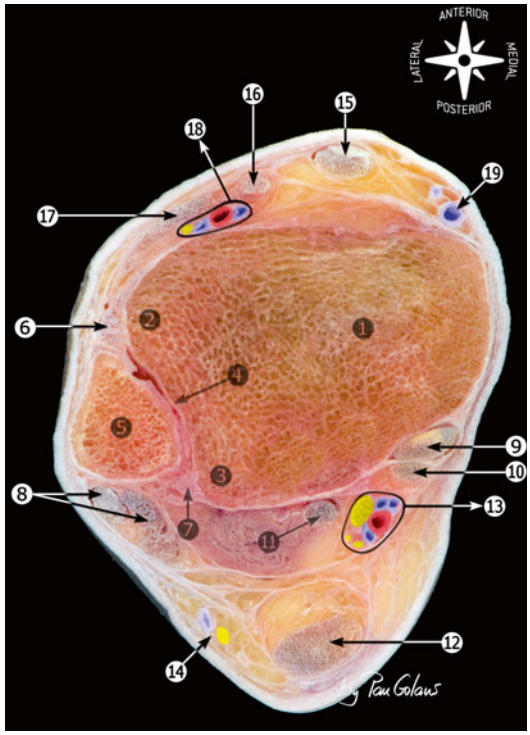

Fig. 15.2 Transverse section of the ankle at the syndesmotic level. *1* tibia, *2* anterior tubercle, *3* posterior tubercle, *4* fibular notch, *5* lateral malleolus, *6* anterior tibiofibular ligament, *7* posterior tibiofibular ligament, *8* peroneus brevis tendon and peroneus longus tendon, *9* tibialis posterior tendon, *10* flexor digitorum longus, *11* flexor hallucis tendon (musculotendinous), *12* calcaneal tendon, *13* posterior neurovascular bundle (posterior tibial nerve and posterior tibial artery and veins), *14* sural nerve and small saphenous vein, *15* tibialis anterior tendon, *16* extensor hallucis longus tendon, *17* extensor digitorum longus and peroneus tertius tendons, *18* anterior neurovascular bundle (deep peroneal nerve and anterior tibial artery and veins), *19* saphenous nerve and great saphenous vein (From: ICL Book 2012 Geneva/KSSTA)

ligament, also called the tibial slip in the arthroscopic literature; and the posterior tibiofibular ligament which is composed of a superficial and deep component or transverse ligament (Fig. 15.2).

The posterior talofibular ligament is a part of the lateral collateral ligament. It runs from the medial surface of the lateral malleolus to the posterolateral surface of the talus. This ligament is also an important reference in posterior ankle arthroscopy. The posterior talofibular ligament helps to find the different working areas: subtalar and talocrural. The posterior subtalar recess is plantar to this ligament and the talocrural joint is located dorsally.

The posterior intermalleolar ligament has been the subject of investigation because of its involvement in the posterior (soft tissue) impingement syndrome of the ankle [25, 46]. Its prevalence of occurrence both in radiological and in anatomic studies varies widely, ranging from 19 % up to 100 % [40, 46, 48]. The posterior intermalleolar ligament is situated between the transverse ligament or deep component of posterior tibiofibular ligament and the posterior talofibular ligament and runs obliquely from lateral to medial and from downwards to upwards. Several shapes are described, depending on the medial origin and thickness of the structure. This ligament is commonly resected during the posterior ankle arthroscopy to allow access to the ankle joint. Although not proven in a study, it seems that resection has no significance in the talocrural joint stability. However unnecessary resection may increase the occurrence of a talocrural arthrofibrosis because of scar tissue formation.

The posterior tibiofibular ligament is named differently in the arthroscopic literature [2, 19]. This part of the syndesmotic complex is formed by two parts, the superficial and deep component. The superficial component originates at the posterior edge of the lateral malleolus and directs proximally and medially to insert in the posterior tibial tubercle. This component would be homologous to the anterior tibiofibular ligament. The deep component is cone shaped and originates in the proximal area of the malleolar fossa to insert in the posterior edge of the tibia. Its insertion is immediately posterior to the cartilaginous covering of the inferior tibial articular surface. This component is also known as the transverse ligament, forming a true labrum to provide talocrural joint stability and to prevent posterior talar translation [53, 61]. The transverse ligament, or deep component, should be routinely explored to assess its normal insertion on the tibia which may be affected, especially in trauma patients.

To arthroscopically approach the posterior ankle compartment, we prefer the one as

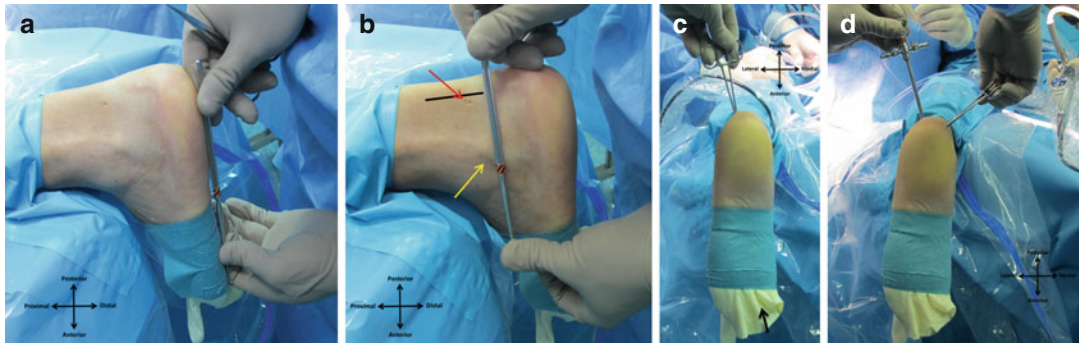

Fig. 15.3 The portals are made with the ankle in a neutral (90°) position (**a**). An endoscopic probe can be very useful to determine the exact location of the posterolateral portal. The hook is "hooked" under the tip of the lateral malleolus (*yellow arrow*) (**b**). The hook is placed parallel to the foot sole, with the foot in a 90° position (**a**, **b**). A straight line is drawn from the tip of the lateral malleolus to the Achilles tendon, parallel to the foot sole (*black line*). The posterolateral portal (*red arrow*) is made just above the line from the tip of the lateral malleolus and 1-cm anterior to the Achilles tendon. The posteromedial portal (*arrow*) is located at the same level as the posterolateral portal, just anterior to the Achilles tendon. An imaginary line can be drawn from the level of the posterolateral portal over the Achilles tendon to determine the location of the posteromedial portal. A mosquito clamp is introduced through posterolateral portal by blunt dissection pointing to the first interdigital space until reaching hard bone (**c**). Again by blunt dissection, instruments are introduced by medial portal into the "safe area" (as described elsewhere) until direct visualization is achieved (**d**) [65]

described by Niek van Dijk in 2000 and later in 2009 [66, 68]. This technique allows easy and safe access to the complete posterior ankle compartment.

The patient is positioned in the prone position with a tourniquet above the knee at the affected side. The affected ankle is positioned just over the edge of the operation table and is supported to allow free ankle movement. A support is placed on the ipsilateral side, to allow some tilting of the OR table to make sure the foot is perpendicular to the floor.

The portals are placed on the medial and lateral site of the Achilles tendon, at the height of the tip of the lateral malleolus, in a line perpendicular to the sole of the foot. With the ankle in the neutral position (90°), a straight line, parallel to the sole of the foot, is drawn from the tip of the lateral malleolus to the Achilles tendon and is extended over the Achilles tendon to the medial side. The posterolateral portal is located just proximal to, and 5-mm anterior to, the intersection of the straight line with the lateral border of the Achilles tendon. The posteromedial portal is located at the same level as the posterolateral portal but on the medial side of the Achilles tendon (Fig. 15.3).

The posterolateral portal is made first; a stab incision is made and the subcutaneous tissue is spread with a mosquito clamp [65, 66]. The foot is now in a slightly (relaxed) plantar-flexed position. The clamp is directed anteriorly, towards the interdigital web space between the first and second toes. When the tip of the clamp touches the bone, it is exchanged for a 4.5-mm arthroscopic cannula with the blunt trocar pointing in the same direction. The trocar is situated extra-articularly at the level of the posterior talar process and is exchanged for the 4.0-mm 30° arthroscope, directed laterally. At this time the scope is still outside the joint in the fatty tissue overlying the capsule.

The second portal is the posteromedial portal, which is also made with a vertical stab incision. A mosquito clamp is introduced through the posteromedial portal and directed towards the arthroscope shaft at a 90° angle until the clamp contacts the arthroscope. The ankle is still in a slight plantar-flexed position, and the arthroscope has remained in position through the posterolateral portal, directed towards the first interdigital webspace. The arthroscope shaft is used as a guide for the mosquito clamp to travel anteriorly. While in contact with the arthroscope shaft, the clamp

glides over the shaft towards the ankle joint until the bone is reached. Once the arthroscope and clamp are both touching the bone, the mosquito clamp is left in position, and the arthroscope is pulled slightly backwards and tilted until the tip of the clamp comes into view. The soft tissue layer covering the joints consists of fatty tissue and the deep crural fascia. At the lateral side, a specialized part of the crural fascia can be recognized, being the fibulotalocalcaneal ligament, also known as the ligament of Rouvière and Canela Lazaro.

After penetrating this ligament, the lateral part of the subtalar joint can be visualized. Now the mosquito clamp is exchanged for a shaver. Introduction of the shaver should be performed exactly similar to the way the mosquito clamp was. While visualizing the lateral part of the subtalar joint, the soft tissue medially is resected with the shaver. While shaving medially, the head of the shaver should be facing the arthroscope, thereby avoiding damage to the FHL. Before addressing any pathology, this tendon should be localized, since just medially to it the posterior neurovascular bundle is located. The FHL determines the working area, basically only lateral to this tendon.

Now the pathology can be addressed, ranging from debridement of soft tissue, removal of an os trigonum, addressing the Cedell fracture, release of the *flexor hallucis longus* tendon or performing a groove deepening in case of recurrent peroneal tendon dislocation, fracture fixation, tarsal tunnel release or even performing an arthrodesis.

15.3 Posterior Impingement

Posterior ankle impingement is a pain syndrome. The patient experiences posterior ankle pain mainly on forced plantar flexion. It is caused by overuse or trauma and the first one has a better prognosis. Posterior ankle impingement is very common in ballet dancers and runners.

Potential causes of deep posterior ankle pain are soft tissue injuries (e.g. FHL tenosynovitis, synovitis due to rheumatological or tumoral diseases), bony or osteochondral injuries (e.g. os trigonum syndrome, osteochondral defects, intraosseous talar cysts, tarsal coalition) and neurovascular injuries (e.g. sural nerve entrapment, tarsal tunnel syndrome). We focus on the arthroscopic treatment of these pathologies.

15.3.1 Os Trigonum/Hypertrophic Posterior Talar Process

The most common type of bony posterior impingement is a prominent os trigonum or Stieda's process. With deep forced plantar flexion of the foot, this bony part impinges between the calcaneus and the tibia (Fig. 15.4) like a nutcracker [4, 26, 41].

During skeletal maturation the os trigonum develops as an accessory bone from the secondary ossification centre of the posterolateral process of the talus [39]. The posterolateral ossification centre of the talus fuses with the talus and mineralizes between the ages of 7 and 13 years old. Incomplete ossification occurs in approximately 7–14 % in a population and in 50 % it occurs bilaterally [38, 39].

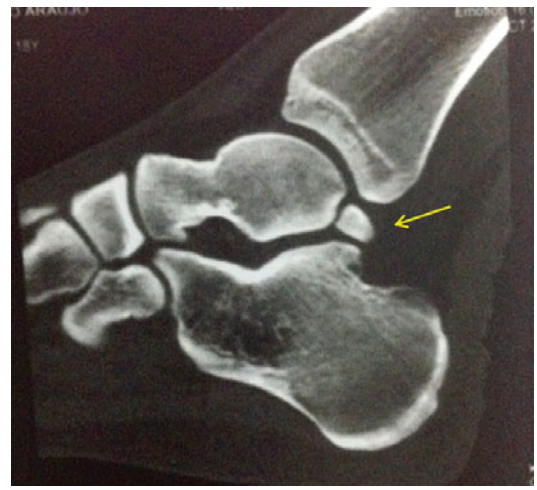

Fig. 15.4 Sagittal CT in plantar flexion demonstrating an os trigonum causing posterior impingement (*yellow arrow*)

Bony impingement can be caused by roughly four different anatomical variations of the posterolateral process of the talus:

1. Normal posterolateral process
2. An elongated normal posterolateral process called Stieda's process
3. Accessory bone or os trigonum
4. Os trigonum (partially) fused with the talus by a synchondrosis

Diagnosis is usually based on clinical presentation and physical examination, supported by imaging findings. Conventional ankle radiographs can demonstrate a prominent os trigonum or Stieda's process; simple lateral radiographs can detect fracture lines but they cannot distinguish between an old or new fracture [38, 52]. Most often standard lateral X-rays fail to show the true form and posterior impingement view is necessary [54]. Computed tomography (CT) of the os trigonum can be useful in detecting bony margins and in planning surgery [38, 52].

Magnetic resonance imaging (MRI) is very useful and superior to CT in detecting bone marrow oedema, soft tissue injuries and tenosynovitis in posterior impingement syndrome [4, 38].

15.4 Flexor Hallucis Longus (FHL) Pathology

A cause for posteromedial complaints with or without a bony impingement can be isolated tenosynovitis of *flexor hallucis longus*. Due to the close anatomical relation of the FHL to the posterior talar process, these two entities often coincide [54, 69]. The inflammation of the FHL is often called the ballet dancers ankle; however the condition is also common in other sports like soccer.

Tendinitis of the FHL is mainly caused by its anatomical location. On the medial side of the posterior talar process, the FHL runs in a tight sliding tunnel with the anterior and lateral border, the smooth talus and the rest surrounded by a tight tunnel of retinaculum. In case of excessive bone swelling of the FHL, a low hypertrophic muscle belly or even a loose body (Fig. 15.5) will be a problem in fitting the FHL within its tunnel thus causing impingement and complaints. This occurs most in a combination of hyper dorsiflexion of the hallux and ankle, a move known as "grand plié" in ballet.

Treatment is identical as posterior bony impingement; however extra care should be given to inspect the tunnel of the FHL and to open it when necessary.

15.5 Cedell Fracture

The Cedell fracture is less common as a cause of posteromedial impingement pain (Fig. 15.6). This avulsion is called after Cedell since he described the first four cases in 1974. An isolated rupture of the deep deltoid ligament (i.e. the posterior tibiotalar ligament) can pull off a bone fragment from its insertion on the talus [6].

A forceful twist with the talus in dorsal extension and pronation in the ankle mortise can cause an isolated rupture of the deep deltoid ligament with avulsion of a bony chip from the insertion on the talus.

Cedell fractures are mostly not visible on radiographs. When after a distortion the posteromedial pain persists, clinical suspicion should be raised, and a CT scan is needed to confirm the diagnosis.

Resection of a Cedell through a posterior endoscopy is more difficult since the safe zone on the lateral side of the FHL should be left. The Cedell is on the medial side of the FHL under the neurovascular bundle. The basic technique is identical to the standard posterior ankle arthroscopy; however from there on, we move to the flexor retinaculum and cut it with a punch. The tendon sheath of the FHL is opened and the FHL is moved medially. The insertion of the flexor retinaculum on the posteromedial talar process comes in view and can be opened by incising it over the full length. The avulsion should then be visible and can de excised carefully.

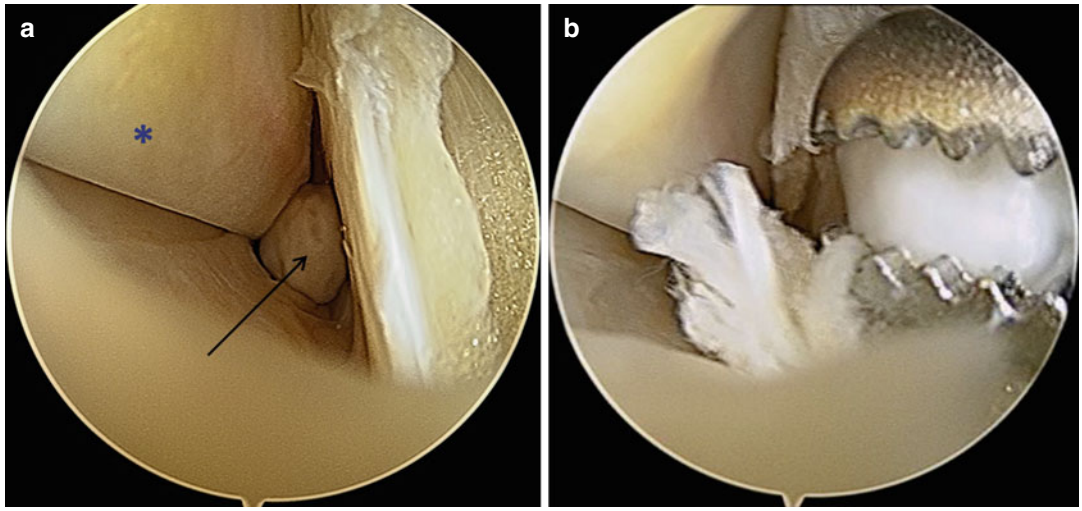

Fig. 15.5 Endoscopic view inside the sheath of the flexor hallucis longus tendon (*) where a loose body was identified (*arrow*) (**a**) and could be removed (**b**)

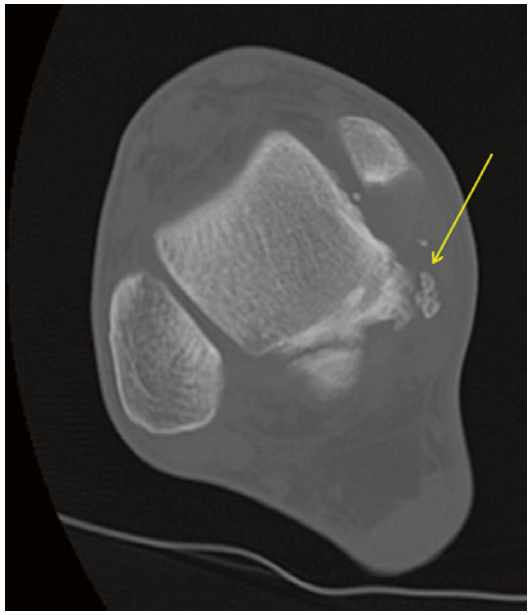

Fig. 15.6 CT scan showing a Cedell fracture (*yellow arrow*)

15.6 Fusion of the Ankle Joints Through the Posterior Arthroscopic Approach

15.6.1 Subtalar Joint

The subtalar joint is a complex joint that is functionally responsible for inversion and eversion of the hindfoot. Several problems can occur in the subtalar joint, but the most common are osteoarthritis and talocalcaneal coalitions. Both can be treated with fusion of the subtalar joint.

In 1905, subtalar arthrodesis was first described by Nieny. In 1985, arthroscopy of the subtalar joint was first described by Parisien and Vangsness [47]. Arthroscopic subtalar arthrodesis was then consequently introduced by Tasto in 1992 [60]. From here on techniques were further perfected to preserve blood supply and lower the morbidity. Also an attempt was made to increase the fusion rate and to decrease the time until fusion and decreasing the complications rate. In 2009, a three-portal approach for arthroscopic subtalar arthrodesis was introduced to offer full exposure and treatment on the posterior facet of the subtalar joint [3].

Potential advantage of this technique is that it is a time-efficient technique with a full exposure of the posterior facet of the subtalar joint (Fig. 15.7). The prone position allows for easy placement of the screws and corrects alignment of the hindfoot [62].

The standard technique is identical to the posterior ankle arthroscopy. If the FHL and subtalar joint are identified, the subtalar joint is opened. With a curette or small chisel, the cartilage that is remaining is removed. In cases where a (pseudo) coalition is present, it might be more difficult to

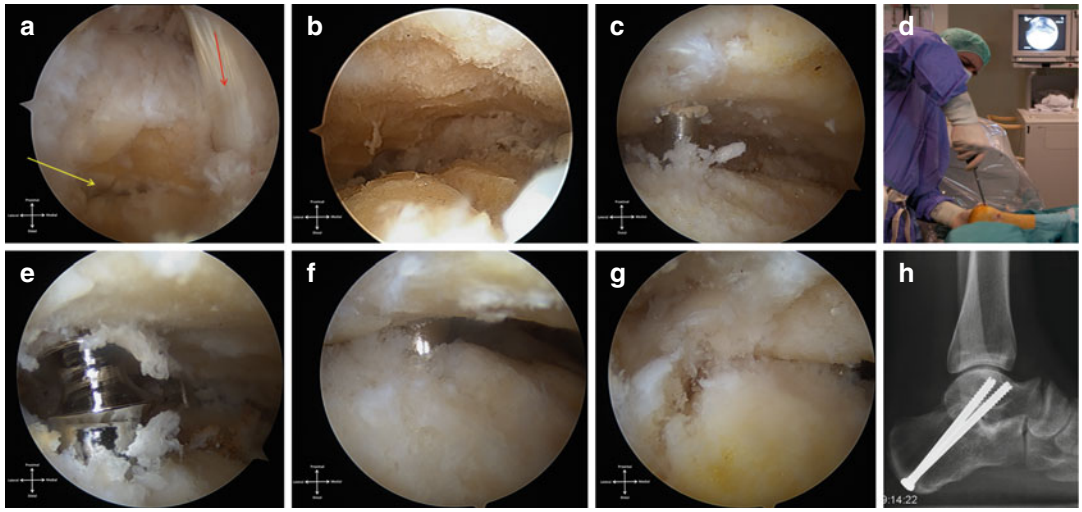

Fig. 15.7 Endoscopic view of posterior compartment where subtalar joint (*yellow arrow*) and flexor hallucis longus tendon (*red arrow*) are identified (**a**). View of the subtalar joint after removal of cartilage and preparation for fusion (**b**). Placement of guide wire under arthroscopic control (**c**). Exterior view of screw placement (**d**). Visualization of the screw progressing through the talus (**e**). Compression effect by the screw making the joint space close (**f**). Final arthroscopic look after two screws' placement with compression effect (**g**). Control X-ray with two 6.5-mm screws in place (**h**)

open the subtalar joint. In these cases it might be helpful to introduce a small chisel under arthroscopic control and to carefully open the (pseudo)coalition first. When starting from lateral without opening the (pseudo)coalition, the danger exists to create a defect lateral with a remaining strut medial causing a pseudarthrosis.

Despite the fact that it seems that no accessory portals might be necessary in some cases, it is important to create an additional sinus tarsi portal. A needle is inserted in the sinus tarsi in the position where it is visible from posterior and runs parallel to the subtalar joint; the needle is removed, a stab incision is made and the soft tissue divided by a mosquito. The blunt trocar is introduced in a sideway manner, first lying next to the subtalar joint and then slide in. This sinus tarsi portal initially allows inserting a large diameter blunt trocar to open the subtalar joint to facilitate the debridement. The subtalar joint is cleaned until the interosseous ligament in the sinus tarsi. After thorough debridement grooves are made with a small (4 mm) chisel on both sides of the joint. Finally the hindfoot is aligned in perfect position and the screws are placed under fluoroscopic control.

15.6.2 Ankle Joint: Cysts, Osteochondral Defects and Fusion

Posterior endoscopy enables access to posterior compartment for treatment of symptomatic cysts (Fig. 15.8) or osteochondral defects [16]. However, one must recognize that, comparing to anterior ankle arthroscopy, there is a significantly denser soft tissue envelope and increased distance from the portals to the injury site. This fact somewhat limits the range of mobility of the surgical instruments. For this circumstance, most authors reserve posterior endoscopy for cysts and osteochondral defects only for cases which cannot be addressed by anterior approach [65].

Numerous techniques to fuse the ankle joint has been posted over the years, arthroscopically, open or using a so-called mini-open technique [7, 22, 42, 44, 45, 50]. Despite the fact that open procedure might have an advantage in realigning the foot, the arthroscopic techniques rapidly increased popularity with rising union rates and lower complication rate compared to open surgery [7, 45, 50].

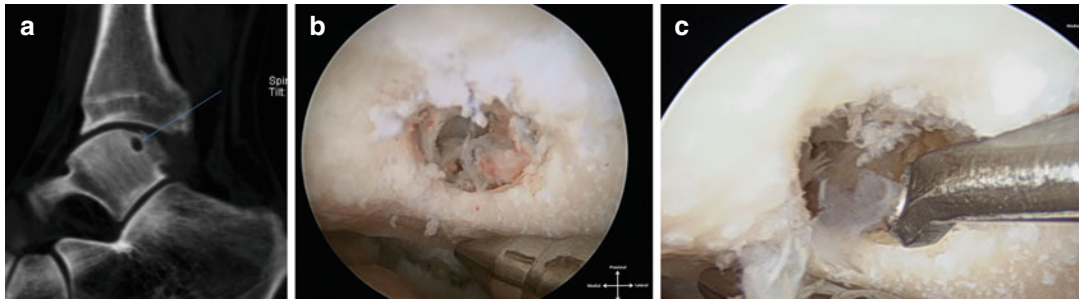

Fig. 15.8 CT scan where a posterior talus cyst is visible (*blue arrow*) (**a**); arthroscopic view of the cyst (**b**) and debridement prior to bone grafting (**c**)

An ongoing discussion is the position and direction of the screws. Studies showed that screws crossing above the fusion point positioned in a 30° angle on the tibial axis seem to produce a rigid fixation [15, 31, 72]. However parallel placed screws give more compression over the joint, which might be more important to allow fusion [37]. Another discussion that might be important is the shape of the debrided joints, flat surfaces or contoured surface in arthroscopic techniques. It remains unclear if the theoretical differences influence the outcome [35, 49, 72].

In this section we describe the arthroscopic technique, which uses the posterior access to the ankle joint. A standard technique for the posterior ankle (Fig. 15.9) is used for debridement of the tibiotalar joint surfaces [66, 68]. An additional anteromedial ankle portal might be used to enable distraction of the ankle joint and debridement of the anterior distal tibial and anterior talar surface if this cannot be reached from posterior [66, 68]. The cartilage, of both the talus and tibia, is removed and the subchondral plate damaged. Then, under fluoroscopic control, two 6.5-mm cancellous screws are inserted through the Achilles tendon with the ankle in the desired position [27, 29, 33].

This technique is developed and described by Kerkhoffs [33] first in a feasibility study; it is proposed to be a safe technique with the possibility of debriding a total joint surface of 95 %, while in anterior techniques this percentage is lower since the posterior part cannot always be reached [28, 29]. At midterm follow-up promising results show with a 100 % union rate [10].

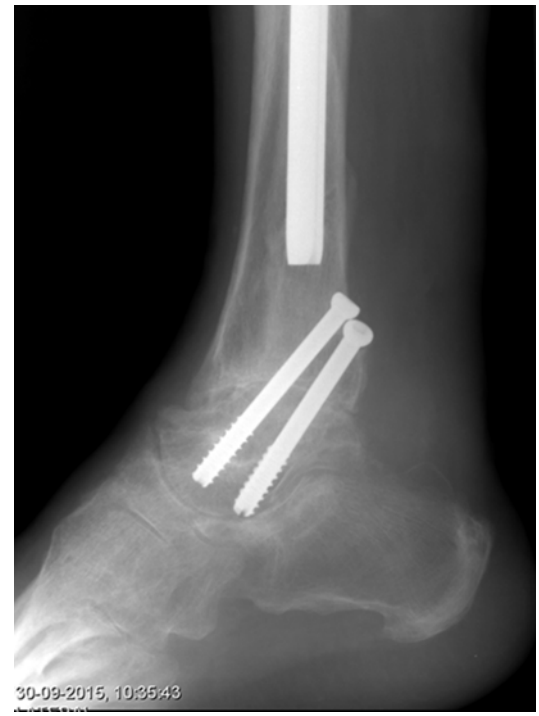

Fig. 15.9 Fluoroscopic image of posterior ankle fusion with two 6.5 screws. The patient had a tibial nail after a fracture (*white arrow*) and the arthroscope is also visible (*yellow arrow*)

15.6.3 Pantalar Fusion

Arthroscopic posterior joint approach provides some advantages in those cases in which both

ankle and subtalar have indication for fusion. Both joints can easily be reached by posterior arthroscopy, and both joints can be prepared for simultaneous fusion minimizing the surgical aggression.

When lying in a prone position after debridement, fixation of subtalar and ankle separately by screws or with a hindfoot nail can be performed.

Literature on this technique is lacking, although cases are shown incidentally. From the author's experience, this seems a promising approach; however the feasibility of this technique has not yet been demonstrated.

15.7 Arthroscopic-Assisted Fracture Repair Through the Posterior Arthroscopic Approach

Several types of fractures can be fixed with arthroscopic assistance.

However in the literature mainly knee and anterior ankle compartment arthroscopies can be found describing the advantages of identifying additional injuries and ensuring perfect intra-articular alignment.

15.7.1 Posterior Malleolus

A perfect indication would be the (isolated) posterior malleolar fracture. Although a rare fracture, in a large series of 2,500 ankle fractures, only 25 were isolated posterior malleolar fractures [43].

Especially the tibial plafond can be perfectly visualized from posterior, and perfect reduction can be controlled. The posterior access can facilitate screw placement under arthroscopic vision (Fig. 15.10).

15.7.2 C2 Talar Body Fracture

For the C2 talar body fracture, arthroscopic-assisted reduction and internal fixation (ARIF) could be a great option. This fracture occurs with an axial load on the foot in a rigid forced dorsiflexion position, most frequently seen in motor vehicle accidents when the driver has a foot on the pedal. Talar fractures occur about 1–6 % of all foot fractures with 20 % being talar body fractures [30].

Sitte et al. described the technique of hindfoot and subtalar arthroscopy for the treatment of talar body fractures [57]. In this technique the patient is in the prone position, and the subtalar joint is approached via a posteromedial and posterolateral portal as described by van Dijk et al. [68]. K-wires are placed percutaneous for stabilization during drilling. Optimal screw position is from posterolateral pulling the talar nose back posterior against the talar body with optimal reduction of the fracture [57].

15.7.3 Calcaneal Fracture

Open reduction and internal fixation of calcaneal fractures can result in up to 25 % wound complications, with 21 % of the patients requiring further surgery [14]. The most important indicator of prognosis after a calcaneal fracture is anatomic reduction of the posterior subtalar joint, even 1- or 2-mm incongruence can result in subtalar arthritis and later secondary subtalar arthrodesis.

Minimal invasive techniques with arthroscopically assisted reduction and fixation provide a good alternative to open surgery. Several reports of arthroscopic-assisted reduction and fixation exist with good results, mainly with subtalar arthroscopy via a sinus tarsi portal and percutaneous placed K-wires [17, 55, 75].

However, posterior portals can also be used. Rammelt et al. described a technique in which type II Sanders fractures were percutaneously reduced, and via a posterolateral portal, anatomic reduction was evaluated; after irrigation the subtalar joint was cleared and loose fragments or clots were arthroscopically removed [51]. If there was incongruency or a step off in the subtalar joint, fragments were aligned percutaneously with K-wires under direct arthroscopic vision.

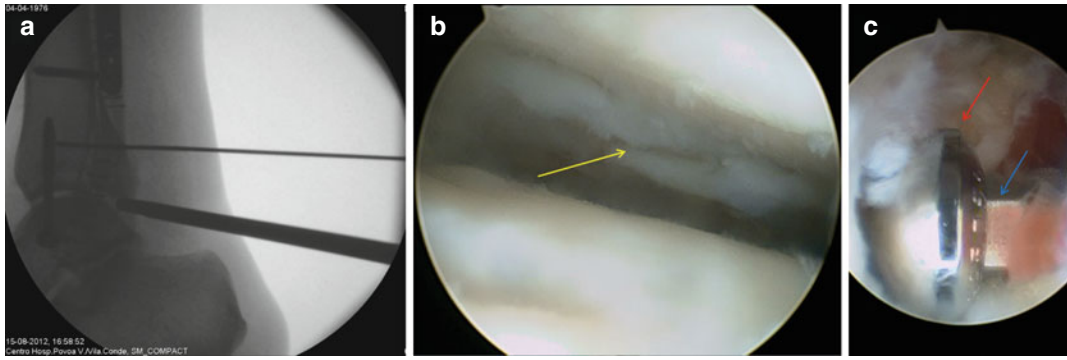

Fig. 15.10 Fluoroscopic image of a trimalleolar fracture in which the posterior malleolus has been reduced and provisionally stabilized with a K-wire. The arthroscope is visible inside the ankle joint for control of reduction (**a**). The joint surface status is controlled by direct arthroscopic visualization. The fracture line is identified (*yellow arrow*) (**b**). Screw placement is also controlled arthroscopically. The screw (*red arrow*) and screwdriver (*blue arrow* and *red arrow*) are visible (**c**)

15.8 Arthroscopic Release of the Tarsal Tunnel

Tarsal tunnel syndrome refers to tibial nerve compression as the nerve passes under the flexor retinaculum. The tarsal tunnel, next to the tibial nerve, passes the flexor hallucis longus (Fig. 15.11), the tibialis posterior, the flexor digitorum longus, posterior tibial artery and posterior tibial vein. The most common causes of tibial nerve entrapment are posttraumatic changes of calcaneus, talus or medial malleolus which result in compression of the tibial nerve.

Patients report pain, burning and numbness of the sole of the foot, the distal foot and sometimes the heel. During examination there is a numbness of the plantar surface of the foot and a positive Tinel's sign may be found.

The rare anterior tarsal tunnel syndrome occurs when the deep peroneal nerve is compressed as it runs through the anterior tarsal tunnel; the nerve can be released surgically via an open or endoscopic approach [76].

For the more common posterior tarsal tunnel syndrome, usual surgical treatment is open surgical decompression of the nerve. An endoscopic technique described by Gkotsoulias et al. makes use of a posteromedial portal and has shown good results [18]. This endoscopic technique provides a good alternative to open surgical treatment of the tarsal tunnel syndrome (Fig. 15.11).

15.9 Calcaneoplasty and Achilles Insertional Tendinopathy

Insertional Achilles tendinopathy refers to pathology at the insertion of the Achilles tendon onto the calcaneum [70]. Physiopathology involves recurrent stress placed upon the attachment site of the Achilles tendon, causing inflammation, micro tears, swelling and pain [36]. Overuse is an important etiologic factor, considering the high prevalence of this condition among long course runners [34]. Despite mechanical overload is considered a major risk factor, correlation with varus hindfoot malalignment, advancing age, dyslipidaemia, male gender and high body mass index has also been described [36]. The diagnosis of insertional Achilles tendinopathy is often clinical, based on a triad of symptoms: pain at the site of insertion of Achilles tendon, accompanied by swelling (which may be due to retrocalcaneal bursitis) and impaired performance of the diseased tendon [74]. Radiological findings might include Haglund's deformity which is an enlargement of the posterosuperior prominence of the calcaneum and/or calcaneal spurs [32].

The first line of treatment is usually conservative (physiotherapy, medication, shoe wear). However, when properly indicated, good outcome has been reported with endoscopic calcaneoplasty as described elsewhere [65]. This endoscopic approach has been growing in

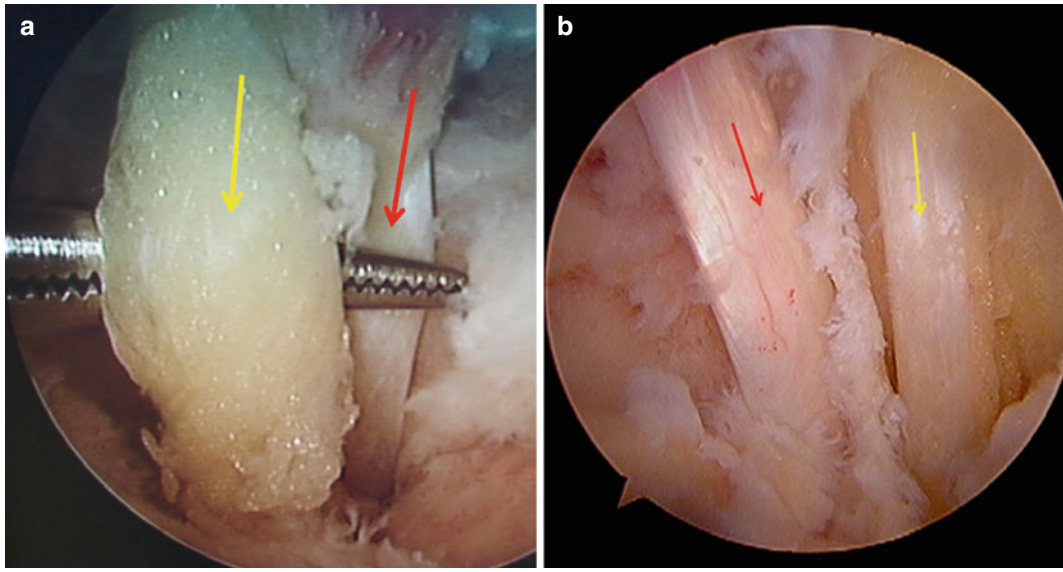

Fig. 15.11 Endoscopic views (**a**, **b**) where the *flexor hallucis longus* tendon (*red arrows*) and the tibial nerve (*yellow arrows*) are identified. Notice the close relation between these two structures

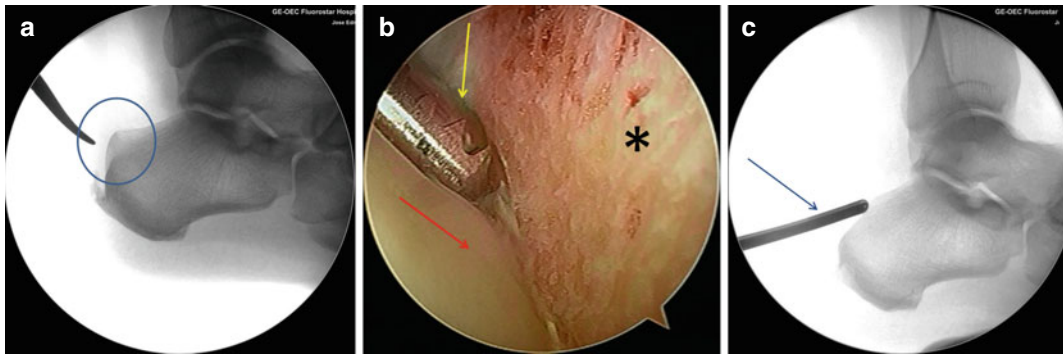

Fig. 15.12 (**a**) Haglund's deformity (*blue circle*) and calcification in the Achilles tendon insertion are visible. (**b**) Endoscopic view where the shaver blade (*yellow arrow*) has its blunt surface facing the Achilles tendon (*red arrow*) and the cutting edge is facing the calcaneal tuberosity (*). (**c**) Fluoroscopy control can be usefull to visualize the amount of resection

popularity when compared to open techniques. It enables addressing retrocalcaneal bursitis, bony deformity and/or Achilles tendon debridement (Fig. 15.12).

15.10 Flexor Hallucis Longus Transfer

Another technical possibility by posterior ankle endoscopy is the transfer of the *flexor hallucis longus* (FHL). This technique has been indicated in selected cases of Achilles tendinosis [11], as augmentation of Achilles ruptures [59]. Good clinical outcome with limited morbidity have been reported in properly selected patients.

A standard two-portal posterior approach is used to harvest the FHL. A tunnel is performed in the calcaneus, and a third incision might be used for precise reinsertion of the FHL under arthroscopic visualization. Reinsertion might be achieved by use of anchors, interference screws or suspensory devices (Fig. 15.13). Further research is needed before more definitive conclu-

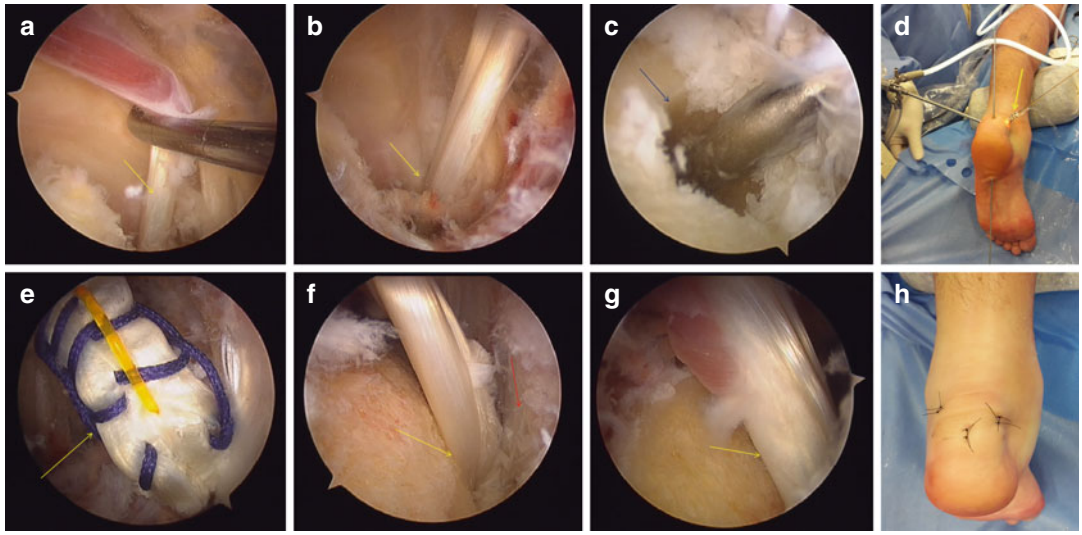

Fig. 15.13 Endoscopic identification of the flexor hallucis longus tendon (FHL – *yellow arrow*) (**a**); identification of the site of liberation/cut of the FHL (**b**); probe inside the tunnel for FHL reinsertion (*blue arrow*) (**c**); outside view (**d**) where the arthroscope is inside the posterolateral portal, the FHL (*yellow arrow*) is brought to the medial portal and prepared with suture for traction. A K-wire is used to prepare the bone tunnel (centre of the ankle). The FHL (*yellow arrow*) is passed through the calcaneal tunnel (**e**); the FHL is now in place (*yellow arrow*) close to the Achilles insertion (*red arrow*) (**f**); inside view of the transferred FHL with the ankle in dorsiflexion (**g**); outside view after wounds are closed (**h**)

sions can be made considering indications, results and possible complications.

15.11 Future Treatment Options

Increased surgical experience accompanied by the development of new tools and fixation devices has enabled an increase in indications and improvement in results of posterior endoscopic approach of the ankle [65].

Increased indications in arthroscopic-assisted fracture repair, assessment of ligaments and tendon injuries are under intense research, and further insights are expected in the near future.

Moreover, tissue engineering and regenerative medicine (TERM) has caused a revolution in present and future trends of medicine and is bringing a new set of therapeutic possibilities [8].

Given the growing experience with posterior impingement surgical treatment, a recent study has proved that the *os trigonum* and/or Stieda's process can constitute a valuable source for bone and cartilage harvesting in selected cases (Fig. 15.14). Viable cells for cartilage tissue engineering approaches have been harvested by this method [9]. This could also overcome some concerns on knee to ankle osteochondral transfer [63] in properly selected patients. Clinical validation of the method is still under research.

Take-Home Message

Since the early twenty-first century, posterior arthroscopic/endoscopic approach has experienced great development.

Posterior impingement and FHL pathology are now frequently addressed endoscopically in most centres.

Arthroscopic-assisted fracture repair despite demands might be helpful in properly selected cases.

Tarsal tunnel syndrome has always been a controversial topic. Endoscopic release might be a minimally invasive option for some patients.

Endoscopic calcaneoplasty is also growing in popularity while also enabling simultaneous privileged access to the Achilles tendon.

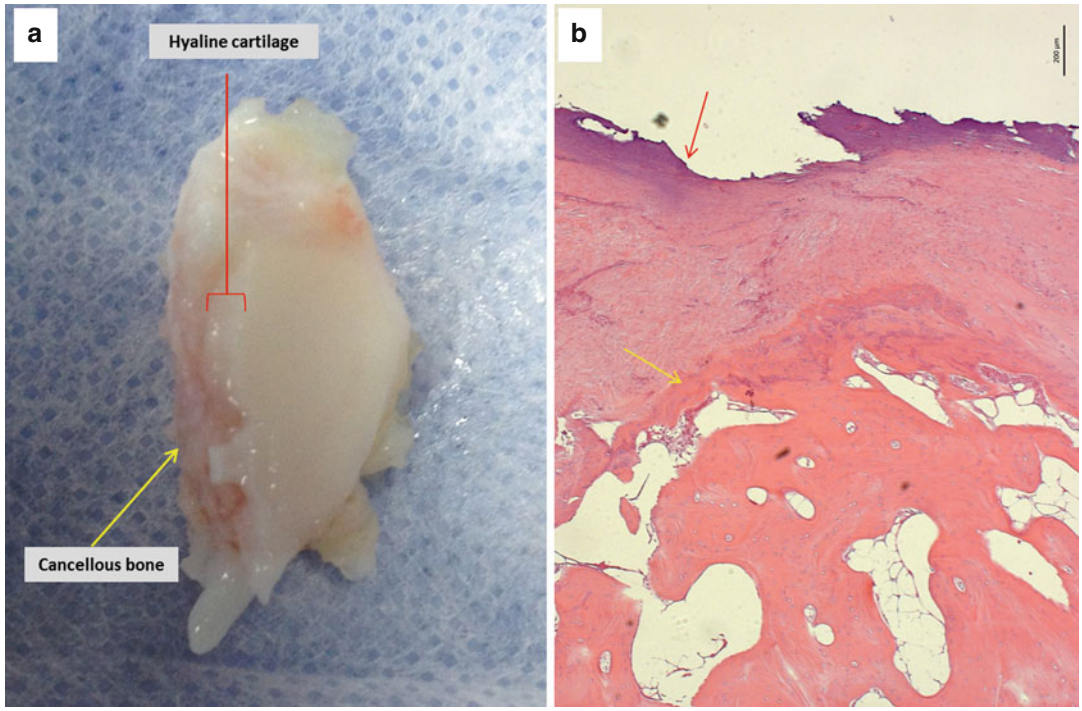

Fig. 15.14 Os trigonum harvested with hyaline cartilage (*red arrow*) and cancellous bone (*yellow arrow*) (**a**). Histologic image of haematoxylin and eosin staining (**b**)

Furthermore, endoscopic FHL transfer is proving to be a valuable resource in selected patients. Basic science research of the posterior compartment of the ankle is also an ongoing concerning anatomy, biomechanics and tissue engineering which might open new possibilities for the future.

This is a fascinating topic. Endoscopy/arthroscopy should be considered as a helpful tool for many situations. However, arthroscopy is not an end in itself. Our obligation is always to find the best approach to deal with our patient's problems while considering our experience and limitations.

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Bony Defects in Revision ACL Surgery (ICL 19)

16

Julian A. Feller, Andy Williams, Karl Eriksson, and Rainer Siebold

16.1 Introduction

Revision ACL reconstruction has been reported to have poorer outcomes compared to primary ACL reconstruction [1–3]. There are many potential reasons for this, including the status of the menisci and articular surfaces. However, if faced with a failed ACL reconstruction, the surgeon needs to understand why the reconstruction failed and what can be done to reduce the risk of failure of the revision procedure. Whatever the cause of failure of the primary procedure, the success of the revision ACL reconstruction relies on obeying all of the principles that one would apply for a successful outcome after a primary procedure. Amongst these is the prerequisite for optimal tunnel positioning in good-quality host bone. This instructional course lecture addresses the specific issue of how to deal with bony defects in revision ACL surgery.

As with any surgical procedure, careful preoperative planning is essential. This includes radiological assessment of bone tunnels to determine both their position and dimension. Malposition of the bone tunnels, particularly the femoral tunnel, is commonly seen in patients undergoing revision ACL surgery. The largest collection of revision ACL cases has been monitored by the Multicenter ACL Revision Study (MARS). In their assessment of failed ACL reconstructions, the MARS group reported that 53 % of the failed reconstructions had identifiable technical errors, of which 80 % were malpositioned tunnels, mainly femoral [4]. Similarly, in a French multicentre study, Trojani et al. reported femoral tunnel malposition in 36 % of patients undergoing revision ACL reconstruction [5]. Tunnel enlargement has been less frequently reported as a cause of failure of ACL reconstruction but is nonetheless a problem frequently encountered during revision surgery. Creation of a new tunnel at the time of revision may also result in confluence with the original malpositioned tunnel, thereby creating a tunnel that is larger than desired. Such situations need to be anticipated preoperatively and strategies devised to address potential scenarios.

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16.2 Radiological Assessment

A number of modalities are available for radiological assessment of bone defects, including plain X-ray, CT and MRI. Plain X-rays can be helpful but are a two-dimensional representation of three-dimensional reality. They are however useful in establishing what metallic hardware is present and alerting the surgeon to possible tunnel malposition or widening. Although being multi-slice and therefore potentially more helpful, standard CT slices are nonetheless also two-dimensional and therefore can be misleading. Reconstructed three-dimensional CT images on the other hand can be very useful in giving a surgeon an accurate assessment of tunnel position and size [6] (Fig. 16.1).

MRI is less able to provide a good representation of bony architecture, but is useful in the setting of a fluid collection. Depending on the situation, assessment of bone quality with vitamin D levels measured on blood testing and DEXA scanning may be appropriate if osteoporosis is suspected.

Each tunnel should be assessed in terms of position and size. The position can be classified as well positioned, very malpositioned and reasonably but not optimally positioned. The size of the tunnel can be classified as enlarged or not enlarged. Well positioned tunnels that are not enlarged and very malpositioned tunnels are essentially 'out of play' and do not pose an impediment to obtaining ideal tunnel position at the time of revision. Reasonably but not optimally positioned tunnels and enlarged well-positioned tunnels pose potential problems at the time of revision and require a planned approach.

If a tunnel appears enlarged, it is helpful to know whether it was drilled to a large diameter at the primary surgery. The shape of the enlargement is important – cylindrical or bulbous. The latter may imply cyst formation, potentially related to use of a resorbable fixation device [7] or mucoid degeneration of graft. It is important to check the maximum tunnel width and where this occurs. The diameter of the tunnel aperture in the joint is of particular concern as excessive widening at this location can have an effect on the quality of the revision graft fixation as well as allowing ingress of synovial fluid into the tunnel. In these situations, special attention needs to be paid to achieving adequate fill of the tunnel at the articular aperture.

16.3 One- or Two-Stage Procedures

The appreciation of lower success rates with revision ACL reconstruction compared with primary cases has led the surgeons considering two-stage procedures for revision ACL reconstruction [8]. The first stage involves removal of fixation devices and graft material plus bone grafting of

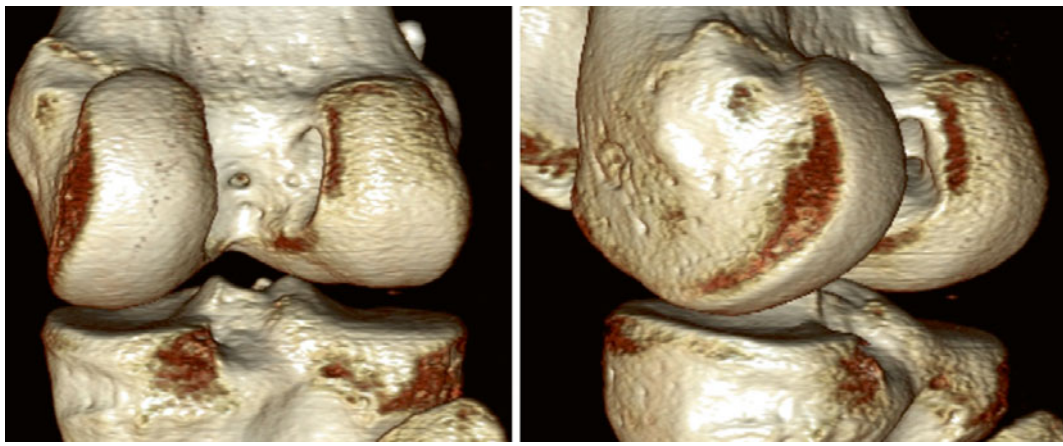

Fig. 16.1 3-D CT reconstructions showing an enlarged femoral tunnel

previous tunnels, with the aim of being able to perform an essentially primary procedure at the second stage. Anecdotally, there appears to have been an increase in the use of two-stage procedures. Although use of a two-stage procedure may well be appropriate, it is not without its disadvantages.

The main problem for patients is the time between the two stages. This interval needs to be long enough to allow adequate incorporation of the bone graft. This can be between 4 and 6 months. Although the patient can weight bear as tolerated after the first-stage procedure, the time involved has significant socioeconomic implications for the patient in terms of time off work, and for a professional athlete, this will effectively mean the missing of another season, which may well prove to be career ending. In addition, the patient is exposed twice to the risks of surgery.

One-stage procedures are therefore attractive but should not result in compromised tunnel position. The potential disadvantages include longer and more difficult surgery, potentially more conservative and slower rehabilitation – although this can also be viewed as an advantage – and possibly poorer fixation and ingrowth of the graft. Strategies to achieve a one-stage revision are discussed below.

16.4 Graft Selection and Modification

It is appears that autograft is superior to allograft and therefore should be used if possible. In the MARS cohort, re-rupture of an allograft was 2.78 times more likely than of an autograft [9]. In the same group, there was no difference in re-rupture between patellar tendon hamstring tendon grafts. Autograft may involve the use of semitendinosus and gracilis hamstring tendons, patellar tendon or quadriceps tendon from the same or opposite knee. Concomitant lateral tenodesis is becoming increasingly used again with the logic of protection of the intra-articular graft during the healing phase and as a secondary restraint to the pivot shift when the patient is fully rehabilitated.

One potential advantage of quadriceps tendon and patellar tendon grafts is the bone block(s) which can be sized to help fill large defects and the strong tendon with physiological insertion to bone. The bone block component of such grafts can be harvested to a large size, and this can be used to fill enlarged tunnels and also to place the tendon component of the graft eccentrically in the tunnel to achieve the preferred position. This can be further assisted by selective positioning of a large diameter interference screw. Additionally, the bone blocked can be flipped and sutured to the soft tissue component to create a shorter and larger graft. Using these strategies, tunnel diameters of up to 15 mm can be accommodated (Fig. 16.2).

However, hamstring tendon grafts are also versatile as they can be manipulated to give a size that is appropriate to requirements by tripling or even quadrupling one or both of the semitendinosus and gracilis tendons. But in the situation where new tunnels can be drilled without encroaching into the old tunnel, an oversized graft should be avoided as larger tunnels have more risk of confluence with the previous tunnels. In such a situation, a simple four-strand graft may be appropriate. The graft can be augmented at either end by wrapping a periosteal flap wrapped around graft [10] to both seal the aperture of the tunnel and augment graft incorporation. If using such a periosteal flap, it is important to understand that the pluripotential stem cells, which have the potential to induce the

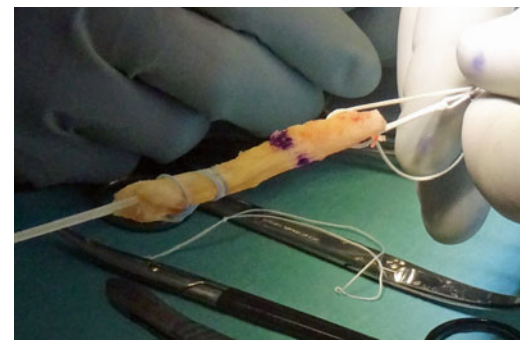

Fig. 16.2 Patellar tendon graft with flipped bone block to the left. This shortens the graft and increases its diameter on the left

formation of bone and cartilage, are in the cambium layer and that this layer must be external on the graft. In general, 12 mm is about the largest tunnel diameter that can be filled with a hamstring tendon graft.

16.5 Bone Grafting of Tunnels

There are a number bone graft options and grafting techniques to address bony defects. Their utility can be considered in terms of their biological activity, their availability and their cost. Options include autologous bone from the iliac crest, proximal tibia or distal femur, allograft and synthetic bone substitutes. Bone can be prepared as dowels, blocks and morcellized bone. Preparation of bone grafts may require specific instruments such as coring reamers.

Although the potential need for bone grafting should be anticipated based on preoperative imaging, it is not always accurate. Having the option of bone grafting is important in revision ACL reconstruction. If this requirement is met, a simple approach is to drill the desired new tunnel and then to assess whether there is confluence with the previous tunnel. If no confluence is present, there is often no need to consider filling the old tunnel with either bone graft or hardware. On the other hand, if confluence is present, this will need to be addressed by one of the strategies described in this chapter. If the tunnel diameter is larger than can be filled by the new graft an appropriate fixation device, bone grafting is necessary. As a rule of thumb, tunnels with a diameter of 15 mm or more should probably be bone grafted.

If a tunnel is to be bone grafted, it is important to ensure that the tunnel walls are cleared of all soft tissue and sclerotic bone. Careful overdrilling or using a microfracture awl to perforated sclerotic bone may enhance incorporation of bone graft (Fig. 16.3).

Grafting of the bone tunnels, particularly as part of a two-stage procedure, does not usually require specific rehabilitation. Rehabilitation is guided by the stability of whatever construct has been used, as well as associated surgery to the meniscal and chondral surfaces. If bone grafting has been performed as part of a two-stage procedure, adequate time needs to be allowed for incorporation of the graft. Most surgeons agree that 4 months is the minimum and that it may be preferable to wait until 6 months to undertake the second stage. Monitoring of graft incorporation is difficult, but an X-ray or CT scan may provide reassurance prior to proceeding to the second stage.

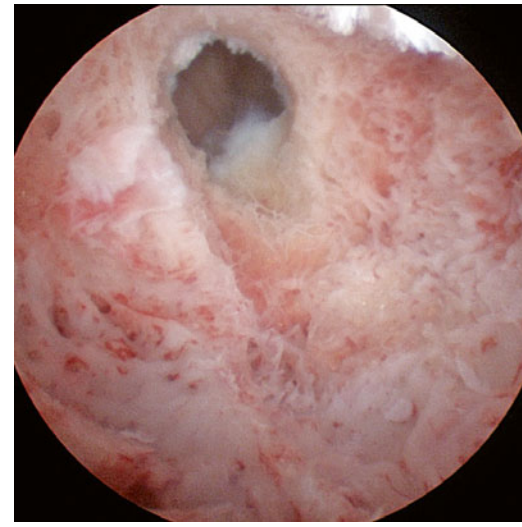

Fig. 16.3 A well-prepared tunnel after removal of all previous graft material

16.5.1 Tibia

If there is confluence between the new an old tunnel, the first consideration is whether this can be dealt with by using a large diameter graft and an appropriately sized and positioned interference screw. If not, some form of bone grafting is appropriate.

One option is to fill the tunnel from the tibial side with morcellized bone using an impaction technique. This may require the use of a curette over the tunnel aperture into the joint to provide a counterforce against which to impact the bone graft, but once there is a compacted plug of bone in the tunnel, this can usually be impacted to the level of the joint under arthroscopic vision. It is unclear whether the new tunnel can or should be immediately drilled or whether it is better to wait for the bone to incorporate and to drill the tunnel at a second-stage procedure. If a decision is made

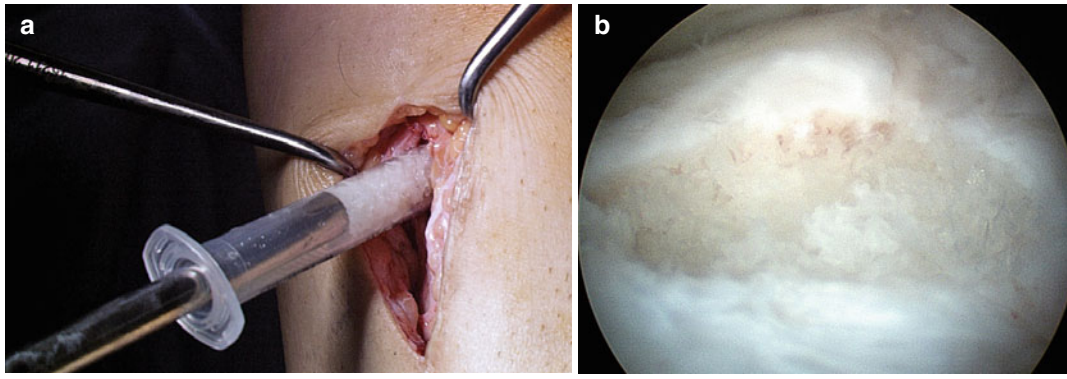

Fig. 16.4 (**a**) Insertion of morcellized graft into the tibial tunnel. (**b**) Arthroscopic view of grafted tibial tunnel

to drill the tunnel at the time of bone grafting, this should be done by initially drilling over a guidewire to a smaller diameter than required and then enlarging the tunnel with sequential impactors. It is helpful to fix the tip of the guidewire in the femur prior to drilling to prevent the guidewire from moving within the tunnel (Fig. 16.4).

An alternative approach to avoid a two-stage procedure is to fill the tunnel with a dowel of allograft bone and to drill through and past the allograft. The concern with this approach is that since the allograft is not incorporated, it may not provide reliable stability for the graft to heal in the tunnel. In such situations, it would be wise to ensure that the interference screw pushes the ACL graft towards the host bone rather than the allograft and that strong and secure fixation is used.

If there is a large defect at the intra-articular aperture, it can be useful to prepare a wedge-shaped bone graft with a drill hole through which a suture is passed. The bone block is placed in the joint with the sutures passing through the tibial tunnel and exiting distally. Once the graft has been inserted, the bone block can be manipulated into position by pulling distally on the sutures and locking the bone block in the desired position.

16.5.2 Femur

Similar principles apply to bone grafting of femoral tunnels. The tunnel can be filled with a dowel or with morcellized bone. If using morcellized bone, the principal difficulty is getting access to the tunnel that allows insertion and adequate compaction of bone. This can be facilitated by using a transparent arthroscopic cannula. It is important that it is in line with the tunnel to be grafted and that it abuts the tunnel entrance. This may require an additional portal and finding the most suitable angle of knee flexion. Bone is then pushed through the cannula and into the tunnel where it can be impacted as necessary (Fig. 16.5).

Alternatively, one or more dowels can be inserted. If only one is used, it is likely to be too large to pass through a cannula and therefore needs to be inserted directly though a portal.

16.6 Avoiding the Need for Two-Stage Procedures

It is the authors' experience that the majority of revision ACL reconstructions can be safely and effectively undertaken in one stage. This can be achieved whilst obeying the basic principles of correct tunnel position and implantation into adequate bone stock. However, it requires careful preoperative planning and having appropriate instrumentation and implants available. In addition, the surgeon needs to be prepared to improvise based on the situation with which they are dealing. As previously described, it is helpful to consider each tunnel as fitting into one of the three categories: well positioned, very malpositioned and reasonably but not optimally positioned. Each tunnel should then be assessed in terms of whether or not it is enlarged to a diameter greater than what can be expected from routine harvest of the chosen new graft.

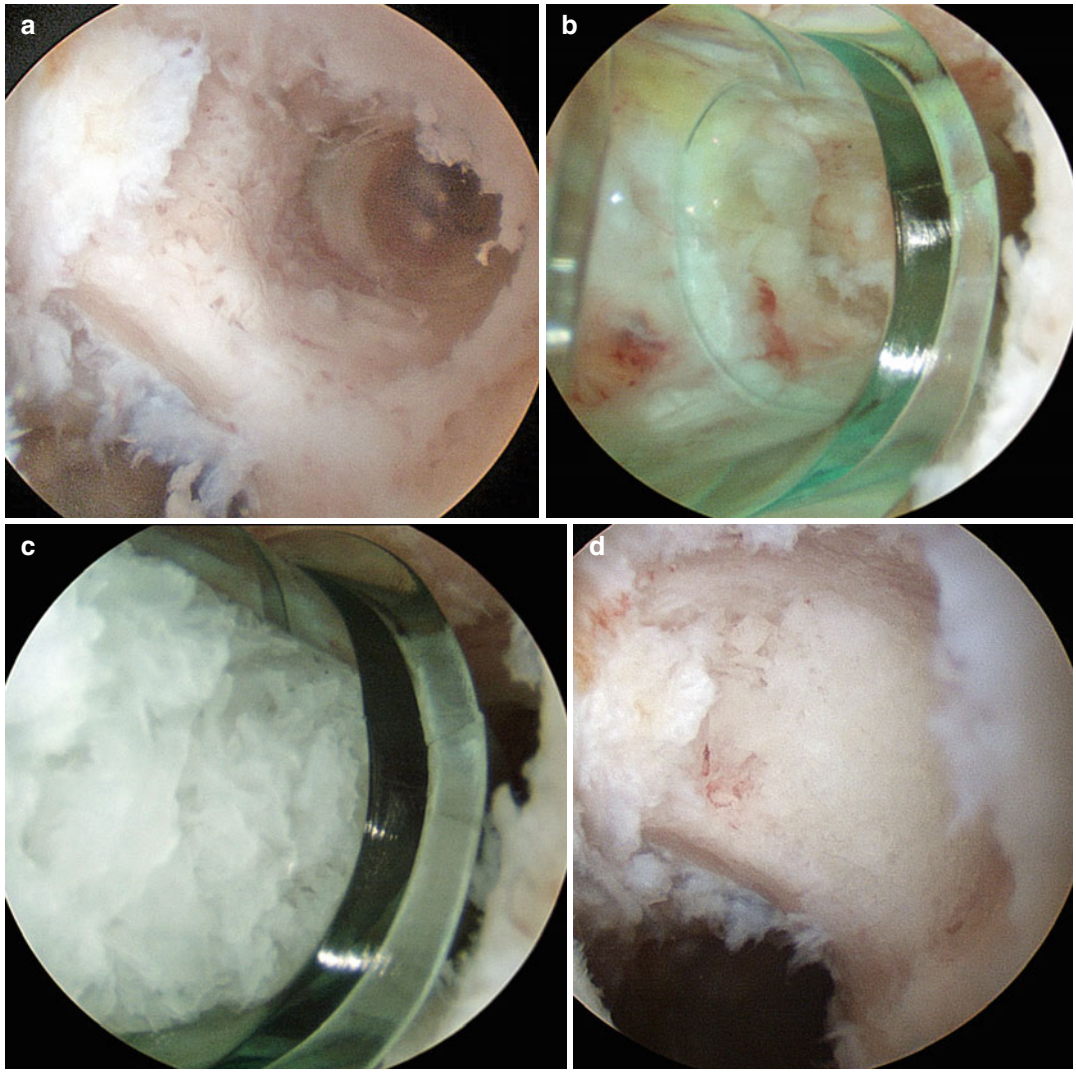

Fig. 16.5 (**a**) Femoral tunnel prior to bone grafting. (**b**) Transparent cannula inserted into tunnel. (**c**) Impaction of bone into tunnel. (**d**) Arthroscopic view of tunnel after bone grafting

16.6.1 Well-Positioned Tunnels

If the previous tunnels are well positioned and, once the hardware is removed, not excessively large, then the revision procedure can be undertaken effectively as a primary one.

If the tunnels are well placed but enlarged, then the use of a large graft (see above) may be appropriate. In addition, the use of metal screws not only provides excellent fixation, but the choice of an oversized screw may fill bony defects of modest size and also allow eccentric placement of a graft within a large tunnel to ensure that graft position is optimal.

16.6.2 Very Malpositioned Tunnels

In many ways, these provide the least challenge as in most new cases, a completely new and 'diverging' tunnel can be drilled to bypass the original tunnel. There is usually no need to remove hardware used in the primary procedure unless it interferes with drilling of the new tunnel

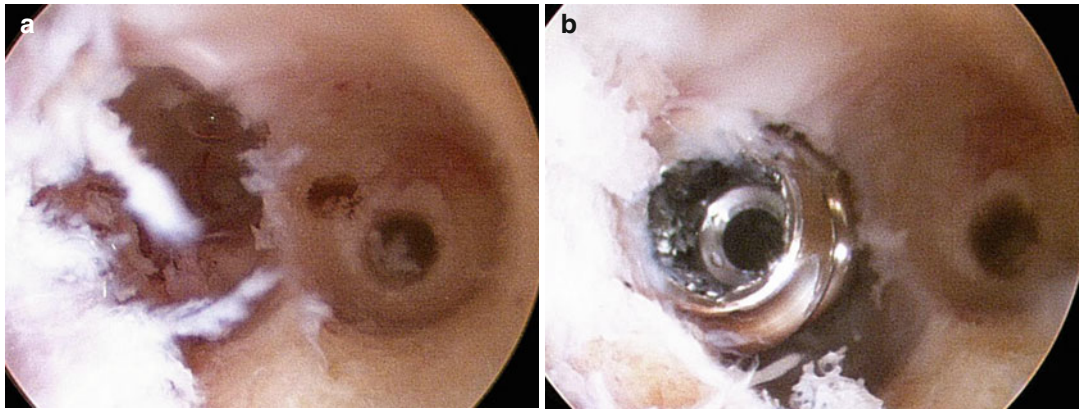

Fig. 16.6 (**a**) Old (*left*) and new femoral tunnels in close proximity. (**b**) Filling of old tunnel with interference screw

or is causing local morbidity. In such a case on the femoral side, one option is to remove the old interference screw to drill the new tunnel and to then replace it in the old tunnel to prevent breaking through the thin bridge of bone separating the tunnel apertures. The position of old hardware should be apparent from preoperative imaging and should be carefully noted, as varying the angle of drilling of the new tunnel can often avoid conflict of the new and old tunnel which contains hardware (Fig. 16.6).

With regard to hardware, one of the frequently stated advantages of bioabsorbable devices for graft fixation is that in the revision situation, one can simply drill through the fixation device without facing the difficulty of its removal. Whilst this is true, such a technique often involves dissemination of bioabsorbable material with the risk of it getting into the joint and causing synovitis or causing direct damage to chondral surfaces, as well as creating unhealthy bone surrounding the new graft. As such, it may be preferable to remove such devices.

As an alternative approach to the malpositioned tunnel, Shino et al. have described using a rectangular tunnel to cope with tunnel malposition but avoid overlap of the tunnels [11]. Two 5 mm tunnels are drilled and connected with a 'box' osteotome. As a result, a rectangular bone block from patellar tendon or quadriceps tendon graft can be placed within a circular tunnel and be stable. If overlap of the tunnels is unavoidable, the gap between the position of the graft and the old circular tunnel can be filled with an interference screw.

16.6.3 Reasonably but Not Optimally Positioned Tunnels

This really represents the main challenge regarding tunnel positioning. It may be possible to deliberately eccentrically ream a new tunnel that pushes the revision tunnel into an optimal position. This will of course increase the magnitude of the tunnel size but this can often be accommodated by a combination of a large graft and larger diameter interference screw than would be normally used in a primary setting.

With regard to a malpositioned tibial tunnel, an excessively posterior position is more difficult to deal with than an excessively anterior one. Although a completely new tunnel may be drilled, its aperture into the joint will be expected to encroach into the previous tunnel. If the original aperture is anterior, then the graft will pull into the more desirable posterior position with tensioning and fixation. However, with a posterior original tunnel, encroachment of the new more anterior tunnel will mean that the graft will tend to move back and forth into the old tunnel and thereby negate the effect of the new tunnel. This situation is an indication for a two-stage procedure.

16.6.4 Alternative Strategies

On the femoral side, if it is clear that an appropriate new tunnel cannot be placed, then the graft can be taken into the 'over the top' position and fixed there, thereby avoiding the old femoral tunnel completely [11, 12].

16.7 Revision Surgery After Double-Bundle Reconstruction

Double-bundle ACL reconstruction aims to reconstruct the anteromedial and posteromedial fibres of the ACL. Many surgeons are worried about revision surgery following double-bundle reconstruction because the technique requires two tibial and two femoral bone tunnels with the potential for significant bony defects. However, as with the revision of a single-bundle reconstruction, the situation depends significantly on the primary surgery. When performed appropriately, the bone tunnels in a double-bundle reconstruction are usually quite small – between 4.5 and 6.5 mm diameter – and separated by a 1–2 mm bone bridge on both the tibia and femur. In such a case, revision surgery may be relatively straightforward. The surgeon may choose to use the same four tunnels and perform a double-bundle reconstruction ACL, using the contralateral hamstrings or an alternative graft source. Alternatively, the anteromedial tunnels can be used to perform a single-bundle revision. This requires over-drilling to a diameter appropriate for the selected graft. Care is required to avoid entering the posterolateral tunnels. Provided there is no confluence, the small posterolateral bone tunnels can be left untouched.

As with single-bundle reconstruction, problematic bone defects can be caused by a number of factors: large bone tunnels from the primary surgery; loss of or a very thin bone bridge between the tunnels; poor tunnel position; cyst formation around resorbable implants, particularly if near the articular aperture; and tunnel enlargement. In such situations, the bony defects may be too large for a one-stage revision surgery, and two-stage approach should be considered so as not to compromise the revision procedure. The situation is then similar to revision of a single-bundle procedure with problematic bone defects, and the same principles of bone grafting apply.

Take-Home Messages

- Whatever the cause of failure of the primary procedure, the success of the revision ACL reconstruction relies on obeying all of the principles that one would apply for a successful outcome after a primary procedure. Amongst these is the prerequisite for optimal tunnel positioning in good-quality host bone.
- Careful preoperative planning is essential. This includes radiological assessment of bone tunnels to determine both their position and size. The position can be classified as well positioned, very malpositioned and reasonably but not optimally positioned. The size of the tunnel can be classified as enlarged or not enlarged.
- The majority of revision ACL reconstructions can be safely and effectively undertaken in one stage.
- If a tunnel is to be bone grafted, it is important to ensure that the tunnel walls are cleared of all soft tissue and sclerotic bone. Good fill of the tunnel is required, and adequate time must be allowed for its incorporation, usually 4–6 months

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Elbow Arthroscopy: From Basic to Advance (ICL 20)

17

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17.1 Elbow Arthroscopy: Setup and Portals

A. Van Tongel

Elbow arthroscopy is becoming more and more popular. Compared to open elbow procedure, this surgical technique has several advantages: able to see better, improved access, magnification (a microscope of the elbow), minimal "collateral damage," less scarring, decreased risk of infection, and less postoperative pain. But it also includes some risks that are more common compared to an open procedure like compartment syndrome and transient or permanent nerve injuries.

A perfect knowledge of the elbow anatomy with a specific focus on the several nerve tracts (ulnar nerve, radial nerve, median nerve, lateral and medial cutaneus antebrachii nerve) is very important before starting with this procedure.

The patient can be positioned supine, prone, or lateral decubitus. Supine can give a good medial and lateral access but a more difficult posterior access. During the procedure, the intra-articular anatomy is more intuitive. The prone position is less used because of the difficulties to position and due to the fact that the anesthetist will have difficulty accessing the airway. The most common used position is lateral decubitus. It eliminates traction and the surgeon can mobilize the elbow through its full range. An important disadvantage of this position is the fact that when standing behind the

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patient and working in the anterior compartment the camera on the screen shows a mirror effect.

After insufflation of the tourniquet, the joint should be distended with normal saline (around 20 cc). This can be done through the lateral soft spot or into the olecranon fossa. During insufflation, the flexed elbow will go into slight extension. Concerning fluid management intraoperatively, gravity-fed fluid inflow or pressure insufflation via a pump can be used (±30 mmHg).

The choice, the order, and the number of portals depend on the surgeon preference and the indication of surgery. It is important to remember that more distal portals are more prone to nerve lesions. Most commonly two to four portals are used for the anterior compartment, two for the posterior compartment and two for the posterolateral compartment. Perioperatively, it is important to have a very low threshold to use an extra portal for retraction. Also the use of the switching stick to switch portals is mandatory to work efficiently.

17.2 Lateral Painful Syndrome

Paolo Arrigoni

The presence of intra-articular findings that may complement extra-articular pathology in lateral epicondylitis has been suggested, but a role for microinstability of the elbow as part of the causative process of this disease has rarely been considered. This study was designed to describe the intra-articular findings in a specific population of patients suffering of lateral elbow pain.

Twenty-eight patients suffering from atraumatic lateral elbow pain unresponsive to conservative treatment and positive to posterior radiocapitellar joint pain and radial head supination pain tests were prospectively enrolled. The presence of capitellar ballottement with annular drive-through sign, synovial plicae, radial head chondropathies, capitellar chondropathies, anterior anteromedial synovitis, anterolateral capsular tears, and laxity of the radial component of the lateral collateral ligament was documented during arthroscopy, and the incidence of the reported findings was calculated.

92.9 % of patients presented at least one intra-articular finding, 82.1 % at least two, 46.4 % at least three. Synovitis was the most common finding (81.1 %), followed by radial head ballottement (42.9 %) and capitellar chondropathy (39.3 %).

The cumulative presence of several intra-articular findings sustains the existence of a pathology of the lateral aspect of the joint based on a minor instability pattern.

17.3 Arthroscopic Management of Epicondylitis of the Elbow

Marc R. Safran

Epicondylitis of the elbow is one of the most common maladies in orthopedic surgery. Lateral epicondylitis, also known as tennis elbow, is much more common that medial epicondylitis, also known as golfer's elbow. Interestingly, in high-level tennis players, medial epicondylitis is more common than lateral. Epicondylitis is a misnomer, because inflammation is not part of the pathology – it is a degenerative process, looking very much like scar tissue, with angiofibroblastic proliferation and neovascularization. Currently, the term tendinopathy and tendinosis are the accepted terms. Lateral epicondylosis involves the extensor carpi radialis brevis (ECRB) and the deeper extensor muscles at the elbow. Medial epicondylosis generally involves the pronator teres and flexor carpi radialis (FCR).

The ECRB may be accessed from within the joint by making a capsulotomy from within the joint proximolaterally. Unfortunately, the pronator teres and FCR, though deep, are not well accessed from within the joint, and with the proximity of the ulnar collateral ligament adherent and beneath those muscles, as well as the ulnar nerve next to the medial capsule and joint, most surgeons will not attempt to arthroscopically or endoscopically address medial epicondylosis. As such, this paper and presentation will focus on the arthroscopic management of lateral epicondylosis.

Nearly one-third of patients with lateral epicondylosis have a tear or rent in the capsule later-

ally before treatment, making the thought of performing a capsulotomy to treat tennis elbow inconsequential. My indications for performing arthroscopic tennis elbow surgery are those with inability to return to usual activities after 6 months of good rehabilitation and one to three injections with corticosteroids. The arthroscopic technique allows for reliable, direct visualization of the pathology, without violating the normal, healthy musculotendinous tendinous overlying the ECRB, and allows for treatment of coexistent pathology that may be seen up to 69 % of the time. Further, as a less invasive procedure, there is better cosmesis, less pain, and more often, quicker rehabilitation. The downside of the arthroscopic approach is there is more of a chance to perform an incomplete debridement, there is a longer learning curve, and there is the risk of iatrogenic injury to the lateral collateral ligament injury (which may also occur with the open technique) and risk of nerve injury. However, staying on the anterior half of the lateral epicondyle and anterior to the midplane of the radial head will help reduce the risk of injury to the lateral collateral ligament.

Several authors have demonstrated excellent results. Grewal et al. found that the outcomes are worse in heavy laborers, those involved with repetitive activity, and patients with worker's compensation claims [5]. Additionally, Oki found that functional recovery may improve for 3 months after surgery and more than 6 months for activity-related pain to be less than 10 [6]. Comparative studies are few. Szabo [7] and Lo [8] found no difference in outcomes when comparing technique for tennis elbow surgery. More recently, Othman found that arthroscopic surgery for lateral epicondylosis had better outcomes when compared to percutaneous technique [9]. A large study of sequential comparison groups found that patients undergoing arthroscopic treatment for tennis elbow had a larger percentage of elbows with excellent outcomes (78 %) as compared with the open technique (67 %), but similar failure rate [10].

There is question as to decorticate the lateral epicondyle as part of this procedure, and recently, Kim et al. found that decortication resulted in increased pain post-op and did not improve outcomes [11].

Arthroscopic management of tennis elbow appears to have several advantages over other techniques and can be performed safely and reliably [12].

17.4 Stiff Elbow

Denise Eygendaal

The elbow can move from 0 to 145° of flexion. Some hyperextension is normal. Pronation and supination range from 85 to 80°. The range of forearm rotation is comparable between both sides, but it is higher in women than in men and inversely correlated with age.

In clinical setting, the contralateral side serves for comparison of flexion, extension, and rotation as the range of motion can vary dependent from age, gender, and constitutional variances [1].

In professional athletes, an extension deficit of up to 10° of the dominant elbow in comparison to the nondominant hand can be noticed.

It has been stated that an elbow needs a minimal range of motion (ROM) of 100° flexion/extension and 100° of pronation/supination to function adequately in daily life.

However in specific groups of patients, as professional athletes, even a slight extension deficit of 10° can result in a dysfunction of the elbow.

Generally the patient notices loss of extension earlier than loss in flexion or rotation. A supination deficit will be earlier noticed by the patient than a limitation of pronation.

Interference, for instance, with daily living activities as eating or hygiene activities is more disabling with limited supination since it may not be compensated sufficiently, whereas the lack of pronation can easily be compensated by abduction of the shoulder and flexion of the elbow [1].

In conclusion the definition of stiff elbow is dependent on the patient, his demands, and the ability to cope with stiff elbow.

In adults, nontraumatic elbow contractures are usually caused by an inflammatory process as osteoarthritis, rheumatoid arthritis, acute or chronic septic arthritis, and periarticular ossifications after head injury.

The elbow is affected more frequently than any other joint by posttraumatic stiffness; the complex anatomy and proximity of tendons, muscles, ligaments, and overlying skin play an important role.

Posttraumatic contractures can be classified into extrinsic (extra-articular) or intrinsic (intra-articular) pathology. The extrinsic contracture involves the skin (skin burns, posttraumatic contracture wounds, or hypertrophic scars), the posterior and anterior capsule, the medial and lateral collateral ligaments, muscles surrounding the joint, and periarticular ossifications. The intrinsic or articular components consist of intra-articular adhesions, cartilage damage, or abnormal anatomy of the articular surface. This is in most patients the result of a trauma resulting in a posttraumatic osseous anatomy.

In most cases, there is a mixture of extrinsic and intrinsic factors as an intrinsic contracture will always result in secondary contracture of extrinsic structures. Extrinsic contracture can possibly lead to intra-articular adhesions or secondary osteoarthritis of the joint.

The exact etiology of the extrinsic of posttraumatic contractures is poorly understood; immobilization resulting in adhesions seems to play a role [3]. Another study has shown an increase of myofibroblasts in the capsule of a posttraumatic elbow [4].

Heterotopic ossification can be a sequel of a traumatic event in which organized bone is formed in the surrounding tissues of the elbow joint. The exact etiology is still unclear; proliferation of mesenchymal cells into the cartilage or osteoblasts after trauma, in the presence of bone morphogenic protein, may play a role [5].

Contractures due to imbalanced muscles as in spastic flexion deformity of the elbow after a cerebral vascular accident or in spastic, hemiplegic children must be carefully assessed by a specialized team consisting of a neurologist, an orthopedic surgeon, and a specialized team for rehabilitation.

History taking is of utmost importance in the work-up of stiff elbow. The details about any traumatic lesion, trauma mechanism, the nonsurgical treatment, or surgical treatment in the past should be known.

The next questions have to be answered before starting an assessment and treatment plan.

- What is the dominant arm?
- What is the occupation of the patient and what are his or her limitations, due to the stiff elbow in daily life, occupation, and sports.
- Is the elbow also painful or is it just a decrease in range of motion that limits the patients in daily functioning?
- Which decrease of movement of the elbow is the most disabling in this particular case?
- Has the loss in range of motion been progressive or stable over the last year?

At physical examination, evaluation must be performed of:

- The skin around the elbow
- Previous surgical or posttraumatic scars
- Neurological evaluation
- Evaluation of muscle strength and voluntary control of muscles
- The bony alignment
- Stability of the elbow joint
- Wrist function especially of the function of the distal radioulnar joint
- Passive and active range of motion in comparison to the uninjured side

Preferably the abovementioned items are registrated in a validated rating system as the Mayo Elbow performance score or the EFA (elbow functional assessment) test [2, 5]. Preoperative imaging consists of standard radiographs of both elbows and wrists.

In intrinsic contractures, CT scan is mandatory in every case, preferably including a three-dimensional reconstruction.

To evaluate the activity of periarticular ossifications, bone scintigraphy can be performed. MRI is in most cases not necessary.

Nonsurgical treatment consists of an appropriate rehabilitation program using (turnbuckle) splints under the supervision of a specialized physiotherapist.

In order to preserve the gain in range of motion after active and passive exercises, splinting can

be used. In the past, dynamic splints that apply a constant tension to the soft tissues over long periods of time (i.e., 12–23 h/day) were popular. However patient-adjusted static braces appear to be more effective although further studies have to be done.

These braces, which use the principle of passive, progressive stretch, are applied for much shorter periods of time and are better tolerated by patients.

Manipulation under anesthesia is, in general, not advised because of possible complications as periarticular fractures, ulnar nerve injury, periarticular ossifications, and elbow instability.

Surgical release is indicated in stiff elbows when nonoperative treatment has failed and function is severely impaired.

The type of surgery depends of the osseous integrity and preoperative range of motion.

If it is mainly a contracture of the capsule, muscles, and ligament, an arthroscopic or open limited approach can be performed. If heterotopic ossification (HO) plays a role, arthroscopic surgery is not indicated and excision of the HO is mandatory in combination with an extended approach.

Different surgical approaches have been described; the choice of type of approach is based on many factors as the site of any previous incision, the presence of neuropathy, and location of periarticular ossifications and intra-articular deformities. The lateral column procedure was first described by Mansat in 1998. The advantage of this approach is the ability to see and treat both the anterior and posterior ulnohumeral and radiocapitellar joint through one incision with preservation of the collateral ligaments. A disadvantage is that patients with an ulnar neuropathy or calcifications in the medial collateral ligament cannot be treated using one single incision; in those cases, a medial approach is preferred. The disadvantage of a medial approach is the risk of injury of the ulnar nerve [7].

Previous reports of the results of surgical release have shown an overall improvement in ROM [8–13].

Mansat and Morrey treated 38 elbows using a limited lateral approach to the anterior and posterior aspects of the capsule. The mean preoperative arc of flexion was 49°. At mean of 3 years postoperatively, the mean arc of flexion was 94°. The mean total gain was 45°. Marti et al. performed a capsulectomy using a lateral approach on 43 elbows, and an additional medial approach was used on 24 elbows to excise ulnar adhesions and perform a more extensive capsulectomy. They achieved an improvement in ROM from 45 to 99°. The rehabilitation program we used in was rather aggressive in comparison to other studies; some mention continuous passive motion and dynamic splinting as risk factors for the development of periarticular ossifications [12]. In our series, using a minimal invasive lateral approach, two patients had minimal periarticular ossifications, in both cases not symptomatic. The ROM was similar at 3-, 12-, and 24 months. Prolongation of physical therapy after 3 months did not improve the functional outcome and probably can be reduced after 3 months [13].

Kelberine published a comparative study between open and arthroscopic arthrolysis of the elbow; the results are almost similar with a significant higher improvement in flexion (7°) in the open group.

17.5 Arthroscopic Treatment of OCD

L.A. Pederzini, E. Tripoli, and A. Cheli

17.5.1 Introduction

OCD is represented by an osteochondral focal lesion that generally involves the capitulum humeri or the radial head with a greatest incidence between 10 and 15 years.

Treatment for stable, early-stage OCD lesions is to avoid repetitive stress on the elbow and observation. If the lesion has not resolved in 6 months, then consideration of surgical management is made [13, 15, 17].

Surgical procedure is indicated for lesions that do not improve with appropriate nonoperative treatment, the presence of loose bodies with mechanical symptoms, or the presence of an

unstable lesion. There are different operative procedures that have been described for treating OCD, including fragment removal with or without curettage or drilling of the residual defect, fragment fixation by a variety of methods, drilling of the lesion, closing-wedge osteotomy of the lateral condyle, reconstruction with osteochondral autograft, and autologous chondrocyte implantation.

The surgical method is generally planned preoperatively using radiography and MRI, but the surgical procedure is finally decided according to arthroscopic findings and/or direct confirmation of the lesion during operation.

Arthroscopic surgery has become the standard procedure for the treatment of capitulum OCD [18–21]. It offers the advantage of assessing the extent of the disease inside the joint and the ability to treat the lesion and remove loose fragments at the same time.

This minimally invasive approach reduces the risk of operative morbidity from a surgical incision and allows the patient to start regaining range of motion early after surgery. Studies on arthroscopic treatment for OCD of the elbow have shown encouraging results with intermediate follow-up. However, long-term results still need to be evaluated [17, 18, 21].

In small or stables or in chronic lesions when refixation is impossible or larger osteochondral defects exceeding 1 cm^2 impossible for refixation or in larger osteochondral defects exceeding 1 cm^2 drilling and debridement represent good surgical options [17–19, 21].

17.5.2 Surgical Technique

The anesthetist identifies nerve trunks by applying electrostimulation and places a catheter without injecting the anesthetic. Patients then undergo general anesthesia. When they wake up, only after a neurological evaluation, peripheral block is performed. After the induction of anesthesia, ROM is carefully assessed and a complete ligamentous balancing is carried out. A well-padded tourniquet is placed proximally around the arm. The limb is exsanguinated and the tourniquet insufflated to approximately 250 mmHg.

The patient is then placed in lateral decubitus but can also be placed in the prone position depending on the surgeon's preference and experience, with the shoulder abducted 90°, the elbow flexed to 90°, and the arm held up by an arm holder secured to the operating table.

Sterile field is set up and elbow joint landmarks are drawn by a dermographic pen (medial and lateral epicondyle, ulnar nerve, radial head, posterior soft spot). Soft spot posterior portals and supero-anteromedial and supero-anterolateral portals are marked.

An 18-gauge needle is inserted in the elbow through the "soft spot" in the middle of the triangular area delimited by the epicondyle, the radial head, and the olecranon, while the joint is distended by injecting 20–25 mL of normal saline through the lateral soft spot. Joint distention displaces the volar neurovascular structures more anteriorly to help protect against iatrogenic injury during portal creation and instrumentation.

Five portals, three posterior and two anterior, are always used. After the incision is made, soft tissues are retracted by using a fine hemostat.

Posterior compartment arthroscopy is firstly performed by introducing a 4-mm 30° arthroscope or a 2.7-mm arthroscope (this may be required for the smaller adolescent patient) through the posterolateral portal (soft spot). Then a second portal is established, 1.5 cm proximal to the latter. These two portals allow to use the scope and the shaver at the same level of the posterior portion of the radial head.

Joint distension is achieved by a pump set at 35–50 mmHg. Once we get a good and complete view of the proximal radioulnar joint (posteriorly), a third posterior portal is placed in the olecranon fossa, close to the triceps medial border and oriented 2–3 cm proximal to the olecranon tip. When we have a good view of the joint, we can perform many different operative procedures including drilling of the lesion, fragment removal with or without curettage of the residual defect, or fragment fixation by a variety of methods.

After evaluating the posterior compartment, anterior compartment inspection is carried out in order to have a good view of the entire joint and to treat associate pathologies. The proximal medial portal is created approximately 2 cm proximal and 1 cm anterior to the palpable medial epicondyle. After the skin is incised, a straight hemostat is usually used to spread the subcutaneous tissues to help prevent injury to the crossing sensory nerves. A blunt trocar is inserted through the proximal medial portal aiming toward the center of the joint while maintaining contact with the anterior humeral border. The anterior compartment of the elbow is evaluated while viewing from the proximal medial portal. A proximal lateral portal is created using an in-out. This portal is approximately 1–2 cm proximal to the lateral epicondyle along the anterior humeral surface. Any associated synovitis is removed with a small, motorized shaver. If present, loose bodies are retrieved with a grasper. The anterior radiocapitellar joint is inspected, with evaluation for any potential cartilage softening or fragmentation. Lesions present on the anterior capitellum are probed. If a large lesion is present with attached bone, fixation can be performed with fluoroscopic assistance. Smaller fragments and purely chondral lesions are debrided with a small full-radius shaver. All affected and unstable cartilage is removed. Next, the arthroscope is placed in the proximal lateral portal to complete the full evaluation of the anterior compartment [17, 18, 21].

Thorough inspection of the capitellum is achieved through the posterior lateral, the direct lateral, and an accessory direct lateral portal. The second direct lateral portal is created under direct visualization after needle localization. In a cadaveric study, Davis et al. [16] reported that 78 % of the entire capitellar surface area was accessible through the dual direct lateral portals. Both portals remained safely proximal and posterior to the lateral ligamentous complex.

All unstable cartilage of the lesion is removed with a combination of a grasper and shaver to a stable bed. A ringed curette assists in creating a stable, perpendicular rim of healthy surrounding cartilage. After the calcified cartilage layer of the lesion bed has been removed, we create microfractures in the lesion bed. Using arthroscopic awls, the subchondral plate is usually penetrated to a depth of 2–4 mm approximately 3 mm apart, beginning at the periphery of the lesion. The inflow is then turned off to verify the efflux of blood and marrow elements from each microfracture hole.

Reports of arthroscopic treatment of OCD of the capitellum with removal of loose bodies, debridement, and abrasion chondroplasty describe overall improvements in pain and range of motions with variable return to pre-injury level of sporting activity [14, 17].

More recently some authors [17, 21] are preferring to use an arthroscopic mosaicplasty (from lateral knee trochlea to capitulum humeri) in order to completely restore the joint surface possibly avoiding a later osteoarthritis.

The patient is then placed in lateral decubitus extrarotating the hip, with the shoulder abducted 90°, the elbow flexed to 90°, and the arm held up by an arm holder secured to the operating table.

We performed an arthroscopic mosaicplasty taking the graft from the homolateral knee, performing knee arthroscopy. The patient is placed in a lateral decubitus position and hip extrarotation in order to approach arthroscopically the homolateral knee to remove the osteochondral cylinder of the lateral femoral trochlea. Two posterior lateral portals in the posterior soft spot of the elbow allow the identification of the OCD and its preparation in accordance with the technique to insert the osteochondral cylinder.

The 6.5-mm cylinder graft taken from the lateral knee trochlea was inserted in the elbow lesioned area carefully checking the angle of the drilling and of the insertion of the bony-cartilaginous cylinder. Arthroscopically the perpendicular insertion of the cylinder allows a complete coverage of the OCD area. The cylinder press fit makes the graft stable.

At 4 months later MRI shows a nice bone incorporation of the graft. Postoperatively the cpm started in day 2 and passive exercises in day 4 post-op. Patients were back to normal activity in 4 months [17].

17.6 Elbow Joint Instability

L.A. Pederzini, E. Tripoli and A. Cheli

Elbow joint is composed from endings of three long bones: the distal humerus, proximal radius, and ulna. The elbow is one of the most congruent and stable joints of the human body. The main reasons for that are almost parallel bony components of joint surfaces and very solid soft tissue stabilizers – lateral and medial collateral ligaments and anterior capsule.

Lateral collateral ligament and anterior bundle of medial collateral ligament start from the endpoints of axis of rotation of the elbow joint.

Medial collateral ligament has two components: the anterior bundle taut in extension but its posterior bundle is taut in flexion. The lateral collateral ligament showes rather constant tension during all activities and functions with or without the radial head; the central part of it called the lateral collateral ulnar ligament attaches to the ulna, thus stabilizing the ulnohumeral joint and, together with posterior and anterior capsule, controlling the pivot shift maneuver.

Muscles crossing the elbow joint also play an important role in dynamic stability. The muscular forces across the elbow compress the irregular but congruous joint surfaces against each other.

The elbow, after the shoulder, is the second most commonly dislocated major joint in adults and the most common among the children. Dislocation may occur as a result of a single event such as a fall from the bike on an outstretched hand, or it may be a summary of repetitive stresses resulting in laxity as a consequence of repeated valgus force, such as with throwing in the overhead athlete.

There are three main mechanisms of injury to the elbow: valgus, posterior translation, and posterolateral rotatory mechanisms. The valgus stress mechanism is the most common and high-incident injury. Injury to the elbow medial collateral ligament (MCL) from valgus repetitive forces was first described in 1946 by Waris in a javelin thrower [22].

Josefsson and Nilsson analyzing 178 acute elbow dislocation demonstrated a peak incidence in the 10–20-year-old age group with approximately ten dislocations per 100,000 and in the 50–60-year-old age group an incidence of 4 per 100,000 [23].

Elbow dislocations might be classified by their direction, presence of associated, fractures, and the timing (acute, chronic, or recurrent).

If elbow dislocation occurs without fracture, it is referred to as a "simple dislocation." It is a surprisingly rare condition, because when meticulous diagnostic studies are performed, minor avulsion fractures of several millimeters from the medial and lateral epicondyle regions or of the coronoid tip occur. When acute dislocations are associated with significant fractures, they are classified as "complex dislocations."

Complex elbow instability consists of a dislocation of the ulnohumeral joint with a significant fracture of one, or several, of the bony stabilizers of the elbow. These include the radial head, proximal ulna, coronoid process, or distal humerus. Following this type of dislocation, there is frequently a tendency to chronic instability and an increased incidence of posttraumatic arthrosis.

X-ray of both elbows is mandatory; in a case of any doubts – CT or MRI are advocated, because even minor fracture, for instance, of the coronoid might be the only sign of posteromedial rotatory instability. In children – both elbows should be investigated, to distinguish the epicondyle epiphysiolysis.

In acute settings, dislocations without important associated injuries might be treated by simple reduction and the arm cast or hinged brace, in majority of cases in pronation.

In delayed cases, more than 10 days – an open approach is preferred.

Long-standing, chronic cases of an open reduction and ligament reattachment or reconstruction are advocated. Special attention is paid to ulnar nerve free gliding.

Associated injuries have to be treated as well at the same time and conditions for early protected motion created.

Complex instability of the elbow is defined as an injury that destabilizes the elbow because of damage to the articular surface.

The clinical investigation should be performed in patient relaxed, in supine position, for valgus

and varus instabilities – with the elbow extended, for posterolateral rotatory instability using lateral pivot-shift as described by O'Driscoll should be performed. Sometimes it needs general anesthesia. In symptomatic cases – an operative treatment is advocated.

17.7 Nerve Compression Around the Elbow

A. Mehmet Demirtaş and M. Derviş Güner

The elbow joint is under repetitive muscle activity and subjected to multidirectional forces. These forces may cause joint instability. Longitudinal stresses and fascial restraints make nerve compression more likely. The athletes and manual workers who perform heavy and repetitive actions have higher risk of nerve compression.

Ulnar, median, and radial nerve crosses the elbow joint, and they are vulnerable to trauma as the muscle and subcutaneous fat is not bulky enough to absorb the energy. Increased pressure around the nerve due to inflammation or vascular aberrations, abnormal fascial bands, boney prominences, and muscular variations may cause nerve compression.

Pain, sensory loss intermittent at the early stages, and weakness are the symptoms. The prognosis is usually excellent if proper treatment decompression has been performed before irreversible damage has occurred.

17.8 Ulnar Nerve Compression at the Elbow

17.8.1 Cubital Tunnel Syndrome

Cubital tunnel syndrome is the most common entrapment condition of the ulnar nerve. Following carpal tunnel syndrome, cubital tunnel syndrome is the second most common compressive neuropathology of the upper extremities.

Ulnar nerve entrapment results from both pathologic and physiologic responses to repetitive trauma. Mechanical factors include compression, traction, and irritation of the nerve. Compression of the ulnar nerve proximal to the cubital tunnel may be due to a tight structure (arcade of Struthers or intermuscular septum) or to hypertrophy of an adjacent muscle (anconeus epitrochlearis or medial head of the triceps). Compression at the level of the cubital tunnel may result from osteophytes, loose bodies, synovitis, or a thickened retinaculum (Osborne lesion). Compression can also occur distal to the cubital tunnel at the FCU aponeurosis or at the deep flexor-pronator aponeurosis after the ulnar nerve passes between the two heads of the FCU. Occupational related causes account for 30 % of cases. Careful neurologic evaluation of the upper extremity is mandatory to rule out more proximal causes of neuropathy. Percussion along the ulnar nerve may elicit Tinel's sign. Diagnosis of cubital tunnel syndrome is based on a combination of clinical findings and electrodiagnostic test findings.

There is a tendency for spontaneous recovery in patients with mild and/or intermittent symptoms if provocative causes can be avoided. Numerous surgical techniques have been described for the treatment of cubital tunnel syndrome, including simple in situ decompression of the cubital tunnel, anterior transposition of the ulnar nerve (subcutaneous, submuscular, or intramuscular), and medial humeral epicondylectomy with decompression of the ulnar nerve; however, there is a lack of consensus concerning which technique is superior. Endoscopic decompression [24–31] is as effective as open decompression and has the advantages of being less invasive, utilizing a smaller incision, producing less local symptoms, causing less vascular insult to the nerve, and resulting in faster recovery for the patient [32].

17.9 Median Nerve Compression at the Elbow

The median nerve is the least frequently entrapped nerve at the elbow. Compression might be caused by the ligament of Struthers, the lacertus fibrosus, the pronator muscle and its fibrous compo-

nents, or the fibrous proximal margin of the flexor digitorum superficialis muscle. Median nerve compression at the elbow is called pronator syndrome and anterior interosseus nerve syndrome.

17.9.1 Pronator Syndrome

Pronator syndrome mimics the symptoms of carpal tunnel syndrome; it is often missed or confused. As the nerve compressed at a more proximal location, forearm tenderness and pain is the main symptom. The pain is aggravated by forceful use of the extremity, especially involving pronation. Hypoesthesia of the median dermatome, weakness, or clumsiness is often noted. These symptoms are similar to those seen in carpal tunnel syndrome. In pronator syndrome, night pain is unusual while carpal tunnel syndrome may awaken patients. Tinel's sign may be present. Weakness in thumb flexion and pinch strength and atrophy in the thenar muscles may be noted in advanced cases. Loss of sensation in the palmar cutaneous nerve distribution (mid-palm and thenar skin) suggests compression proximal to the carpal canal. Lacertus fibrosus provocation like hyperflexion of the elbow past 120° with resistant forearm supination may reproduce forearm symptoms if the nerve is compressed by this structure. Resisted forearm pronation with the elbow flexed followed by elbow extension that increases symptoms suggests the pronator teres as the site of median nerve compression. Radiographs are necessary to rule out supracondylar process in the distal humerus or any bone pathology. Electrodiagnostic studies (EMG/NCS) are rarely diagnostic. They may be helpful in excluding coexisting pathology and may implicate other causes of nerve compression.

17.9.2 Anterior Interosseus Nerve Syndrome

The anterior interosseus nerve is the branch of the median nerve 5 cm distal below the medial epicondyle and then passes posteriorly through the two heads of the flexor digitorum sublimis muscle. The anterior interosseus nerve has no sensory component; numbness is not associated with this syndrome. Anterior interosseus nerve innervates the flexor pollicis longus, pronator quadratus, and the flexor digitorum profundus of the index finger. This causes weakened index finger-thumb pinch. In contrast to pronator syndrome, pain may be elicited by resisted flexion of the flexor digitorum sublimis of the long finger and may also be present at rest and on local palpation of the nerve. EMG/NCS may be diagnostic in anterior interosseus nerve syndrome. The initial treatment for median nerve compression is conservative. Surgical release is performed either open or with endoscopic assisted methods. Full recovery may take as long as 6 months even after surgical decompression. If there is severe nerve damage, recovery may take longer and may be incomplete.

17.10 Radial Nerve Compression at the Elbow

Radial tunnel syndrome is often confused and thought to be tennis elbow (lateral epicondylitis). One of the more difficult diagnoses to make in the upper extremity is distinguishing between radial tunnel syndrome and lateral epicondylitis.

The radial tunnel syndrome results from dynamic compression of the posterior interosseus nerve in its course from the anterior capsule of the elbow joint proximally to the arcade of Frohse distally.

Symptoms include deep, dull proximal dorsal forearm ache, often with distal radiation. The pain is often described as a cramp. Night pain is common. Sensory loss over the dorsoradial aspect of the second metacarpal head suggests radial sensory branch involvement. Motor findings are usually absent. Symptoms are aggravated by resisted supination and extension, resisted extension in the metacarpophalangeal joint of the long finger with the wrist extended, and repetitive forearm pronation with the wrist flexed. EMG/NCS is not helpful in confirming the diagnosis but may be useful in identifying coexisting pathology. Injections

into the lateral epicondylar area can sometimes help differentiate radial tunnel syndrome from lateral epicondylitis. Conservative treatment is attempted in most cases. Efforts should be made to modify patient activity to avoid provocative positioning of the arm. Ergonomic evaluation should be completed to modify the offending task or job. Task that requires elbow extension, forearm pronation, and wrist flexion repetitively or for long periods of time contributes to the development of radial tunnel syndrome.

Initial treatment should include rest, stretching, and splinting. Surgical intervention may be considered if the symptoms are not relieved by rest, activity modification, nonsteroidal anti-inflammatory medication, or a corticosteroid injection. Before considering surgery, precise localization of the pain to the radial tunnel must be confirmed.

17.11 Future of Elbow Arthroscopy

Roger P. van Riet

Despite the obvious risk of complications, elbow arthroscopy has become a common procedure. It can be performed safely with low risk of complications [33–35]. However complications, such as permanent nerve injury, are probably underreported [36–40], as larger series have always been published by experts in the field. The proximity of neurovascular structures may limit the extent of what will be possible with elbow arthroscopy in the future.

Common indications include removal of loose bodies, debridement and drilling of OCD lesions, synovectomy, capsulectomy, removal of osteophytes, and the treatment of lateral epicondylitis [41].

Less common and sometimes challenging procedures include arthroscopy for the treatment of intra-articular fractures [42], ulnar nerve release [32, 43, 44], bursectomy [45], and ligament [46] and tendon repair [47]. Many of these have been described years ago, but should still be included in the future of elbow arthroscopy.

17.12 Biceps Endoscopy

Biceps endoscopy can be used for partial or full tendon ruptures. The greatest advantage lies in partial tendon ruptures as this technique allows for the biceps insertion to be evaluated atraumatically with an enlarged view, which is not possible with an open technique. The decision to debride, repair, or reconstruct can be made on the basis of the endoscopic view and can be performed safely at the same time, with the use of retractors. Care should always be taken to avoid injury to the anterior neurovascular structures of the antecubital space. A potential specific disadvantage is excessive swelling of the forearm, due to the irrigation fluid that is used.

17.13 Lateral Collateral Ligament Repair or Imbrication

A lateral collateral ligament reconstruction requires a large incision and complications, such as elbow stiffness, are not uncommon. In fact, most patients will loose some degree of their motion [48]. An arthroscopic technique will allow the surgeon to evaluate the entire intra-articular joint space and to address any other intra-articular pathology at the same time, without the need for a larger approach or additional incisions. The arthroscopic technique can be challenging due to difficulty in precisely locating the position of anchors or bone tunnels, but a simplified technique has been shown to have excellent results [49].

17.14 Trauma

Intra-articular fractures are amendable to arthroscopically assisted or all arthroscopic reduction and fixation. Arthroscopic treatment of radial head fractures [50], capitellar shear fractures, and trochlea fractures [42, 51, 52] have all been reported, but arthroscopy is particularly helpful in the treatment of coronoid fractures. Arthroscopic reduction and screw placement can be done very precisely, without the need for a medial incision, therefore decreasing the

morbidity that is common with open reduction and internal fixation of coronoid fractures.

A thorough understanding of the anatomy of the elbow is essential in order to forward the field. Besides this, elbow arthroscopy requires a specific skill that will only be acquired with experience. Patients always need to be informed of the possible complications before surgery is performed. When a surgeon is at the beginning of the learning curve, the patients also need to be informed that arthroscopy is a means to an end and not a goal as such. Although this is hardly ever necessary, if arthroscopy cannot be performed safely, a conversion to an open procedure should be contemplated. Only if these circumstances are met, the surgeon will be able to perform more advanced procedures and decrease the chance of complications.

The future of elbow arthroscopy therefore lies in two fields. Firstly, common procedures need to be simplified and standardized, so that they can be done safely, even in less experienced hands. Simple tricks, such as positioning of the patient, portal placement, and pressure of the irrigation, are crucial. The use of specialized and specific instrumentation greatly helps the surgeon. A "distal outflow only" cannula and retractors are examples of instruments that should be more available than they are now.

Besides optimizing existing procedures, the future will also hold an increase in indications. Especially soft tissue procedures and arthroscopy in elbow trauma hold great promise. Some advantages and disadvantages will be discussed for selected procedures.

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Complications in Rotator Cuff Treatment (ICL 21)

18

Wolfgang Nebelung, Bruno Toussaint, Eduard Buess, Karsten Labs, Leo Pauzenberger, and Philipp R. Heuberer

18.1 Introduction

Arthroscopic rotator cuff reconstruction (ARCR) is a challenging operative procedure in the treatment of symptomatic cuff tears. The literature does not consistently report on surgical complications after this procedure.

The work of a Switzerland group around M. Flury and L. Audige serves as the basis for developing a standardized definition of complications and a uniform documentation process of complications in ARCR. An ongoing project defines a minimum complication list (i.e., a core set) to be applied after surgery. The main fields of possible complications are:

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1. Intraoperative surgical problems with instruments, anchors, sutures, or the arthroscopic pump, and bleeding, extravasation, or surgical damage of vessels or nerves.
2. Anesthesiological problems with high or low blood pressure, edema, or nerve damage by nerve block anesthesia, problems with patient positioning.
3. Postoperative stiffness. Loss of motion can be a main factor for the clinical outcome.
4. Postoperative infections.
5. Postoperative retears. Not all reconstructed tears heal.
6. Postoperative neurological deficiencies.

The complication rate after revision ARCR is about twice the published rate for primary rotator cuff repair. There is a direct correlation between the complication rate and the number of revision surgeries.

18.2 Arthroscopic Revision of Failed Rotator Cuff Reconstruction

Eduard Buess

Retears after ARCR (arthroscopic rotator cuff repair) occur frequently, i.e., in 10–30 % of small to medium and in 30–50 % of big to massive tears. In the case of a symptomatic patient (unable

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Table 18.1 Typical failure mode for each repair technique

Single row	Retear (or failure to heal) at tendon footprint
Double row	Subacromial knot impingement
	Tear at medial anchor location (central cuff failure)
Suture bridge	Central cuff failure (with intact tendon tissue at footprint)
	Loss of lateral fixation

to return to previous work or sports activities) 4–6 months after a rotator cuff repair (RCR), we routinely perform an MRI. This provides excellent information about the healing of the cuff. We have to beware of artifacts and high-signal areas inside the tendon that can be an expression of the normal healing process and tend to disappear with time. Quite often we will discover a defect in the reconstructed cuff, which can be understood either as a re-rupture, a failure to heal, or – most frequently – an incomplete healing. The risk factors are well described in the literature [10]. Open revision has sometimes produced disappointing results; however, arthroscopic revision seems to be more successful in recognizing and treating the multiple pathologies. Our personal experience with 57 revision cases has been described earlier [3]. The revision rate has dropped from 4.5 % to 3.1 % of all RCR cases with better technique, better implants, and growing experience of the surgeon.

Each repair technique has its typical failure mode (Table 18.1) ranging from retear at the footprint, central cuff failure [5, 30], to failure in continuity [18]. Double-row and suture-bridge repairs are prone to overstress the tendon, which seems to be the main issue of failure.

The AGA (German-speaking society for arthroscopy and joint surgery) started a prospective multicenter study in 3/2012 entitled "Results of arthroscopic revision for re-rupture or failure to heal after open and arthroscopic RC-reconstruction." Ten shoulder centers participated and data of 112 patients have been collected. Follow-up includes the subjective shoulder value (SSV), the Oxford shoulder score (OSS), and constant score (CS) at 6 and at 24 months. At 24 months the integrity of the repair is verified by MRI. Preliminary results are shown in Table 18.2.

Table 18.2 Preliminary results of the AGA multicenter study of revision cases after failed rotator cuff repair

	CS (max 100 P)	OSS (max 48 P)	SSV (max 100 %)
Preop ($n=96$)	42	25	44 %
6 months ($n=63$)	57	34	66 %
24 months ($n=16$)	72	40	76 %

Outcome was better ($p=0.04$) for patients with an arthroscopic compared to an open revision. We also found a gender specific difference ($p=0.04$) with higher improvement of the CS in men than in women. However no influence of age, tear size, subscapularis involvement, or cartilage damage on the outcome could be detected so far.

18.3 Postoperative Shoulder Stiffness After Rotator Cuff Repair

Karsten Labs

18.3.1 Incidence

Surgical repair of full thickness rotator cuff tears is well accepted. Even though most patients enjoy satisfactory functional recovery after rotator cuff repair, studies still report considerable complications.

Postoperative shoulder stiffness (POSS) is an acquired loss of motion, occurring after a known surgical or traumatic event. Biomechanically, a stiff shoulder is one in which at least one of the shoulder as motion interfaces has been compromised, thus, limiting maximal excursion. The definition of what POSS is remains controversial, with a wide variability in its definition.

Denard et al. [9] saw an incidence of transient stiffness responsive to nonoperative management in 10 %. The incidence of resistant stiffness that was permanent or required capsular release was 3.3 %.

Huberty et al. [12] defined stiffness as patient dissatisfaction, and patients who judged as having a disabling lack of shoulder motion were regarded as having a stiff shoulder. On the basis

of this definition, Huberty et al. [12] found that 24 of 489 patients (4.9 %) developed postoperative shoulder stiffness after rotator cuff repair at a mean of 8 months.

Brislin et al. [2] applied a definition of stiff shoulder as a forward flexion of less than 100°, or external rotation with the arm at the side of less than 10°, or external rotation with the arm in 90° abduction of less than 30° and found postoperative shoulder stiffness after arthroscopic rotator cuff repair in 23 of 268 patients (8.6 %) within 3 months.

Similarly, Parsons et al. [24] defined shoulder stiffness as passive forward flexion of less than 100° and external rotation of less than 30° and showed that 10 of 43 patients (23 %) had a stiff shoulder at 3 months.

The incidence of postoperative stiffness in the study of Chung et al. [7] was 18.6 % (54/288) at 3 months, 2.8 % (8/288) at 6 months, and 6.6 % (19/288) at final follow-up.

Cameron et al. [4] reported a 32 % incidence of significant persistent postoperative stiffness after mini-open rotator cuff repair.

It accounts for one of the most common complications following surgical repair of the rotator cuff. Management of POSS is important as it can severely limit the activities of daily living.

18.3.2 Etiology

The stiffness arises from a capsular contracture and postsurgical adhesion to the surrounding soft tissues. Although there is still debate, several factors, such as preoperative shoulder stiffness, diabetes mellitus, operative technique (e.g., open or mini-open repair), prolonged immobilization, and decreased compliance with a postoperative rehabilitation program, have been suggested as causes of postoperative stiffness.

There remains a lack of consensus in regard to the etiology and prevention of POSS.

18.3.3 Risk Factors

Overall, tear size appeared to affect the development of transient or resistant stiffness. One study reported that patients with tears measuring less than 3 cm were more likely to have transient stiffness, although the difference did not reach statistical significance with the sample size of 43 patients. In the two larger studies, there was a trend ($P=0.08$) toward stiffness in smaller tears [2] and significantly higher rates of stiffness in partial articular-sided tears versus 3- or 4-tendon tears (13.5 % versus 2 %, $P<0.05$) [12]. Both studies analyzed fixation techniques and did not observe a relation to stiffness. Additional statistically significant risk factors for stiffness were described in one study and included workers' compensation (8.6 %), age less than 50 years (8.6 %), calcific tendinitis or adhesive capsulitis (15.6 %), or concomitant labral repair (11 %) [12].

Older age is an important risk factor for postoperative stiffness throughout the follow-up period. Early postoperative stiffness is affected by preoperative stiffness. However, late postoperative stiffness, especially newly developed stiffness, is closely related to a retear and significantly worse functional outcome after surgical repair.

When a patient complains about newly developed stiffness in the late postoperative period, a retear should be considered.

However, other surgical procedures including repair technique, SLAP repair, biceps tenotomy, biceps tenodesis, and distal clavicle resection did not affect postoperative shoulder stiffness [7, 12].

18.3.4 Treatment

Two articles focused on preoperative stiffness in patients undergoing arthroscopic rotator cuff repair (ARCR). Tauro [29] retrospectively categorized 72 patients with full-thickness tears undergoing ARCR into having a mild (0–20°), moderate (20–70°), or severe (>70°) deficit in total preoperative range of motion. No capsular releases were performed at the time of ARCR. Final deficits in each plane of motion were not provided. Overall, mean total range-of-motion deficits decreased from 10 to 4° in the mild group, 36–12° in the moderate group, and 89–31° in the severe group. In patients with a

total deficit of less than 70°, there was no resistant postoperative stiffness. Of the six patients with a preoperative deficit of more than 70°, three had resistant postoperative stiffness.

Cho and Rhee [6] prospectively compared 15 patients with preoperative stiffness (passive forward flexion <100° or external rotation <40°) with 30 patients without preoperative shoulder stiffness.

In contrast to the study by Tauro [29], a manipulation under anesthesia was performed in the patients with stiffness before ARCR. At final follow-up of more than 2 years, there was no significant difference in forward flexion or external rotation between the groups with and without preoperative stiffness. The rate of motion recovery, however, was slower in the group with preoperative stiffness.

The postoperative rehabilitation protocol remains controversial. We are still far from definitive guidelines for the management of pre- and postoperative stiffness, and prospective double-blinded randomized clinical trials are needed to obtain evidence allowing to establish a reliable and effective management plan for shoulder stiffness.

18.3.5 Nonsurgical Treatment

A supervised physical therapy program along with passive manual stretching should be started as soon as possible. Good outcome is expected if stiffness is recognized early and appropriate measures are taken. However, unlike primary idiopathic adhesive capsulitis, postoperative stiffness is more frequently resistant to a nonsurgical approach. I do not believe that manipulation under anesthesia is indicated in such settings because of the possibility of collateral injury or retear of the healed rotator cuff tendon. Most of the literature has reported that the manipulation under anesthesia is a safe and effective method with few complications. However, there were some alarming studies reporting iatrogenic injuries and even reporting crack fracture at the surgical neck of the humerus or at the glenoid rim [15].

For nonsurgical management to be effective, the stiffness must be recognized early, and pain must be controlled. Pain can be controlled by reducing inflammation through the use of both subacromial and intra-articular steroid injections, systemic oral steroids (pharmacological arthrolysis) and NSAIDs (nonsteroidal anti-inflammatory drugs). I prefer to delay the use of steroids or NSAIDs until after 12–14 weeks because of their potential adverse effects on tendon healing. Icing and judicious use of oral narcotic medications usually are needed. Symptomatic relief also can be provided by electrical stimulation (TENS).

In general, patients with significant stiffness following rotator cuff repair initially should be managed nonsurgically with a structured therapy regimen for at least 3–4 months after months after the repair. During this period, the pain typically subsides and the patient's tolerance to stretching will improve. Because the clinical course is usually one of the improvements, it is generally appropriate to wait 4–6 months after the primary rotator cuff repair before surgical intervention for stiffness. Patients usually improve significantly during this time frame, and it is rare that patients need surgical treatment. That being said, there may be instances where early intervention for stiffness might be necessary, such as in the case of a suspected infection.

18.3.6 Surgical Treatment

The arthroscopic capsular release is performed with the patient in the lateral decubitus position with the arm in 20–30° of abduction and 20° of forward flexion with 5–10 lb of balanced suspension. A standard diagnostic arthroscopy is performed through a posterior portal with a pump maintaining pressure of 60 mmHg.

Order of steps for capsular release after rotator cuff repair [9]:

1. Release rotator interval and superior glenohumeral ligament through anterior portal with electrocautery or vaporization.
2. Perform three-sided release of subscapularis if necessary.
3. Move arthroscope to anterior portal and perform posterior capsular release from the

11 o'clock to the 7 o'clock position introduced through the posterior portal.
4. Perform inferior capsular release through posterior portal.
5. Perform anterior capsular release through posterior portal.
6. Perform manipulation under anesthesia.
7. Perform subacromial lysis of adhesions.

18.3.7 Outcome

In a series of 489 consecutive arthroscopic rotator cuff repairs, Huberty et al. [12] found that 24 patients (4.9 %) developed postoperative stiffness. Twenty-three of 24 patients (95.8 %) showed complete healing of the rotator cuff. Forward flexion improved from 138° to 166° and external rotation from 32° to 49° after capsular release in these 24 patients.

Arthroscopic release resulted in normal motion in all cases.

18.4 Infections Following Shoulder Arthroscopy: Incidence, Risk Factors, and Prophylaxis

Leo Pauzenberger and Philipp R. Heuberer

Shoulder arthroscopy has rapidly developed over the last decade and has been shown to be highly successful for the treatment of various shoulder disorders. The number of shoulder arthroscopies performed is continually increasing, whereas reportedly more than half of all procedures are rotator cuff repairs [13, 14]. With an overall reported complication rate ranging from 4.8 % to 10.6 %, shoulder arthroscopy is not free from complications [1, 2, 19, 23, 28]. The number of infectious complications alone was reported at 0.03–3.4 % [2, 19, 26, 31]. Although deep infections following shoulder surgery are generally rare, they can have devastating consequences for the joint and ultimately upper extremity function [11, 21, 33]. However, only a handful of small studies report on the incidence of infectious complications after arthroscopic shoulder surgery [2, 23, 31], whereas even fewer studies investigate the effect of preventive strategies including perioperative antibiotic prophylaxis [26, 32]. Due to the paucity of available literature, we searched our database for shoulder arthroscopies performed from 2004 to 2014 to determine the incidence of infectious complications, find possible risk factors, and evaluate the effect of perioperative antibiotic prophylaxis. Overall we identified nearly 7,000 all arthroscopic procedures that were done over this 10-year period. The standardized protocol for operating room hygiene was constant throughout this time. For surgical site disinfection, an alcohol-based skin antiseptic was used in all patients. Routine use of perioperative antibiotic prophylaxis started in 2010 with either *cefazolin* or *clindamycin* (in case of allergies). The overall rate of infections was 0.45 %, whereas 93.3 % of these occurred following rotator cuff repair. Only two cases of infection occurred after non-reconstructive shoulder arthroscopy without the use of anchors or suture materials (e.g., subacromial decompression, treatment of calcifying tendinitis, capsulotomy, etc.). An analysis of potential risk factors showed that patients with infectious complications tended to be older at the time of surgery (>65 years), were predominantly male (96.7 %), did not receive perioperative antibiotics (83.3 %), and had comparatively longer operating times. Perioperative antibiotic prophylaxis was given in 43.3 % of cases. The rate of infection was reduced by the introduction of antibiotics from 0.66 % to 0.17 % overall, whereas risk reduction was most noticeable in rotator cuff repairs (1.39 % versus 0.26 %). The three most commonly identified pathogens prior to the administration of perioperative antibiotics were *Staphylococcus epidermidis* (44 %), *Propionibacterium acnes* (24 %), and *Staphylococcus aureus* (12 %). Interestingly, after the introduction of routine antibiotic prophylaxis, the sole causal infectious agent was *P. acnes*. Although first-generation cephalosporins and lincosamides have been successfully used in the treatment of *P. acnes* infection [8, 16, 17, 20, 22, 25], they proved insufficient in the prevention of the same. These insufficiencies emphasize the

need for further research toward improved preventive strategies against *P. acnes* infection. Furthermore, in any case meticulous care must be taken to preserve sterility when performing reconstructive shoulder arthroscopy, especially in extensive repair procedures involving a high number of material and instrument passages through the skin. Patients with *S. epidermidis* or *S. aureus* infections presented with classical infectious signs (fever, pain, redness, swelling, secretion) within the first 3 weeks postoperatively, whereas patients with *P. acnes* infections presented not until the fourth to sixth postoperative week and more subtle signs of infection. Patients were initially treated with open or arthroscopic revision surgery including thorough debridement and removal of all foreign materials. All patients that were tried to be treated arthroscopically had to be revised eventually by open surgery. These unsatisfactory results might be explained by the multi-compartmental nature of the shoulder that results in difficulties to sufficiently address the problem by arthroscopy alone.

18.5 Conclusion

The overall risk for infection following shoulder arthroscopy is relatively low. Factors potentially associated with an increased risk of infection include the male gender, higher age, the use of sutures or anchors, and extensive operating times. Perioperative antibiotic prophylaxis with *cefazolin* or *clindamycin* significantly reduced the risk for infection in reconstructive surgery, especially rotator cuff repair. However, the rate of *P. acnes* infection could not be reduced by routine antibiotic prophylaxis. Based on the literature and our own analysis, we highly recommend the use of perioperative antibiotic prophylaxis in all reconstructive (e.g., rotator cuff repair) shoulder arthroscopies.

Furthermore, special care should be taken to preserve sterility when passing the skin multiple times during extensive repairs. If patients return to the hospital between 4 and 6 weeks postoperatively with painful shoulders and subtle signs of infection, surgeons should be very suspicious of possible *P. acnes* infection. For treatment of infections following shoulder arthroscopy, we highly recommend open over arthroscopic revision surgery with removal of all materials followed by appropriate antibiotics.

18.6 Complications Related to Positioning and Anesthesia During Cuff Reconstruction

Wolfgang Nebelung

Neurological complications after shoulder arthroscopy were described related to the lateral decubitus and beach chair positioning of the patient [27]. Both methods of positioning are characterized by a number of advantages and disadvantages and possible risks for specific complications.

With the lateral decubitus position, traction injuries of the cervicobrachial plexus can occur. Measuring SSEPs (somatosensory-evoked potentials) during arthroscopy with traction of the arm in a lateral position revealed changes of the signal of the musculocutaneous nerve in 100 %, while other nerves of the brachial plexus were less commonly affected. Several case reports give low rates of postoperative dysesthesia of the thumb or other fingers in 1 % of patients after undergoing surgery in the lateral decubitus position. All of these sensory deficits were transient. Nevertheless, the surgeon using lateral decubitus positioning should intend to minimize the traction load on the arm and the time periods of increased traction required for some surgical steps. During beach chair positioning, neurapraxia of the cutaneous branches of the cervical plexus can occur. An interscalene block is an efficient alternative to mere general anesthesia leading to shorter hospitalization and less pain. If applied under ultrasound control, the efficiency is around 90–95 %. A number of related complications have been reported, including brachial plexus neurapraxia, induction of spinal or epidural anesthesia, or seizures. In addition, unintended anesthesia of phrenic or laryngeal nerves can occur.

The use of hypotensive anesthesia during arthroscopic shoulder surgery allows to maintain

a clear surgical field and is often essential for complex reconstructive procedures. Concerns have been raised using hypotension in an upright position as reports on ischemic brain and spinal cord injury have been published. Cerebral hypoperfusion can be caused by decreased blood pressure and the higher position of the head in relation to the upper arm, where the pressure is measured. In addition, inadequate neck flexion or extension during surgery can compromise the blood supply. If the cuff is positioned on the upper arm, the difference of blood pressure between brain and arm can easily be between 20 and 25 mmHg. This needs to be considered by both the surgeon and the anesthesiologist to appropriately stratify an individual patient's risk.

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19 Clinical Utility of Diagnostic Ultrasound in Athletes with Tendinopathy (ICL 22)

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19.1 Introduction

Chronic painful tendinopathy is common in elite and recreational athletes and in sedentary subjects; all may have to stop or decrease their level of physical activity [1, 2]. Midportion Achilles tendinopathy and for the younger and heavy loading population also patellar tendinopathy are problematic injuries. However, recent research on innervation patterns histopathology and pain mechanisms in Achilles and patellar tendons has led to an increased knowledge about the chronic painful tendon [3–6].

Classically, the term 'tendinitis' was used considering that the fundamental lesion was an inflammation of the tendon. However, by the time these lesions become clinically evident, at histology there is an absence of inflammatory cells. Instead, the injured tissue presents fragmentation, an alteration of the collagen and vascular hyperplasia [7–9], and a pathological picture compatible with a failed healing response.

Better, though still incomplete, understanding of the pathophysiology of tendinopathy has induced changes in the therapeutic approach used in the management of tendinopathy. Most authorities have abandoned the goal of eliminating inflammation of the tendon and tried to impact on the biology of the tendon to stimulate its regeneration [10].

Chronic pathologies are characterised histologically by irregular tendon structure with a failed healing response, with the presence of numerous fibroblasts and pathological neovascularisation [11].

Ultrasound (Fig. 19.1) and colour Doppler findings [12], showing localised high blood flow inside and outside regions with structural tendon abnormalities, have shown to be important to diagnose tendinopathy [13–15]. Immunohistochemical analyses of biopsies have shown sensory and

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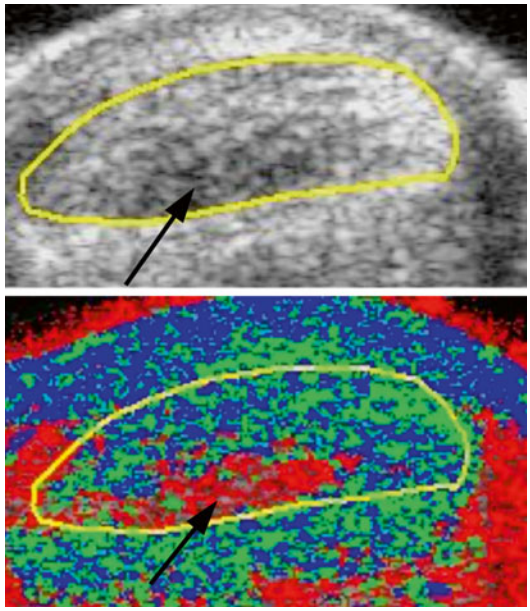

Fig. 19.1 Patellar tendinopathy studied with high-definition colour Doppler ultrasound. Comparison between right and left patellar tendons. Longitudinal view reveals intensive thickening (11 mm vs. 3.9 mm) combined with hypoechoic zones

sympathetic nerves in close relation to the outside of the tendon. These findings have led to the development of new treatment methods. Alfredson et al. [15] suggested that these new vessels and nerves were involved in the mechanisms of tendinopathy pain, but the answer as to the origin of the pain is an issue that is still under debate.

19.2 Can US Replace MRI in the Diagnosis and Management of Tendinopathies?

Currently, ultrasound is the imaging modality of choice for the assessment of tendons as it has superior spatial resolution to MRI and ultrasound and colour doppler examination can be used to diagnose partial ruptures. However, clinical improvement is not correlated with changes in imaging status or the amount of neovascularity [16].

Also, ultrasound is dependent on the skills of the operator and, as MRI, produces a bidimensional image of a tridimensional structure. This may introduce limitations in assessing the structural integrity of the tendon.

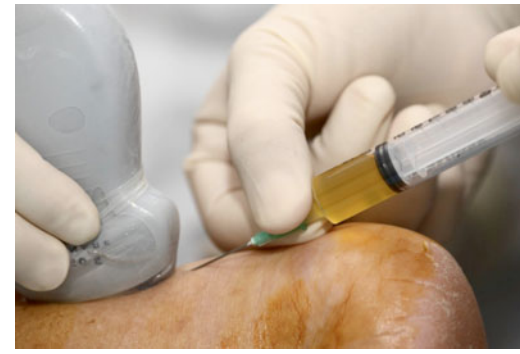

Fig. 19.2 UTC imagines showing 55 % type 1 echoes (*green*) when normal is approximately 70 %. The tendon has areas of matrix degeneration. This area is demonstrated at 1–1.5 cm from the calcaneum (*black arrows*) on the ventral aspect of the tendon and is demonstrated by the focal area of type 3 echoes (*red*)

A new novel imaging modality ultrasound tissue characterisation (UTC™) provides a more detailed imaging profile of the tendon. UTC imaging (Fig. 19.2) produces a multiplanar and 3D coronal view to assess in detail the structural integrity of the tendon [17]. These ultrasonographic images provide objective information on the integrity of the tendon matrix from the distal insertion to musculotendinous junction. The scans are analysed to assess for focal areas of echo change and to establish the overall health of the tendon.

UTC may play an important role in monitoring athletes' tendon health during each phase of the rehabilitation process and for managing in-season tendon pain. Managing tendinopathy during the competitive season is particularly challenging as training and competition loads are high and often there is not sufficient time for a full recovery. Excessive loading provokes tendon pain: the greater the load, the greater the pain experienced [18]. UTC data combined with clinical markers assess the tendon tolerance to load, such as 24-h pain response, morning stiffness, pain on single-leg heel raise, and single-leg hops. This information is used to adjust and modify tendon load to ensure that the tensile-loading capabilities of the tendon are not exceeded and the tendon remains

pain-free. This enables athletes, their clinicians and coaches to make informed and effective decisions about the capacity for training and performance. Research has also demonstrated that UTC is valid, reliable and sensitive at detecting a tissue response to load [19, 20].

19.3 Neovascularity in Tendinopathy

In the 1990s, Newman et al. [21] described blood flow in symptomatic tendons at power Doppler ultrasonography. Subsequently, Ohberg and Alfredson [22] defined this blood flow as 'neovascularisation' (Fig. 19.3). From an etiological perspective, the neovessels were thought to be secondary to the essential abnormality of tendinopathy, the failed healing lesion [23]. Using colour Doppler ultrasound, Ohberg and Alfredson showed, in a case-control study, increased blood flow and neovascularity in all painful tendons and absence of these features in the asymptomatic control tendons [15]. Healthy tendons are relatively avascular [24].

Symptomatic tendinopathic Achilles tendons with neovascularisation show evidence of a statistically significant association between the site of maximum tenderness on palpation and the site of maximum presence of neovessels [25]. Also, neovessels were detected in 29 % of asymptomatic athletes [26] and in 100 % of subjects after strenuous exercise [27].

Recent research, it appears that detecting neovessels may have no additional value for the diagnosis, no firmly confirmed prognostic value and no proven relation with symptoms [28]. Also, all these issues can be compounded by the lack of standardisation of machine settings regarding the use of power or colour Doppler [29].

19.4 Injection Therapies in Tendinopathy

Injection therapies include a range of options such as corticosteroids, high-volume saline, prolotherapy, autologous blood, platelet-rich plasma, aprotinin, botulinum toxin, sodium hyaluronate, polysulphated glycosaminoglycan and polidocanol [30].

Injection therapies can be guided by real-time ultrasound imaging or performed 'blind', they can be administered in isolation or in combination with any of the above interventions, they can

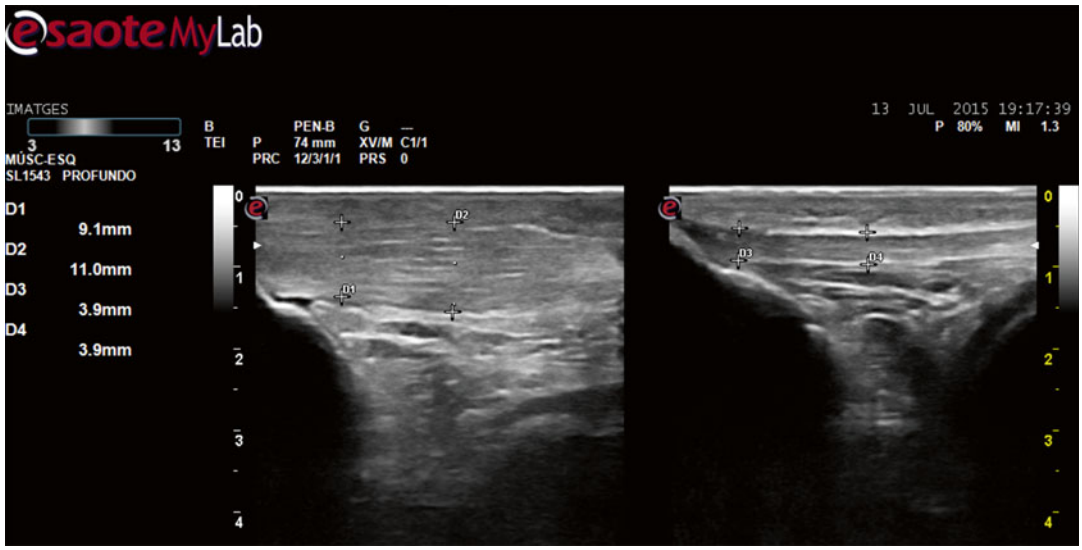

Fig. 19.3 Ultrasound high-resolution grey-scale and colour Doppler with lineal probe image of the proximal patellar tendon. Intensive neovascularisation (*arrow*) with hypoechoic zones and thickened tendon is shown

Table 19.1 List of common injected therapies

Autologous blood	Promotes repair activity through the administration of growth factors
Platelet-rich plasma	Promotes repair activity through the administration of concentrated growth factors (present in a person's own blood that has been spun at a high speed to separate out the platelet-rich plasma layer)
High-volume saline	Produces a mechanical effect on the new vascular ingrowth associated with tendinopathy, resulting in the new blood vessels stretching and breaking
Polidocanol	Disruption of vasculature and nerves by administration of a sclerosant to precipitate fibrosis
Prolotherapy	Hypertonic glucose injected locally to initiate repair activity by causing local tissue trauma
Aprotinin	Inhibits collagenase, which would otherwise break down collagen
Polysulphated glycosaminoglycan	Prevents destruction and facilitates repair through inhibiting metalloproteinase enzyme activity
Botulinum toxin	Decreases tensile stress through the tendon and inhibits substance P
Sodium hyaluronate	Absorbs mechanical stress and provides a protective buffer for tissues
Corticosteroid	Downregulates (acting to decrease) inflammation

be administered in a single dose or consist of a course and they can be injected locally into the tendon or targeted at specific sites (such as areas of vascular ingrowth). There is no consensus on many of these factors and the exact intervention is at the discretion of the responsible clinician [31]. Some injection therapies are used to deliver a drug directly to the damaged tendon while others like polidocanol are to be injected outside the tendon in specific regions. In general, these substances are thought to act either pharmacologically (e.g. corticosteroids or polidocanol) or mechanically (e.g. high-volume saline to disrupt neovascular growth). The table below lists common injection therapies [32] (Table 19.1).

19.5 Ultrasound-Guided Mini Surgery for Tendinopathy Treatment

Originally, ultrasound Doppler-guided injections of the sclerosing substance polidocanol [33, 34] targeting the regions with high blood flow outside the tendon were used. The clinical results were good, but often multiple injections during a 3–6 months period of time were needed. Also, the procedure is technically demanding with a relatively long learning curve. However, using this method lot of knowledge about the location for pain was achieved. This knowledge was used when moving into mini-invasive surgical methods [35, 36]. For the chronic painful tendinopathy of the main body of the Achilles tendon, an ultrasound Doppler-guided scraping technique, targeting the regions with high blood flow and nerves on the ventral side of the tendon, was described. The procedure is indicated when 3 months of heavy loaded painful eccentric training have failed and has been shown to be very successful in elite athletes as well as recreational athletes and sedentary patients. Very few complications are reported, but proper wound care needs to be emphasised. Early (4–6 weeks) return to heavy tendon loading sport activities was obtained. In follow-up studies, remodelling of the tendon structure over time was seen. We are now starting to use a percutaneous surgical technique allowing for an even earlier return to activity.

Recently, plantaris tendon involvement in midportion Achilles tendinopathy has been highlighted [37–39].

In a subgroup of patients, often complaining of localised medial tendon pain, and having a poor result of eccentric training, a nearby, sometimes invaginated, plantaris tendon can be of importance for the pain. The plantaris tendon can be tendinopathic, and the paratendinous tissues between the Achilles and plantaris tendons were richly innervated. Often, also the plantaris tendon itself was richly innervated. In patients with midportion Achilles tendinopathy and a suspected

plantaris tendon involvement, surgical treatment is instituted early. Ultrasound Doppler-guided removal of the plantaris tendon, together with the scraping procedure for the Achilles, is used. The clinical results have been shown to be very good, with an early return to heavy tendon loading activities. Follow-up studies have shown a quick remodelling of the medially located structural abnormalities in the midportion of the Achilles tendon, indicating a possible compressive or shearing disturbance from the plantaris tendon.

For patients with patellar tendinopathy/jumper's knee in the proximal patellar tendon, ultrasound Doppler-guided arthroscopic shaving technique, targeting the regions with high blood flow and nerves on the dorsal side of the proximal tendon, has been invented [40, 41]. The method is used when 3 months of heavy loaded painful eccentric training has failed and has been shown to be very successful in elite and recreational athletes. Very few complications were reported, with an early (6–8 weeks) return to heavy tendon loading sport activities. In follow-up studies, remodelling of the tendon structure over time was seen.

19.6 Autologous US-Guided Treatments in Tendinopathy: How Should It Be Done?

Platelet-rich plasma (PRP) is a general term for new technologies that are focused on enhancing the healing response after injury of different tissue types [42, 43].

Tendons have low basal metabolic rates and are predisposed to slow healing after injury [44]. Basic science studies have shown that co-cultures of tenocytes and a preparation rich in growth factors increase the proliferation and secretion of VEGF and hepatocyte growth factor [45].

PRP has also proven to be effective in treating chronic tendinopathies. Mishra and colleagues [42] showed a significant reduction, at 8 weeks, in tennis elbow symptoms in a group treated with PRP compared with a control group. A group from the Netherlands led by Gosen [46] has replicated this protocol and compared the PRP group with a group treated with cortisone injection for tennis elbow. They observed that the PRP group enjoyed better and faster functional recovery and pain relief after 6 months.

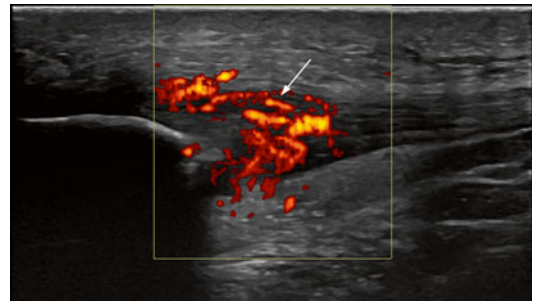

Fig. 19.4 Ultrasound-guided PRP injection in Achilles tendinopathy

Marcacci and colleagues [47] have studied the effects of PRP in jumper's knee (chronic refractory patellar tendinopathy) after previous classical treatments have failed. They observed significantly better results in terms of Tegner, EuroQol and visual analogue scale scores and pain level compared with baseline and with controls treated with physiotherapy.

Through the actual research, it is hard to draw any clear conclusion for the effectiveness of PRP treatment in terms of tendinopathy [48]. In case of PRP use, the treatment protocol consists of applying PRP under ultrasound control (Fig. 19.4) and filling the gap (if needed) under strictly ultrasound guidance.

Take-Home Message

- Accurate clinical diagnosis is the key: be specific and consider all differential diagnoses.
- Carry out a detailed examination with a thorough history and ultrasound examination.
- Before commencing a loading programme, consider the irritability of the tendon. Monitor overall load on the tendon.
- Eccentric loading may be effective but consider other types of treatments when eccentric fails.
- Standardise the ultrasound examination and study the presence of high blood flow.
- Think about the use of ultrasound-guided minimally invasive techniques explained or surgery when appropriate rehabilitation has not given good results.

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How to Make a Video (ICL 23)

20

Nicolas Graveleau, Katja Tecklenburg,
David Putzer, Abdou Sbihi, and Daniel Smith

20.1 Introduction

Videos for teaching and learning purposes have become an important tool in the state-of-the-art educational environment.

Stockwell et al. [1] found that video assignments lead to increased attendance and satisfaction. This validates a new model for science communication and education.

Videos present live and applied science in a matter of multisensory learning.

In the world of orthopedic science, a video can be used in several different settings and can be addressed either to other orthopedic surgeons and residents or to the patient as an educational and informative application.

Technical aspects of a surgical procedure can be highlighted and transported to the audience through a video. A video can help to visualize a technically difficult step during surgery much better than regular photos or a written description.

However, videos can also help to educate young colleagues in their ability to do a proper joint examination. Functional tests can be visualized just like an in vivo situation. Normal and pathological signs can be addressed and put together in a video to underline the differences in the same test procedure. Furthermore, a video can quickly be loaded on a normal notebook and can therefore be used in daily practice as well as in the patient environment. Patients will furthermore benefit from an interactive video regarding their decision making about a possible surgical intervention. A video gives a reproducible and well-defined overview of all treatment options and can also include a sequence of the surgical procedure.

20.2 Technical Aspects and Pitfalls of Making a Surgical Video

David Putzer

Education in medicine is challenging in many aspects. Medical professionals have to deal with

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very complex three-dimensional structures during surgical procedures. However, didactics rely heavily on anatomical illustrations and images, two-dimensional projections of the specific anatomy. Teaching surgical techniques requires three-dimensional models which can be achieved by using life demonstrations, surgical simulators, surgical videos, or textbooks. All of these teaching tools rely on a realistic presentation of the human body; the latter further requires the student to imagine the actual situation.

To reach the educational goal, it is a prerequisite to clearly state the purpose of the video. Final image quality is a combined result of image acquisition and the elaboration process. It is crucial to obtain images in the best achievable quality. The more parameters that can be controlled while filming, the better the end product will be. The most important ingredient to producing a successful video however is to base it on, and strictly follow, a good screenplay.

The most realistic presentation of a surgical technique is provided by an intraoperative video. However, an intraoperative setup also provides a lot of limitations and challenges:

- Surgical time is limited and surgical steps can usually not be repeated.
- The actual surgical procedure may change significantly during the process which might collide with the initial screenplay.
- Besides recording excellent image quality (a function of the used lens, CCD chip), the camera has to meet the requirements of a medical device if it was to be inserted into the surgical field.
- Camera placement and movement is limited by the patient position, the presence of the surgeon and assistants, as well as a variety of necessary medical devices.
- Illumination can change significantly during surgery and is influenced by operation room lights and surgeon headlights.
- Background sounds cannot be completely eliminated or controlled.

To overcome many of these limitations when teaching surgical techniques, it can be preferable to use cadaver specimens instead of live patients. Additional information (X-rays, MRI, CT, fluoroscopy), if available, should be included in the video.

Avoiding pitfalls: Many surgical videos are taken "on the fly," without any preparation whenever an interesting case is randomly contained in the daily routine. By being adequately prepared, many pitfalls can be avoided easily and a lot of time saved during the video elaboration process. Having at least basic knowledge of camera settings and of the possibilities video elaboration software provides helps to improve the educational value of a surgical video significantly.

Conclusion: Creating intraoperative or cadaver-based videos remains an indispensable educational tool for all medical professionals. Providing more detailed information and a higher quality presentation in such videos should be planned for in advance. In the end, better educated surgeons will provide better surgical results for the patient.

20.3 Practical Guidelines on How to Make a Video for Your Presentation

Abdou Sbihi

Video in particular is often attractive as a means to capture lecture content and present direct instruction. Of all the technological components involved in the learning experience, it is often the most visible and the most resource intensive. It is easy then to assume that it will be the most impactful. It is indeed a powerful medium, but as with anything else, video must be created with an eye for strong pedagogical choices in order to be most effective. Likewise, just as video is one tool in the media toolbox, lecture is one strategy on the instructional palette. Video can also be designed for presenting case studies, interviews, digital storytelling, student-directed projects, and more. Choosing the appropriate instructional strategy and pairing it with an effective media format is part of the analysis performed during your course design process.

Anytime you give a presentation, there are general guidelines you want to follow to make it

interesting and relevant to your audience. Giving a presentation with videos adds a layer of complexity because of the technology involved. Special considerations need to be made for remote presentations to make sure everything goes smoothly.

Develop a clear focus for your video project before you begin: The script is the most important element in creating a good explainer video. The script is where you will need to spend the majority of your focus. It is best if you write your explainer video script yourself.

There are tips and tricks for every step when making a video:

- Clip(s) you have chosen to feature can be extracted from a larger video file. Before you begin assembling the video, you can already start cutting any unnecessary sections that you want to delete.
- Whenever the project is in need of explanatory text, it may be written text and/or narration. To add text, you can use the provided white or black image in the video editor or upload a text image previously created and formatted as a .jpg, .bmp, or .gif in a drawing tool. Screen text should be brief, spell-checked, and in a simple font large enough to read.
- To add narration, you can upload previously recorded audio files such as .wma, .wav, or .mp4. Before recording the audio file, know correct pronunciations and practice until it sounds natural with a consistent tempo, volume, and modulation.

20.4 Videos as Tools for Patient Decision Making

Daniel Smith

With video resources, a surgeon can aid patient decision making. To improve our prospects of making the right decision, we need to be well informed. Video can offer a number of advantages over a physical consultation – what are these advantages and how best can they be executed? What are the disadvantages and limitations? We can have patient decision aid that utilizes a combination of video and interactive questions. What can we measure during video playback? Can video be interactive as well as engaging? What is the patient's perspective? We consider the opinion that better informed patients will have an improved outcome though the management and measurement of their expectations – video can play an important role.

20.5 How to Manage Your Video: Export, Side, Format, Reader, Quality

Nicolas Graveleau

Once you have finished editing your video, you will need to greatly reduce its file size so that it can be used in your presentation or transferred over the Web effectively. Compressing audio and video can be as much an art as a science, but we should attempt to simplify the process.

You will need to make two major decisions about how to present your audio and/or video on the web:

- **Format**: Do you want to present your media in Mac or Windows Media format, or universal? Each format has its own strengths and weaknesses. QuickTime has high quality, wide compatibility, and low cost (free). Because all Macs support QuickTime creation and playback natively, and because iMovie and Final Cut Pro generate QuickTime by default, QuickTime is an especially convenient choice if most of your media is generated on Macintosh computers, as it is in many media production environments. The choice of format you use for a given project will probably be determined by the publication you are working for. Be sure to find out in what format media is expected before you enter the final phases of production.
- ***Compression Methods***: Once you have chosen a format, you will need to decide how much to compress your audio or video. The more you compress, the smaller the file sizes

will be and the easier it will be for modem users to access your media over a slow connection through a Web presentation. However, more compression means throwing away more data (bits). Therefore, high compression means low fidelity and vice versa. Ideally, plan to deliver two files: A high-quality, high-bandwidth version for cable/DSL users or local computer presentation and a low-quality, low-bandwidth version for modem users, although this is not always possible. Again, this decision will likely be determined by the publication you are working for.

Deciding exactly what parameters to use when exporting compressed audio and video is as much an art as a science and depends on many factors. Both iMovie and Final Cut Pro come with "default" export options, which let you use a canned "set" of export parameters for high-, low-, and medium-bandwidth users. Both programs also let you override the defaults to choose codecs, dimensions, bitrates, and framerates manually.

20.6 Future Treatment Options

Videos as tools for interactive and patient-orientated learning will become an even more important part of our educational environment. Videos at the moment are mainly used to visualize a surgical procedure and to present interesting cases seen in daily practice. Furthermore, educational videos showing normal joint and body examination as well as pathological clinical signs seem to become more and more implemented in the education of medical students and orthopedic residents. A wider use of videos in the medical education of young colleagues should be promoted.

Such progress already finds practical application in the Arthroscopic Surgery Skills Evaluation Tool (ASSET), a standardized video recording of North American orthopedic residents during arthroscopy that has been implemented as part of their skills testing. Orthopedic residents are being recorded during a certain number of diagnostic arthroscopic knee and shoulder procedures. The Arthroscopic Surgery Skill Evaluation Tool was developed as a video-based assessment of technical skill with criteria for passing established by a panel of experts. Koehler et al. [2] determined the validity and reliability of the ASSET as a pass-fail examination test and concluded that such a video-based tool is a useful tool when evaluating surgical skills in diagnostic arthroscopy [3, 4].

However, videos should also be embedded in a well-organized and informative discussion between patient and consultant. A professionally designed video, showing all aspects of a surgical procedure, will help in the decision-making process of a responsible patient. This tool has rarely been used in our environment up to now. Many surgeons are reluctant about making their own videos in their clinical practice. Using the technical knowledge and software applications of a technician who ideally works in the same institution as the medical specialist will improve the quality and the acceptance of such a video.

However, by using simple software-processing programs like iMovie®, it is also possible to create a video in daily clinical practice that provides acceptable technical standards and quality. Orthopedic surgeons could improve their examinational and surgical reproducibility by getting involved in making their own videos. New hardware such as Google Glass® and GoPro Hero®, both video-making tools that can be worn on the surgeon's head while performing a surgical intervention, may be able to revolutionize the reproducibility and training in orthopedic surgery. Head-on wearable devices allow for recording full surgical procedures or clinically interesting examination procedures with relative ease and without the need of technical personnel, equipment, and coordination required for traditional surgical videography [5].

Videos as part of a presentation seem to have already become a standard in a high-quality scientific presentation and should be even more considered in the future.

Take-Home Message

A good surgical video must be easy to follow and easy to listen to. It must provide fundamental goals for the audience. It should also include excellent video production techniques and incorporate multiple viewing angles so that viewers feel as though they are in the operating room [3].

Similar criteria apply to any other video used either as an educational tool for residents, medical students, or other medical staff or used as an informative video addressing your patients. However, not all videos have to be made with professional standards; new wearable video-making technologies allow for a live and easy to use video production that can be applied by any surgeon.

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