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Recent Advances in Arthroscopic Surgery

Edited by Hiran Amarasekera

RECENT ADVANCES IN ARTHROSCOPIC SURGERY

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Meet the editor

Hiran Amarasekera is a Consultant Orthopaedic Surgeon from Sri Lanka currently undergoing a hip preservation fellowship at the University Hospitals of Coventry and Warwickshire, UK. His special interests include young adult hip and knee problems, sports injuries, hip and knee arthroplasty, and keyhole joint surgery. He graduated from Kasturba Medical College, Manipal, India, and obtained the MBBS. He did post-graduate training in trauma and orthopaedics at the Postgraduate Institute of Medicine, Colombo, and was awarded his MS by The University of Colombo. He was initially trained at the National Hospital of Sri Lanka and then completed advance training at the Oldchurch Hospital in Essex, UK; The Avenue Hospital Melbourne, Australia; and University Hospitals of Coventry and Warwickshire, UK. After completion of training, he obtained the board certification in trauma and orthopaedics from the Postgraduate Institute of Medicine, Colombo, and passed the FRCS from the Royal College of Surgeons of Edinburgh. Later, he was elected as a fellow of the Sri Lanka College of Surgeons and awarded the FCSSL. He has a keen interest in academia and research.
He worked as a clinical research fellow in Warwick Medical School and obtained his MPhil in Medical Sciences during this training and completed a research fellowship at the University of California Los Angeles (UCLA). His main research areas are the study of blood flow to the hip, failure mechanisms of hip implants, designing new hip prostheses, developing surgical approaches to the hip and femoral acetabular impingement, and research and developments in arthroscopy.
He has over 30 international publications, presentations and several book chapters to his credit. He works as a reviewer for international orthopaedic journals and has reviewed over 60 papers and is a member of the editorial board of Sri Lanka Journal of Surgery.

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Preface

Over the last decade, arthroscopy (keyhole surgery of the joints), has developed rapidly. Arthroscopic procedures were previously limited to large joints; however, with modern technology, it has been possible to perform arthroscopy in almost any joint, including small joints of the hand and foot. Over the years, arthroscopic work has shifted from a diagnostic procedure towards more therapeutic procedures. Modern arthroscopic surgeons perform major operative work through keyhole surgery either as a total procedure or as an arthroscopic-assisted open procedure. With the development of technology and innovation, it has been possible to perform more and more complex procedures through keyhole joint surgery.

This book discusses the advances and techniques of arthroscopic procedures on a region-wise basis, concentrating on major joints.

The chapters are arranged according to the four major joints where common keyhole surgery is practised today; namely knee, hip, shoulder, and elbow.

The knee section has chapters discussing the traditional arthroscopic ACL reconstruction, modern role of arthroscopy in articular cartilage replacement, and feasibility of arthroscopy being performed as an out-patient procedure.

The shoulder section has chapters on arthroscopic treatment of subscapularis repair and management of meso-acromion.

The book also has chapters on the complications of arthroscopy, mainly concentrating on the elbow joint and role of modern arthroscopy in hip surgery. Every chapter offers information and discusses the authors' experiences regarding these procedures, which will enable the reader not only to understand the procedure but also to learn from the authors' experience.

This book will give readers and practitioners of orthopaedics an overview and scope of arthroscopic surgery in modern day practice.

Many thanks go to all authors and contributors for submitting the chapters, to all the staff including Author Service Manager, Anita Condic, at IntechOpen Publishing, and finally as always to my wife Anuji and my daughter Nuwanji, for having patience and supporting me through all my research and publication work.

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Section 1

Knee

Successful Knee Arthroscopy: Techniques

Chia-Liang Ang

Additional information is available at the end of the chapter

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Abstract

Knee arthroscopy is one of the most common arthroscopic procedures required of an orthopedic surgeon. A successful case hinges primarily on adequate pre-operative planning, proper intra-operative set-up and thoughtful portal placement. This chapter will discuss in detail the necessary ingredients of a smooth and successful knee arthroscopy case. Advanced techniques to deal with intra-operative difficulties will be presented. Though uncommon, complications arising from knee arthroscopy will be presented and their management techniques described. Common procedures will be discussed, including simple knee arthroscopic debridement, arthroscopic cartilage reconstruction, anterior cruciate ligament reconstruction, and meniscus repair. Surgical steps for a safe and smooth case will be presented.

Keywords: knee arthroscopy, arthroscopic techniques, arthroscopic debridement, microfracture, anterior cruciate ligament reconstruction, meniscus repair, cartilage repair

1. Introduction

Knee arthroscopy is one of the most commonly performed orthopedic surgeries today. Its first reported use was by a Danish surgeon, Dr. Nordentoft, who made his own endoscope with a 5 mm trocar. He presented his work on knee endoscopy in 1912 at the 41st Congress of the German Society of Surgeons in Berlin [1]. Over the last century, technological advances in illumination and optical systems for viewing have facilitated the development of arthroscopic surgery, to the point where today, a large proportion of intra-articular pathology can be successfully treated with arthroscopic techniques. Arthroscopic surgeries involve much smaller incisions through skin, subcutaneous tissues, fascia and muscle, allowing rapid healing of these structures and early mobility of the patient, which is vital in reducing two key complications that threaten the success of any knee surgery: wasting of the quadriceps and stiffness of the knee. Furthermore, arthroscopy allows access to the posterior parts of the knee joint much more effectively compared to open surgery, where accessing the posterior horn of the menisci requires a subluxation of the knee joint. Arthroscopy can also be an adjunct to fixation of peri-articular fractures, where a direct intra-articular view can help dictate fracture reduction [2]. However, one issue in such uses is the potential lack of a contained space where a constant stream of arthroscopic fluid provides a clear visualization. In such cases, the peri-articular fractures would have to be almost nearly reduced before a proper visualization can be obtained via arthroscopy to guide the final reduction.

Arthroscopy is a completely different skill set from performing open surgery. One of the key differences is that in open surgery, the surgeon's hand movements directly correlate with movements at the tip of the instruments, whereas in arthroscopy, the surgeon's hand movements are in opposite directions with movements of the tip of instruments due to the presence of a pivot point at the incision. This negative correlation with the surgeon's hands is the primary difficulty for any learning arthroscopist and is the main component of the learning curve. The second major difficulty with arthroscopy is the locations of the portals. The incisions will have to be precisely situated to create a cone of movement that allows the best access to intra-articular structures. The third difficulty is learning how to improve access to the posterior parts of the knee joint, in particular when repairing meniscal tears or meniscal roots. Also, to interpret the anatomy of intra-articular pathology, the arthroscopist should correlate what he views through the scope with a mental overview of normal knee anatomy. These will be discussed further in the chapter.

Notwithstanding the benefits of arthroscopic surgery, a successful clinical outcome depends almost as much on the surgical technique as on good post-operative rehabilitation. Self-exercises such as isometric quadriceps contraction and active ankle and toe movement should be started immediately post-operation. Weight bearing and knee range of movement would depend on the pathology treated and the surgeon's comfort level.

2. Basic set-up

2.1. Patient and OT positioning

The surgeon will stand on the side of the knee to be operated on (**Figure 1**). An assistant surgeon, if available, stands proximal to the surgeon, and the scrub nurse stands distal to the surgeon with her instrument trolley further distal to her. Across the operating table, the arthroscopic towers stand at the level of the opposite knee (**Figures 2** and **3**). Proximal to the tower is the Mayo stand which holds all the arthroscopic instruments. A separate table may be utilized adjacent to the scrub nurse instrument trolley for graft preparations. The operation bed and surgeon should be within the confines of the laminar flow ceiling.

The patient should be supine on the operation table. For a routine arthroscopy, a side support on the lateral side of the thigh and a sandbag or an attachable foot rest beneath the foot should be placed (**Figure 4**). Placement of this side support must facilitate two functions: one, to allow the knee to be placed at a 90° angle, and two, to act as a post against which a valgus force can be applied to the knee to open the medial joint. For a right knee scope,

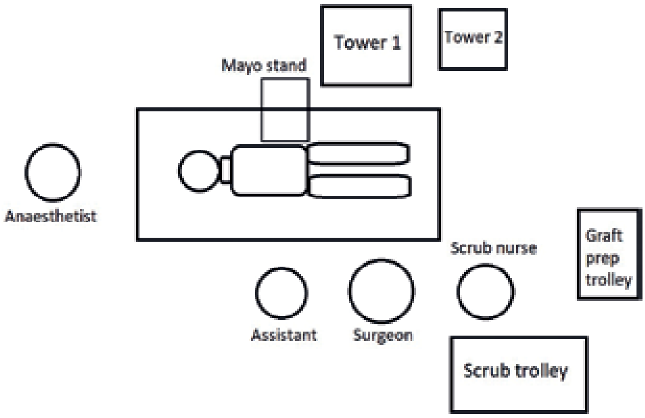

Figure 1. Operating theater set-up.

Figure 2. Arthroscopic tower 1. From top the bottom, the components are: screen, arthroscopic camera system, image management system, shaver console, arthroscopic light source, photo printer.

Figure 3. Arthroscopic tower 2. The top console is the fluid pump management system, and the bottom console is the radiofrequency ablation system.

the surgeon can place the patient's foot into his left hip and use his body to exert a valgus force with the patient's knee at 20–30° of flexion (**Figure 5**). The operation table may have to be lowered or the surgeon may place his left foot onto a stool. Therefore, the surgeon must check both positions before instructing the attendant to secure the side support in place. If a sandbag is used, it should be securely taped down to the table to prevent movement during the surgery.

A tourniquet is applied to the patient's proximal thigh. A properly applied tourniquet is a great aid to visualization during the surgery, especially during femoral drilling for Anterior Cruciate Ligament (ACL) reconstruction. A thick wad of cotton should be applied first to the thigh, and it is important that the width of the applied cotton is larger than the width of the tourniquet. This allows the even distribution of pressure from the tourniquet to the thigh. The tourniquet itself should be tightly applied over the cotton such that it will not admit even one finger. A crepe bandage is then secured over the lower half of the tourniquet and the lower edge is folded inwards beneath the lower edge of the tourniquet. For ACL reconstruction, an additional foot rest is applied to allow the knee to achieve maximum flexion during surgery (**Figure 6**). Positioning of this more proximal foot rest should be slightly less than full knee flexion. If the knee were fully flexed during positioning, the foot rest will not be able to hold the knee properly after draping adds bulk to the entire set-up.

Figure 4. Set-up for standard knee arthroscopy.

Figure 5. Placing the patient's foot in the surgeons' left groin, the surgeon can exert a valgus force on the knee.

Figure 6. Set-up allowing hyperflexion for ACL reconstruction.

2.2. Equipment

The arthroscopic lens used most commonly for knee arthroscopy is the 30° lens (**Figure 7**). This means that the line of visualization is at a 30° angle to the scope. When visualizing the posterior horn of the meniscus, this is important because the direction of the lens should be turned upside down to direct the angle of visualization towards the back (**Figure 8**). An upright image is maintained by adjusting the scope handle. In the author's experience, there has not been a need for a straight lens. The 70° lens can be used for the following situations: treating pathology behind the patella tendon, such as scar tissue; inspecting the superior portions of the medial and lateral gutters, and visualizing the posterior tibial step-off for Posterior Cruciate Ligament (PCL) reconstructions.

An arthroscopic debrider, commonly called a shaver, is used to debride damaged tissues. The author routinely uses a 4.5 mm shaver with serrated cutting edges for maximal debridement efficiency, especially for a torn ACL. When using this for cartilage or menisci, the shaver edge is first used to debride the damaged tissue, and the shaver gradually moved towards normal tissue with a controlled gradual movement to achieve a smooth tissue edge. When used carefully, there is no risk of accidentally debriding normal tissue.

The next important instrument is the radiofrequency ablation probe, or commonly called a wand. The wand delivers electrical energy to its tip, generating intense localized heat that coagulates tissues. There are two modes, cutting and coagulation. The cutting mode delivers a continuous high-frequency current, which heats the tissue so strongly that the cells are explosively destroyed, severing the tissue. The coagulation mode delivers high-frequency current in pulsed mode, delivering a lower energy such that the tissue dries out without being severed. The wand is a useful instrument for shrinking synovial tissue, smoothing out a rough meniscal edge or cartilage edge with fibrillations, and dissecting tissue off bone, for example when preparing the lateral femoral condyle in ACL surgery.

The most commonly used arthroscopic fluid is 0.9% Sodium Chloride, which is a physiological irrigation solution compatible with living tissues. For standard arthroscopy cases such as

Figure 7. Arthroscopic instruments. From top to bottom, they are: arthroscopic viewing camera, radiofrequency ablation instrument (wand), arthroscopic debrider (shaver).

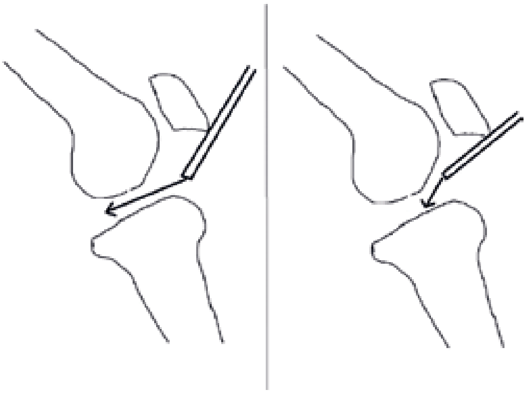

Figure 8. The diagram on the left illustrates the correct way of directing the angle of visualization to the posterior part of the knee. The diagram on the right is the wrong way.

cartilage or meniscal debridement and wash-out, a fluid management pump is not required. The author uses a fluid management pump for ACL surgeries, in particular for the drilling of the femoral tunnel. This is because hyperflexion of the knee for drilling of the femoral tunnel may decrease the tourniquet effectiveness due to the extreme positioning. At this stage, the irrigation pressure can be increased to 80 mmHg to maintain adequate visualization. At other times of the surgery, the fluid pressure can be at 50–60 mmHg to maintain just a clear view without excessive risk of fluid extravasation into tissues.

3. Standard knee arthroscopy

A standard knee arthroscopy starts with the positioning and set-up as detailed in the previous section. A dose of intravenous antibiotics as according to each surgeon's institution guidelines should be given at least 5 minutes before the inflation of the tourniquet. Following cleansing and draping of the knee, surface markings are drawn followed by inflation of the tourniquet and commencement of the procedure (**Figure 9**). The first portal to be established is the anterolateral portal. This should be situated at the level of the inferior pole of the patella with the knee in 90°, and as close to the lateral edge of the patella tendon as possible. Correspondingly, the anteromedial portal is at the same level and situated as close to the medial edge of the patella tendon as possible. Taking in mind that the tibial plateaus are dish-shaped, the height of the portal at the inferior pole of the patella allows access to the posterior part of the tibiofemoral articulation. In the author's experience, portals established any lower to this height will have poorer access to the posterior of the knee.

The incision of the portal should be with a Size 11 surgical blade, made with the knee in 90°, and aimed towards the trochlear. In the author's experience, fluid injection into the knee before incision is not necessary. Furthermore, a wrong injection into synovium will cause marked synovial swelling that will severely obstruct visualization. Following incision, a straight arterial haemostat is inserted through the synovial tissue with a controlled force and the tip of the haemostat felt to touch the trochlear. A controlled insertion is important to avoid inadvertent

Figure 9. Standard incisions for ACL reconstruction.

damage to the trochlear cartilage. The haemostat is then opened to dilate the track. The scope trocar is inserted in the same direction, and similarly felt to contact the trochlear, before the knee is extended and the trocar driven beneath the patella into the suprapatellar pouch. The trocar is then removed, leaving the sheath, and the 30° lens inserted and locked into place. Following visual confirmation of placement in the suprapatellar pouch, fluid irrigation can be started. Where there is a lot of synovial debris, a washout of the suprapatellar pouch will first be performed using the irrigation.

A diagnostic arthroscopy starts with examination of the suprapatellar pouch with the knee in extension. Pathology that can be observed at this stage includes loose bodies, synovitis or plicae. The lens is directed upwards and the undersurface of the patella cartilage inspected. Following inspection of the suprapatellar pouch, the lens is taken over the medial side of the medial femoral condyle while the knee is allowed to flex over the side of the table. The medial gutter can be inspected at this juncture. The medial femoral condyle should be inspected in its entirety, followed by the anterior horn of the medial meniscus and the ACL. Frequently though, the fat pad posterior to the patellar tendon can interfere with visualization and it is at this point that a 21G hypodermic needle can be inserted through the surface marking of the anteromedial portal. The direction of the needle should be checked and confirmed to be able to give a direct line of access to the posterior horn of the medial meniscus. A stab incision is then made and the track dilated with a straight haemostat. The author routinely use a 4.5 mm incisor shaver to debride adhesions and reduce the size of the fat pad and synovium just enough for visualization. There is often a rudimentary ligament at the anterior aspect of the tibiofemoral articulation which can be safely excised. The fat pad can also be downsized using the 90° wand, alternating between coagulation (for hemostasis of bleeding points) and cutting (for shrinking tissues). Adequate visualization is achieved when the anterior horn of both medial and lateral menisci are easily visualized together with the intermeniscal ligament. The ACL and PCL can be checked for laxity using a probe.

With the knee at different angles of flexion, the direction of the portal changes slightly due to the difference in position of the skin relative to the capsule and synovium. With experience, primarily through development of muscle memory, the surgeon is able to quickly locate the right direction of entry without forcefully creating another tract. Additional tracts through the capsule or synovium should be avoided as these are all potential sites for joint fluid extravasation and represents unnecessary additional tissue damage. To enhance easy insertion of instruments and changing of the scope through different portals, the track should be adequately dilated using the haemostat. With the scope in the anteromedial portal, the wand should be inserted through the anterolateral portal and used to shrink the synovium around the opening of the tract and vice versa.

To visualize the posterior horn of the medial meniscus, the knee is held at a 20–30° flexion with the patient's foot resting in the surgeons' hip. Putting the knee at 20–30° eliminates the ACL's contribution to stability, leaving only the medial collateral ligament (MCL) as a restraint against a valgus force. The patient's thigh is blocked by the side support, and the surgeon can exert a valgus force on the knee by moving his entire body outwards. Additionally, an assistant can help to apply more valgus force onto the knee (**Figure 10**). By slowly varying the angle of flexion using his hip, the surgeon will be able to find an angle of best access. Sometimes, this maneuver does not suffice to allow access to the posterior horn in muscular young adult male patients or patients with post-traumatic knee arthritis and joint stiffness. A method of improving access is by needling the MCL from within. An 18G spinal needle is inserted from the anterolateral portal. The spinal needle is directed towards the body of the medial meniscus, inferior to it. The curved tip is pointed inferiorly to avoid injury to the meniscus. The deep MCL and superficial MCL is then needled below the meniscus, with a gap of about 2–3 mm in between each penetration. This is done with the knee in 20–30° with a constant valgus force applied to gradually open up the medial compartment. It is important to apply a sustained gradual force and avoid sudden excessive valgus forces to avoid creating an iatrogenic MCL tear. This technique is sufficient to open up the medial compartment for visualization and instrument access. A similar method is needling the MCL from outside the skin and observing the needle penetrating the joint below the meniscus [3]. Both techniques work well but doing it from within avoids puncture marks on the skin and is more accurate in avoiding the meniscus.

To visualize just the posterior root of the medial meniscus, the scope can be inserted from the anterolateral portal and driven through the notch. This can easily be done in patients with a lax ACL and a wide notch. In patients with an intact ACL, a trans-patellar tendon portal is sometimes required in order for the scope to adopt the right direction to penetrate the notch. The direction of the scope should be medial to the ACL and inferior to the femoral insertion of the PCL.

Figure 10. Applying valgus force on the knee with an assistant's hand acting as a pivot.

To visualize the posterior horn of the lateral meniscus, the tip of the scope is first placed just lateral to the ACL with the knee at 90°. The leg is then brought over the other leg to adopt a 'figure of 4' position. A downward force on the knee is applied by an assistant and the scope can be inserted into the lateral tibiofemoral compartment (**Figure 11**). This position allows work to be done on the posterior horn of the lateral meniscus, with the scope inserted from the anteromedial compartment and the instruments inserted from the anterolateral compartment.

Following an arthroscopic inspection of the whole joint, the required work is then performed. Standard knee arthroscopies are often done as a debridement procedure in middle-aged patients with knee osteoarthritis. Worn-down or damaged cartilage is graded according to the Outerbridge or International Cartilage Repair Society (ICRS) classification. Menisci damage is classified according to the morphology (fraying, tear, horizontal cleavage) and location (within the white-white, white-red, or red-red zone). Routine debridement procedures involve

Figure 11. Applying downward force with the knee in a 'Figure-of-4' position opens up the lateral joint.

debriding damaged cartilage or menisci down to a stable and smooth rim with a combination of the shaver and wand. Degenerated menisci involving the white-white zone can be safely debrided. However, if the meniscal damage involves the red-red zone, an attempt should be made to repair the meniscus wherever possible and biologically feasible. Intra-articular loose bodies or prominent osteophytes, especially patellar osteophytes, can also be removed. Plicae, if present, are usually abnormal condensations of the capsule/retinaculum and can create pain when they abrade or impinge against the femoral condyles. They can be excised with a combination of the arthroscopic scissors and the shaver. Boggy synovial hypertrophy can be downsized as synovitis is also often an important contributor of pain. At the completion of the procedures, the knee is repeatedly washed out using the arthroscopic fluid to remove debris and inflammatory cytokines. The wounds are closed with non-absorbable sutures to achieve a water-tight closure, and generous local anesthetic can be infiltrated around the wounds. A bulky post-operative dressing is applied.

A lateral release is a commonly performed step of routine knee arthroscopy for patients who have tight lateral retinaculum causing a lateral patellar tilt. Patients will commonly have anterior knee pains after walking or running, and examination will show reduced medial translation of the patella and lateral patellar facet tenderness. This should be corroborated by a skyline x-ray view of the knee showing abnormal lateral patellar tilt. Patients with these findings will then do well with a simple lateral release. This step is usually performed at the end of the arthroscopy, because there will be fluid extravasation into the subcutaneous tissues once the lateral release is done. With the knee in extension, a small incision into the suprapatellar pouch is made about 1 cm proximal to the superolateral corner of the patella. A hook radiofrequency ablation tip is inserted through the incision and used to incise the retinaculum longitudinally about 1–1.5 cm from the lateral edge of the patella. The release of the retinaculum should be performed from 1 cm above the superior edge of the patella to 1 cm below the inferior edge of the patella. It is important that only the retinaculum be ablated and released, without ablating the more superficial subcutaneous layer. Another method of doing this is to insert the radiofrequency hook through the anterolateral portal. The patella should be checked for increased medial mobility and the knee taken through flexion to check for an adequate release.

In standard arthroscopy cases without meniscal or cartilage repair/reconstruction, the patient is allowed to weightbear fully after the surgery as pain allows. Static quadriceps contractions, straight leg raise, and active flexion of the knee is encouraged from immediately after surgery.

4. Arthroscopic cartilage repair/restoration

Cartilage repair or restoration is a group of surgical techniques of treating cartilage lesions in suitable cases [4]. Generally, these are middle-aged patients with fairly localized Outerbridge grade 3–4 degenerative cartilage wear, usually over the medial femoral condyle or beneath the patella facet. Patients with Outerbridge grade 1–2 cartilage wear can usually be satisfactorily treated with debridement. Young active patients with very localized cartilage lesions will benefit from Autologous Cartilage Implantation (ACI), where the first stage involves arthroscopically harvesting cartilage from the anterior non-weightbearing surface of the medial or lateral trochlear. The cartilage chondrocytes are then cultivated in the laboratory. The second stage 4–6 weeks later involves an open procedure where a periosteal patch is first harvested from the proximal tibia, stitched in a water-tight fashion over the defect, and the chondrocytes injected beneath the periosteal patch. This procedure aims to regenerate 'hyaline-like' cartilage and has been shown in studies to have results comparable or superior to microfracture [5].

For most patients, the most basic method of treating cartilage lesions is microfracture, known as a marrow stimulation technique. The idea is to allow the release of mesenchymal stem cells from within the marrow into the cartilage defect, forming a blood clot. The blood clot then forms fibrocartilage over 3–6 months. This works well for Outerbridge grade 3–4 lesions about 1 cm × 1 cm in dimension and is more effective for the weight-bearing femoral condyles than for a patella lesion [6]. The area of damaged cartilage is first sized using the tip of the probe (which measures 5 mm), and the damaged cartilage debrided down to subchondral bone. It is important to create vertical wall edges wherever possible. This allows more effective trapping of the resultant blood clot within the defect. An arthroscopic awl is then used to create subchondral punctures in the bone to allow the escape of fat globules from within the marrow. The punctures should be spaced about 3 mm apart. Patients who had microfracture alone do not require protected weight-bearing after surgery. In fact, weight-bearing is beneficial because it compresses the femoral condyles against the tibia, closing off the cartilage defect and allowing formation of a contained blood clot.

Patients who have areas of cartilage damage larger than 1 cm × 1 cm will benefit from a cartilage reconstruction procedure using a commercially available hyaluronic acid scaffold. The scaffold traps the in-coming blood clot effectively, allowing the mesenchymal cells to differentiate and grow along the scaffold. This can come in the form of either a mesh (e.g. Hyalofast) or an injectable gel (e.g. Cartifill). The lesion should not be any larger than 3 cm × 3 cm, and should not have any associated subchondral bone defects. Disease processes such as OsteoChondritis Dissecans (OCD) or Spontaneous OsteoNecrosis of the Knee (SONK) with involvement of the subchondral bone will benefit from Osteochondral Autograft Transfer System (OATS).

Reconstruction using a hyaluronic acid scaffold can be done arthroscopically for lesions on the femoral condyles or tibial plateaus. Following debridement and microfracture of the defect, the surgical field must be adequately dried to prevent loosening of the scaffold during implantation. The fluid inflow is first turned off and remnant intra-articular fluid is drained. Small surgical patties can be used to dry the area around the defect. The knee can be infused with carbon dioxide which effectively dries the area and pushes surrounding synovium away. For lesions on the weightbearing surfaces of the femoral condyles, the knee is place at 90°. Any flexion angle higher than this should be avoided because the anterior knee structures will begin to press downwards onto the condyles. The foot should be propped higher using towels while keeping the knee at 90°, thus flexing the hip. An assistant is vital to keep the leg in this position during implantation. The defect is thus made more horizontal, allowing easier implantation.

When using the scaffold mesh, it should be cut to the defect size or slightly larger, as the mesh will usually shrink when in contact with fluid. The mesh should be lightly dampened with saline to make it more firm and easier to manipulate. The superior point of the mesh is grasped with an arthroscopic grasper, and the mesh brought into the knee, laying the mesh first in the superior portion of the defect. An accessory anteromedial or anterolateral portal is essential to allow insertion of a probe to assist in seating the rest of the mesh. Following seating of the mesh, a fibrin sealant glue (such as Evicel or Tisseel) is laid over the edges of the mesh. It is important that synovium is kept far from the defect so that the glue will not inadvertently stick to the synovium. If it does so, the glue can be allowed to harden first before snipping the adhesion with an arthroscopic scissors. Two minutes is allowed to lapse for the hardening of the glue, and the knee is then ranged carefully to check for the stability of the mesh. It is imperative that throughout the implantation process, the area is kept dry.

For patella lesions, a mini-arthrotomy is often required as there is no conceivable way to implant the scaffold since the patella is downward-facing. With the knee extended, the incision can be done at the midpoint between the edge of the patella and the femoral condyle. Strong vicryl sutures are inserted into the deepest layer of the retinaculum and used to evert the patella, assisted by an assistant's finger on the outside of the patella as a pivot point. It is often possible to satisfactorily treat the lesion with the patella everted to just vertical. The cartilage defect is prepared and the microfracture performed, followed by implantation of the scaffold as described above (**Figures 12** and **13**).

Post-operative care for cartilage restoration includes bracing the knee in a hinged brace, allowing for 0–30° of movement as tolerated. Toe-touch weight bearing with two crutches is allowed. This is applicable for both femoral condyle and patella lesions. Isometric gentle quadriceps exercises and active ankle movement exercises can be started immediately after surgery. The allowable range of movement is gradually increased, and free range of movement can be allowed after 6 weeks.

Figure 12. Open view of a 1.5cm x 1.8cm patella cartilage lesion through a mini-open arthrotomy.

Figure 13. Following debridement of damaged cartilage and microfracture, an injectable collagen scaffold has been injected into the lesion, filling up the cavity and forming a smooth surface contour.

5. Arthroscopic anterior cruciate ligament reconstruction

ACL reconstruction is one of the most common arthroscopic surgeries performed today. Different graft types (hamstring autograft, allograft, bone-patellar tendon-bone), different fixation methods (interference screw, suspensory, transfixion) and different techniques (single-bundle, double-bundle) exist and this chapter will not discuss the large amount of medical literature studying the pros and cons of each. The author performs ACL reconstructions primarily using single-bundle hamstring autografts. Allografts are used for example in revision cases, or if it is a combined ACL/PCL reconstruction. Double-bundle reconstructions are performed only for competitive athletes. The author's method is a trans-portal method that recreates the femoral attachment at the anatomical location. Transportal techniques have been shown to have better clinical outcome and knee laxity scores as compared to transtibial techniques [7]. The following technique describes a single-bundle hamstring autograft reconstruction using a femoral endobutton and a tibial interference screw.

The patient's own hamstrings can be harvested using a 3–4 cm oblique incision placed directly over the palpable 'speed-bumps' that insert into the anteromedial surface of the tibia. Where the speed-bumps are not well-felt, the lowest-most end of the incision should be 2 cm medial and 1 cm inferior to the tibial tubercle. The hamstrings consist of the sartorius, the gracilis, and the semitendinosus and the latter two are harvested. The hamstrings should be harvested with the knee in 90° flexion to allow the tendons to relax and allow for easy identification. Following incision and dissection through subcutaneous fat, the sartorius fascia will be encountered. An incision in line with the skin incision is made in the sartorius fascia and the fascia dissected and peeled away from the tendons. The sartorius fascia will be overlying the terminal tendons of the gracilis and the semitendinosus and will be effectively merged with the tendons at the insertion, so they cannot be properly identified at its insertion. Identification of the tendons should start at the proximal-most end of the incision, where the tendons are still separate. Glistening white tendons should be identified, and from the lowest semitendinosus up. This is because the sartorius may occasionally be mistaken for a tendon on its own especially in large muscular adults, where the sartorius may be more round and tendinous at its insertion instead of spread out like a sheet. The sartorius should not be harvested because it has multiple attachments to the medial tibial surface and surrounding structures due to its sheet-like insertion. Once the semitendinosus and gracilis tendons are identified, the interval between them can be identified and then dissected distally to its insertion, thereby properly separating the tendons. The tendon insertions can then incised, keeping in mind to preserve as much length as possible, the tendon end whipped-stitched, and surrounding adhesions dissected and cut before stripping the tendon. Before stripping the tendon, the ubiquitous band to the gastrocnemius should be cut. The entire length of the surgeon's index finger should be inserted into the wound and felt circumferentially around the tendon and the soft muscular portion of the hamstrings should be felt before proceeding to strip. A closed, blunt stripper is then inserted over the tendon and the tendon stripped from its muscle belly with sustained controlled force. The stripper tip should comfortably pass into the muscle belly before encountering much resistance. If there were resistance felt within the first few centimeters of inserting the stripper, it is likely that there are remnant adhesions. Failure to properly dissect off adhesions to the tendons may result in truncation of the tendons during stripping.

The saphenous nerve is in the vicinity during harvest of the hamstrings. The reported incidence of post-operative sensory disturbance is as high as 74–88% as reported in the literature [8, 9]. The infrapatellar branch of the saphenous nerve is also commonly damaged during hamstring harvest. While it is not possible to completely eliminate the risk every time due to anatomical variabilities, steps can be taken to minimize the risk. It has been found that an oblique incision carries a lower risk compared to a vertical incision [10]. After incising the sartorial fascia, dissecting the fascia separate from the tendons is done carefully and in a blunt manner. This is because the saphenous nerve can be closely apposed to the sartorial fascia at this level. Any obvious nervous structure should be preserved. Also, the nerve is also in close proximity with the distal portion of the gracilis tendon. Cutting of bands from the gracilis tendon must be done under direct visualization, and all sartorial and surrounding adhesions must be bluntly freed before stripping the tendon. During closure of the wound, stitching of the fascia must be done with only small needle bites, and the fascia is merely apposed but not bundled tightly together. Using these steps, the author finds a rate of less than 10% of patients reporting persistent post-operative numbness or sensory disturbance in the infrapatellar area of the knee, and perhaps 1–2% of patients reporting saphenous nerve sensory disturbances.

The graft is prepared on the back-table by first removing all remnant muscular attachments. For a quadrupled graft, both ends of the both tendons are whip-stitched and the folded quadrupled graft sized and then kept under tension. After drilling of the femoral tunnel and measurement of the tunnel length (usually femoral tunnel length will be about 40 mm), the appropriate endobutton will be opened and the graft threaded through the endobutton. The intra-articular portion of the quadrupled graft is then stitched together. If a particularly long graft is obtained (e.g. more than 24 cm), each graft can potentially be tripled to produce a sextupled graft. Generally at least 8–9 cm of graft will be a sufficient length for appropriate fixation in both femoral and tibial ends using a femoral endobutton and a tibial interference screw. If a sextupled graft is used, then the whip stitches will only be at one end of the graft.

Following threading of the graft through the endobutton, the graft is tripled, and the entire graft stitched together at the loop of the endobutton and throughout the entire graft, to prevent the graft from adjusting within the loop.

Standard positioning for ACL reconstruction is with 2 foot-rests. Following standard arthroscopic evaluation and debridement of remnant ACL tissue, the femoral tunnel is prepared first. Remnant tissue if available on the lateral femoral condyle can be used as a guide to the insertion point of the guide wire. Otherwise, the Resident's Ridge is a reliable landmark which is consistently present in nearly all knees. With the knee in anatomical position, the Ridge is a linear landmark that runs from superior-anterior to inferior-posterior across the lateral femoral condyle, more-or-less dividing the wall of the lateral femoral condyle into an anterior and posterior half. With the knee bent at 90°, the terminology can be confusing, so it is important to only refer to the landmarks based on anatomical terminology. The femoral insertion site of the ACL is in the posterior half of the lateral femoral condyle and slightly superior. Preparation of the wall of the lateral femoral condyle should show the Ridge and the entire wall inferior, posterior and superior to the Ridge. The anatomical landmark is at the halfway point between the Ridge and the posterior cartilage margin, and just slightly (1–2 mm) superior to the halfway point between the inferior and the superior cartilage margins. Proper visualization of the wall is through the anteromedial portal with a 30° lens. With the knee hyperflexed, the guidewire can be first inserted through the accessory anteromedial portal to judge its trajectory and position. The accessory anteromedial portal is more medial to the standard anteromedial portal and is as low as possible without injuring the medial meniscus. This ensures a trajectory of the guidewire exiting the anterolateral femoral cortex. With this method, there is no necessity to perform a notchplasty. The guidewire can be lightly tapped with a mallet to first engage the femoral condyle wall, before being advanced with the drill. With satisfactory guidewire positioning, the lateral cortex is then broken. The length of the tunnel can be measured at this point, following which the guidewire is re-inserted and the appropriate reamer used to create the femoral tunnel to a depth about 5 mm less than the length of the tunnel. For a standard 40 mm femoral tunnel, the 15 mm endobutton is used, giving a 25 mm length of tendon within the tunnel.

The tibial tunnel position should be centred at a point about 40% of the antero-posterior length of the tibial plateau from the anterior end backwards. Medio-laterally, it should be centred just slightly lateral to the medial tibial intercondylar tubercle. Arthroscopically, the centre of the tibial tunnel should be on the medio-lateral line just traversing the posterior part of the anterior horn of the lateral meniscus, and on the antero-posterior line just traversing slightly lateral to the highest point of the medial tibial intercondylar tubercle. This will ensure the entire graft is situated anterior to the line connecting the highest points of the medial and lateral tibial intercondylar tubercles and is medial enough. This is the anatomical position for a single-bundle reconstruction and will give the best results in terms of anterior drawer and rotational control. With the scope in the anterolateral portal, it is important to assess the tibial tunnel position from both an anterior view and from a lateral view to obtain an accurate judgment of the location. Sometimes, the 70° scope is used to assess the anatomy accurately. The tibial drill guide is inserted through the anteromedial portal and the guidewire inserted through the incision used for harvest of the hamstrings. The tunnel is then reamed and a shaver inserted through the tunnel to clear out debris and smooth the entry and exit edges of the tunnel.

Figure 14. With the knee in 90°, the reconstructed ACL graft should appear as a low-lying graft passing from the anterior part of the medial tibial eminence to the lateral femoral condyle.

Following passage of the graft and flipping of the endobutton, the knee is cycled about 15–20 times while maintaining tension on the graft. This allows even distribution of tension throughout the diameter of the graft and allows stress relaxation. The tibial end is then fixed with an interference screw usually 0.5–1 mm larger than the diameter of the tunnel itself and with the knee in 20° of flexion and a posterior drawer on the tibia. A final check arthroscopy can then be done, assessing the final position of the new graft. The knee can also be brought to full extension and the graft arthroscopically checked to ensure no impingement on the femoral trochlear, though with anatomical positioning of the tunnels, there should be none (**Figure 14**). The wounds are closed in standard fashion followed by a generous subcutaneous infiltration of long-acting anesthetic.

The author's post-operative rehabilitation protocol consists of the following:

1. First 2 weeks: A hinged knee brace locked at 0–30°, worn all the time. Patient to perform static quadriceps and straight leg raise exercises.
2. Second 2 weeks: The brace can be removed while awake and not ambulating, but worn at night and if ambulating. The degree angle need not be adjusted as the patient can perform flexion exercises when the brace is not on. Patient can start to perform prone hang and passive flexion exercises.
3. Third 2 weeks: The brace can be removed at night, and worn only during ambulation. Again, the brace angle need not be adjusted. The locked brace will continue to protect the patient's ACL during activities such as ascending/descending stairs or getting in/out of a car. Closed-chain exercises can commence. The brace can be taken off after the third 2 weeks.

6. Arthroscopic meniscal repair

Meniscal repair methods include all-inside, inside-out, and outside-in techniques. However, with the advent of a range of commercially available products and instruments for all-inside repair, this technique has become standard practice to treat all meniscal tears wherever possible. Meniscal tears are classified by their location and pattern of tear. Tears affecting the white-white zone, the edge of the meniscus, can be debrided to a stable and smooth edge since this zone is avascular and will not heal well with repair. Tears affecting the white-red zone or the peripheral red-red zone should be repaired wherever possible. An MRI is a prerequisite before surgery to repair the meniscus. It elucidates the location and the likely pattern of tear, but it should be noted that MRI is a static assessment of the meniscus with the knee in an extended position. Significant displacements that occur with the knee in a deep flexion position may not be seen on the MRI [11]. It is therefore important that arthroscopically, an assessment of the stability is made both with a probe and with the knee in varying degrees of flexion. One important pathology to look out for on the MRI is a root tear. The signs of a root tear on the MRI include the 'ghost' sign on the sagittal cut of the root (meniscus root appearing faintly and poorly defined), the truncation sign on the coronal cut (the posterior horn appears to be abruptly truncated and separated from its tibia attachment), and extrusion of the body of the meniscus on the coronal cut, indicating a lateral displacement of the entire meniscus [12]. Root tears should always be repaired as an unrepaired root is grossly unstable and will quickly lead to osteoarthritis.

All-inside fixation devices typically consist of a delivery needle that penetrates the meniscus and deploys fixation tabs behind the capsule. These come with a pre-tied, self-sliding knot that can be pushed downwards onto the meniscus after deployment of the fixation tabs, locking the meniscus in place. The delivery needles are usually curved slightly, giving the surgeon versatility in the direction of the penetration into the meniscus. Vertical mattress sutures have been shown to have higher fixation strength than horizontal mattress sutures. Importantly, these devices are only used for the posterior horn and body of the menisci. Anterior horn tears will need to be repaired with an outside-in technique usually. When using the all-inside devices, the needle itself can be used as a reduction device since there is usually little room to admit another instrument to hold the meniscus in place. For example, for a horizontal flap tear in the posterior horn of the meniscus, the needle can first be used to penetrate the upper flap, and used to bring the upper flap over the lower flap in a reduced position, then penetrated through the lower flap to the deploy the first tab (**Figures 15** and **16**). For bucket-handle tears, it is often useful to provisionally reduce the meniscus by using a smooth suture passed through the body of the meniscus using an outside-in needle. The body of the meniscus can be held in place with a grasper while the needle penetrates the body. The suture is passed through the needle and retrieved outside either of the anterior portals. The needle is then passed one more time from outside-in either above or below the meniscal edge, and a lasso passed through and retrieved outside the same portal as the one with the end of the suture. This end of the suture can then be shuttled back outside the knee, and traction applied to provisionally reduce the body of the meniscus. The rest of the meniscus can then be fixed using all-inside fixation.

Repair of the meniscus will start with an assessment of the location and morphology of tear, in order to guide optimal suture placement. Fibrillated or torn edges in the white-white zone can be debrided to a stable rim. The remaining tear surfaces in the white-red or red-red zones are first abraded using an arthroscopic rasp to create bleeding vascular channels to optimize

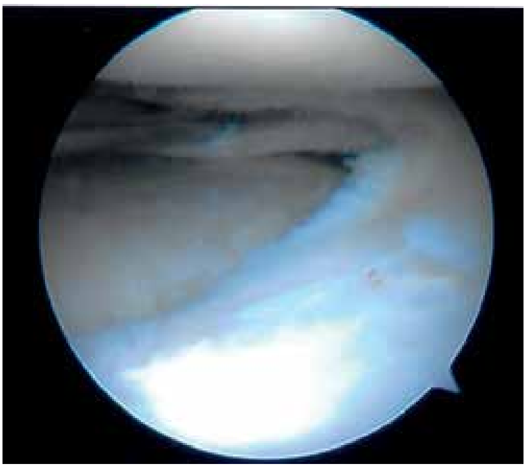

Figure 15. A cleavage tear of the posterior horn of the medial meniscus.

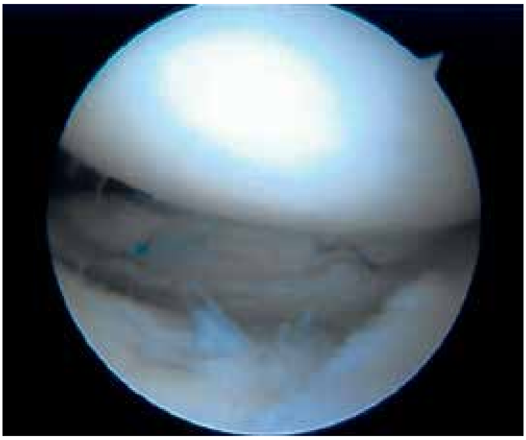

Figure 16. Following meniscal repair with all-inside fixation devices closing the cleavage and debridement of the frayed edges.

biological conditions for healing. Another described method is to use a needle to penetrate the tear surfaces, called trephination. When working with very unstable tears, it is useful to use a grasper to hold the meniscus in place while the rasp or needle is used. The grasper can be inserted from an accessory portal on the same side as the meniscus tear. Following abrasion or trephination, the meniscus can be repaired. Sometimes, instead of a tear in the meniscus itself, it is a separation of the meniscus from the capsule, called a menisco-capsular separation (also called a ramp lesion). This will result in abnormal increased mobility of the meniscus and should be repaired as well. Radial tears can be repaired using an arthroscopic suture-passer (for example Arthrex Knee Scorpion) or an all-fixation device (for example Smith & Nephew FastFix 360). The arthroscopic suture-passer is small enough and allows easy passage and retrieval of suture through the meniscus. The surgeon then ties arthroscopic knots to repair the meniscus.

Meniscal root tears, as mentioned above, should always be repaired [13]. The attachment site of the root on the tibial plateau should be freshened with a serrated curette or even a motorized burr to create a fresh bleeding surface. Using the ACL tibial drill guide aimer, a transtibial tunnel is created. The undersurface of the root should also be freshened with a rasp. There are different methods of repairing root tears, including using trans-tibial sutures to pull the root down or suture anchors inserted via an accessory posteromedial portal. There are also different ways of suture passage through the root. One commonly used method is cinching the suture, meaning passing the suture through its own loop. However, this often creates fixation only along the edge of the meniscus. The author's preferred method is to insert the suture in a cruciate manner in the root, creating an undersurface area of fixation rather than just an edge of fixation. The dimensions of the cruciate should be slightly larger than the width of the transtibial tunnel, which is usually about 4 mm to admit a suture lasso device to shuttle the root sutures through the tibial tunnel. The sutures can then be tied over a button on the surface of the proximal tibia.

7. Complications of arthroscopy

Even though uncommon, every surgeon should be aware of potential complications of arthroscopy and these should be fully discussed with the patient before a decision for surgery is made. Infection remains one of the most feared complication with an incidence rate of 0.1–0.4%, and the most likely period of presentation within the first month after surgery. Where there is a suspicion of an intra-articular infection, aspiration should be performed for an immediate diagnosis through Gram Stain and bacterial cultures. Proven intra-articular infection of the knee should be treated with an open arthrotomy, wash-out and synovectomy. In ACL reconstructions, if the presentation had been fairly acute and treatment fairly expeditious, the graft may be retained. However, for more insidious infections that typically present over a longer time-frame, the graft should be excised and the femoral and tibial tunnels curetted. Infection in ACL reconstructions carries a high risk of a poor outcome with eventual stiffness.

There are several nerves which may potentially be damaged during arthroscopic surgery. When harvesting the hamstrings for ACL reconstruction, the anatomical variation of the saphenous nerve and its infrapatellar branches means that there is a high risk of damage to some of these branches with a resultant numbness or sensory difference in the infrapatellar area. In the literature, sensory nerve damage is very common during hamstring harvest, but the resultant numbness can be minimized using careful dissection and harvesting techniques as described in Section 5 above.

When repairing the lateral meniscus around the body/posterior horn junction using all-inside fixation devices, a potential risk is overpenetration of the needle device, injuring the common peroneal nerve. To minimize this risk, it is important to carefully penetrate the needle device through the meniscus, and ensure the tip penetrates to just immediately outside the capsule. It is important to have a mental awareness of where the tip ends up even though it will be out of our visualization once it penetrates the capsule. It is also important to use a trajectory that is away from the central popliteal neurovascular bundle, and to use a curved delivery device that allows the surgeon to direct it away from the area of danger. Also, the penetration depth should be adjusted depending on the size of the patient [14]. For average sized males, a penetration depth of 14 mm can be used quite safely, 16 mm being the distance from the point of penetration on the meniscus to the tip of the device. For slim females, the depth can be adjusted to 12 mm. Keep in mind that penetrating the meniscus and pushing the device through the meniscus will also compress the meniscus towards the capsule, so if the device is entirely pushed through to the pre-set depth limit, the tip of the device may end up even deeper than anticipated. If repairing the lateral meniscus using inside-out methods, a posterolateral incision should be made and the biceps femoris retracted posteriorly to protect the nerve. The common peroneal nerve branches off the sciatic nerve at the distal part of the thigh and runs in between the lateral head of the gastrocnemius and biceps femoris muscles. It follows the biceps muscle distally where it wraps around the fibular neck. Injury to the common peroneal nerve is a debilitating complication causing the patient to develop foot-drop. The prognosis of a neurapraxic injury of the nerve is moderate at best, with 50% achieving full recovery within 6–12 months and 50% never recovering fully. Treatment is essentially supportive with an ankle-foot orthosis.

When performing PCL reconstructions, the proximity of the popliteal neurovascular bundle to the PCL mandates a posteromedial incision with the dissection just along the posterior capsule of the knee. The knee should be at 90° of flexion. The medial head of the gastrocnemius muscle is lifted posteriorly and a blunt trocar used to create a track along the posterior edge of the tibial plateau. When performing this step, the surgeon should maintain intra-articular visualization using the scope and observe the trocar come into view. The PCL is intra-articular at the femoral end and extra-articular at the tibial end, and so debriding the torn PCL will open the posterior capsule already, allowing the trocar to come into the posterior part of the knee. Seeing the trocar come into view indicates the correct placement of the trocar in the posterior part of the knee anterior to the popliteal bundle. This tract can then be dilated and the posterior tissues lifted off with the trocar during PCL tibial tunnel guide-wire drilling. When reaming the tibial tunnel, the terminal reaming of the posterior cortex should be strictly done by hand.

Deep vein thrombosis after a knee arthroscopic surgery remains very uncommon, and it is not routine to anticoagulate patients unless they have predispositions for deep vein thrombosis, such as inherited clotting tendencies, or combinations of factors such as poor mobility, cancer or smoking. The post-tourniquet syndrome is a commoner complication, consisting of numbness of the leg and weakness of the quadriceps following a prolonged period of tourniquet inflation, causing a neurapraxia of the femoral nerve. Neurapraxia of the sciatic nerve with resultant foot-drop is rare. This syndrome is treated symptomatically and is expected to recover fully. It is recommended that the tourniquet should be temporarily let down after about 100 – 120 min of inflation to prevent this complication. Death by pulmonary embolism is very rare but may be a reason for litigation, as are unfortunate situations such as wrong-sided surgery or retained instruments [15].

8. Conclusion

Knee arthroscopy is a vital skill for all orthopedic surgeons to have. This chapter describes the essential techniques required of an arthroscopist. The keys to technical success are appropriate pre-operative planning and thoughtful execution. To interpret the anatomy of intra-articular pathology, the arthroscopist should correlate what he views through the scope with a mental overview of normal knee anatomy.

Conflict of interest

The author has no conflicts of interest associated with any of the medical devices mentioned in this chapter.

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Single-Bundle Anterior Cruciate Ligament Reconstruction

Kavin Khatri, Darsh Goyal and Deepak Bansal

Additional information is available at the end of the chapter

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Abstract

Anterior cruciate ligament (ACL) reconstruction is one of the most common procedures performed in orthopedics. The research has focused extensively on surgical technique factors like tunnel position, graft choices, fixation methods, and rehabilitation protocols following surgery. The advantages and disadvantages of each graft option shall help in deciding the correct graft in an individual case. A thorough understanding of anatomy and biomechanics of normal ACL has improved the understanding of complexities of knee joint stabilization over the preceding decades. The chapter shall discuss in detail about the anatomy, biomechanics, and surgical techniques along with postoperative rehabilitation protocol in current perspective.

Keywords: anterior cruciate ligament, injury, repair, ACL rehabilitation, preoperative rehabilitation, postoperative rehabilitation

1. Introduction

Anterior cruciate ligament (ACL) is the primary stabilizer for pivotal activities of the knee. In the early nineteenth century, Hay Groves and Ivor Palmer advocated repair of ACL [1]. However, the high rate of failure after repair shifted the focus to reconstruction of ACL. Macintosh advocated extra-articular reconstruction of ACL which was subsequently replaced by intra-articular approach popularized by Erikson [2, 3]. The choice of graft also shifted from patellar tendon to semitendinosus over the years [4, 5]. There has been marked improvement in surgical procedure with change from open to arthroscopic procedure. Similarly the pain management has improved significantly since then.

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2. Anatomy

The major reason for the failure of ACL reconstruction is the improper placement of tunnel either femoral of tibial. So, it is imperative to know about the natural anatomy of the ACL insertion over the tibia and femur. It is an intra-articular but extrasynovial ligament of knee providing primary constraint to the anterior translation of the tibia and secondary stabilizer to varus and valgus stress to the knee. It comprises type I collagen peptide and viscoelastic properties similar to other ligaments in the body.

It comprises two bundles, i.e., anteromedial bundle and posterolateral bundle (**Figure 1**). The anteromedial bundle is tightened in 60 or more degrees of flexion, while posterolateral bundle is tight in extension. In extension both bundles are in parallel orientation along the sagittal plane, whereas in flexion of the knee, the insertion of posterolateral bundle moves anteriorly, and they appeared crossed [7, 8].

The names of the two ACL bundles are based upon the relationship between the two at the insertion point on the tibia. Both bundles originate from the posteromedial aspect of lateral femoral condyle and insert over the tibia just anterior to the intercondylar eminence. The diameter of both bundles varies from 7 to 17 mm, while the length of anteromedial bundle is slightly longer than posterolateral bundle measuring approximately between 28 and 38 mm [9, 10]. The cross section of the ACL bundle in midsubstance cross section varies from 36 to 44 mm^2.

The blood supply of ACL is primarily from middle geniculate artery which is a branch of popliteal artery. Inferomedial and inferolateral genicular arteries supply the ACL through anterior fat pad. ACL receives nerve fibers for proprioception through a branch of posterior tibial nerve [11].

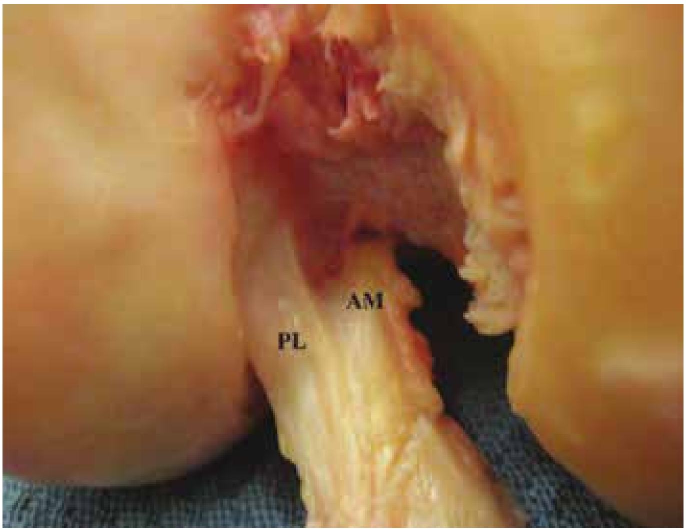

Figure 1. Distal femoral condyle showing the two bundles (anteromedial [AM] and posterolateral [PL] bundles) of the anterior cruciate ligament (reprinted with permission from Ref. [6]).

3. Biomechanics

The tensile strength of native ACL has been estimated to be within the range of 1725 ± 269 N [12]. ACL was initially thought be subjected to isometric stresses throughout the range of motion; however, biomechanical studies demonstrated that the ACL is subjected to differential stresses in movement of the knee [13]. The anteromedial bundle experiences maximum stress in flexion, while posterolateral bundle experiences maximum stress in extension [14]. The posterolateral bundle bears the majority of the stress during knee motion. The single-bundle ACL reconstruction had stressed upon the restoration of anteromedial bundle leaving behind the posterolateral reconstruction [15]. Consequently, it was noticed that there were experiences of rotational instability and persistent pain in almost 31% cases. There has been now shift in focus from single-bundle to double-bundle ACL reconstruction improving the knee biomechanics.

4. Mechanism of injury

In majority of the cases, the flexed knee is subjected to rotational stress leading to ACL injury. The contraction of quadriceps leads to subluxation of the tibia anteriorly with failure of hamstrings to prevent the anterior subluxation.

In contact sports like football and hockey, the direct blow from the lateral aspect of the knee in a flexed and externally rotated position leads to tear in medial collateral ligament (MCL) and anterior cruciate ligament.

5. Diagnosis

5.1. History

The athlete gives a history of twisting injury to knee with popping sensation. There is associated swelling and pain. There is sensation giving away of the knee with respect to body. There are marked variations in the presenting symptoms ranging from mild pain and swelling to inability to bear weight. In the presence of associated injuries like fracture of the tibial shaft or femur, the injury to ACL is sometimes missed [16].

5.2. Physical examination

5.2.1. Swelling

There is swelling of the knee associated with the ACL injury due to hemarthrosis. The swelling might take some time before manifesting itself. The knee can be aspirated in selected cases of severe knee pain. If there are fat globules in the aspirate, then the intra-articular fracture is suspected.

5.2.2. Joint line tenderness

Both medial and lateral knee joint line should be palpated to assess the injury to medial and lateral meniscus. There is an associated meniscal injury in up to 50% of cases. The lateral meniscal tear is more common than medial meniscus tear. McMurray's test is difficult to perform in cases of acute knee injuries due to limitation in flexion.

5.2.3. Lachman test

It is the definitive test to detect the ACL injury. The knee is positioned in 20–30° of flexion. One hand is placed over the thigh to hold it firmly, and another hand is positioned such that the thumb is over the tibial tubercle and fingers across the calf region. The tibia is pulled forward with the lower hand placed over the tibia, and degree of anterior tibial translation is noted. The anterior displacement of the tibia by less than 5 mm is graded as 1+, between 5 and 10 mm as 2+, and more than 10 mm as 3+. Practically the firm end point indicates no injury, while soft end point indicates ACL injury.

5.2.4. Pivot shift test

It is a more consistent test to detect the ACL injury. The patient lies supine with legs extended. The examiner holds the heel of the involved leg and with opposite hand holding the leg just distal to the knee applies a valgus stress and an axial load while internally rotating the tibia when moving from full extension to flexion. A positive test is indicated by tibial subluxation with femoral rotation followed by reduction of the tibia at 30–40° of flexion.

5.2.5. Anterior drawer test

This test is usually carried out in chronic ACL injuries. The knee is bent at 90°, and both hands are kept over the proximal tibia giving an anteriorly directed pressure to look for anterior subluxation of the tibia. Positive test is indicated by soft end point with anterior subluxation of the tibia. Before performing the test, it is mandatory to rule out posterior cruciate ligament (PCL) injury by noting the anterior step off of the tibia with respect to femoral condyle.

5.2.6. Active quadriceps test

The anterior subluxation of the tibia on active contraction of quadriceps is indicative of ACL-deficit knee. The active quadriceps contraction is generally avoided in recently constructed ACL to prevent excessive pressure over the graft.

5.2.7. KT-1000 arthrometer

It is used to measure anterior and posterior translation of the tibia with respect to the femur. It is used to quantify the amount of anteroposterior translation of the tibia in ACL injury. The patient is placed in supine position with thighs supported with bolster keeping the knee in approximately 30° of flexion. The arthrometer has two sensing pads: one is positioned over the patella, and the other is placed over the tibial tubercle. The arthrometer is secured to the leg with Velcro straps. The anteroposterior translation is measured by relative motion between sensory pads. When the examiner applies anterior force through handle, a tone is heard at 67, 89 and 133 N. The readings are recorded and evaluated. A side-to-side difference of less than 3 mm at 67 N and maximum force is considered normal. The side-to-side difference is more than 5 mm and is considered diagnostic of an ACL tear.

5.2.8. *Range of motion*

The movement of the knee is compared with the uninjured knee. The loss of extension is seen in cases with associated bucket handle tear of meniscus or torn fragments of ligament impinging anteriorly.

5.2.9. *Assessment of collateral ligaments*

The injured knee is given varus and valgus stress at 0 and 30° of flexion. The opening of medial or lateral joint space is graded from zero to three depending upon the amount of opening noticed on stress. Grade I injury is mild opening of less than 5 mm, grade II is opening between 5 and 10 mm, and grade III is opening of more than 15 mm.

5.2.10. *Associated ligament injuries*

It is important to document associated PCL and posterolateral corner injuries as the influence of the management of ACL injury.

5.2.11. *Neurovascular assessment*

It is imperative to document injures to neurovascular injuries though they are rarely associated with isolated ligament injuries.

5.3. Imaging

5.3.1. *Radiographs*

Anteroposterior and lateral radiographs of the knee are carried out to detect the bony avulsions, osteochondral fractures, and tibial plateau fractures.

5.3.2. *Computerized tomography*

It is used to detect the suspected tibial plateau fracture that may be associated with ACL injury.

5.3.3. *Magnetic resonance imaging*

In acute setting the hemarthrosis may mask the ACL and meniscal injuries and sometimes even the minor injuries to ACL present as significant strains. It may detect the associated bone bruises and other ligament injuries. Generally the MRI examination should be delayed by

2–3 weeks for correct assessment of ACL injury. However, it is important to note that a good clinical examination is more informative and useful that an MRI to assess knee ligamentous injury (**Figure 2**).

5.3.4. Examination under anesthesia

The patient should be examined under anesthesia to reconfirm the findings of previous examinations. Sometimes due to spasm of muscles and pain, the laxity of the knee may be graded on a lower scale; hence, examination under anesthesia is important to assess the ligamentous injuries.

5.3.5. Diagnostic arthroscopy

Sometimes the findings of the MRI and clinical examination are equivocal, and diagnostic arthroscopy is carried out to look for pathology. In few cases the MRI findings may be falsely positive which can be ascertained on diagnostic arthroscopy [18].

5.4. Treatment decision

The treatment of ACL should be individualized to the patient. The two options in ACL tear are:

a. Activity modification: the patient can opt for sports like cycling or swimming from contact sports. If there are no giving away episodes, then he can opt for conservative treatment.

b. ACL reconstruction: in order to prevent early degenerative arthritis and return to previous activity level, the patient is advised to undergo ACL reconstruction.

Various factors should be considered before opting for operative or nonoperative treatment.

Figure 2. Signs of anterior cruciate ligament tear: (A) midsubstance discontinuity (white arrow heads), residual stump of ACL on tibial (white arrow), and femoral side (white asterisk); (B) complete resorption of ACL fibers and buckling of posterior cruciate ligament (PCL); (C) some fibers are shown in continuity (white arrows) suggestive of partial ACL tear (reprinted with permissions from Ref. [17]).

5.4.1. Age of patient

The older patients are given the option of nonoperative treatment with lifestyle modification. Young patients involved in sports activities are subjected to ACL reconstruction.

5.4.2. Activity level

The sportsperson shall require operative treatment in order to return back to sports activity of the same level.

5.4.3. Degree of instability

If side-to-side difference on KT-1000 arthrometer is more than 7 mm, then chances of successful surgical reconstruction are good.

5.5. Nonoperative management

a. The use of extension splints and crutches for mobilization in early ACL injury as it allows the healing of associated meniscocapsulolabral tears

b. Cryotherapy to reduce the swelling and pain

c. Range-of-motion exercises to regain the movement of the knee

d. Progressive strengthening exercises to regain tone of the quadriceps and hamstrings

5.6. Operative management

5.6.1. Timing of operative intervention

There is controversy over the timing of repair. Shelbourne had advised wait period of 3 weeks before reconstruction. He advocated that there are high chances of knee stiffness and loss of range of motion if operative procedure is carried out in acute phase [19]. However, Pinczweski reported good results with early reconstruction of ACL [20]. The general consensus is to wait till the swelling subsides, and good range of motion is achieved at the knee.

5.6.2. Graft selection

The various grafts available for ACL reconstruction are patellar tendon bone graft, hamstring graft, allograft, and synthetic tapes. The choice of graft depends upon the individual case, surgeon's experience, and preference.

In the 1970s, Erikson popularized the patellar tendon bone (PTB) as the graft for ACL reconstruction. It was the popular choice till the late 1990s. However, due to morbidity associated with the PTB, the focus was shifted to other grafts like hamstring graft, synthetic graft, allografts, etc. Fowler and Rosenberg popularized the use of hamstring graft. Initially there were apprehension about the strength of hamstring graft in comparison to PTB, but biomechanical testing and the use of newer fixation techniques like endobutton installed confidence in minds of surgeons opting for it. The success of the reconstruction depends upon various factors like patient selection, surgical technique including correct tunnel placement, rehabilitation, and other associated ligamentous injuries.

5.6.2.1. Patellar tendon

It is considered as the gold strand in terms of graft for ACL reconstruction. There are advantages and disadvantages associated with this use of this graft.

5.6.2.1.1. Advantages

a. Early bone-to-bone healing at 6 weeks

b. Consistent size and shape of graft

c. Ease of harvest

5.6.2.1.2. Disadvantages

a. Harvest site morbidity: the common long-term problem is kneeling pain experienced with it. It was due to graft site morbidity that many surgeons had switched to hamstring tendons.

b. Anterior knee pain: injury to infrapatellar branch of the saphenous nerve can produce anterior knee pain. It may also be due to patellofemoral syndrome.

c. Late patellar tendon rupture.

d. Loss of range of motion.

e. Patella fracture: the cases of intraoperative patella fracture have been reported in patients when the graft was harvested with osteotome instead of saw. Sometimes the fractures are detected in late postoperative period due to overrun of saw. The stress risers that go beyond the limit of bone block should be avoided. The proximal saw cuts should preferably be boat shaped to avoid the stress riser formation.

f. Late chondromalacia of patella.

g. Patellar tendonitis: it leads to pain in some cases; however, it subsides by the end of the first year.

h. Quadriceps weakness: inadequate participation in the rehabilitation program can result in quadriceps weakness.

5.6.2.1.3. Indications for the use of PTB graft for ACL reconstruction

The ideal patient for this graft is young athlete who would like to continue in contact sports for a longer time. The elder individuals can also be advised to undergo ACL reconstruction but with a caution that they had to undergo aggressive physiotherapy following reconstruction procedure.

5.6.2.1.4. Contraindications for the use of PTB graft

a. Small patellar tendon: if the width of the patellar tendon is less than 25 mm, then harvesting the patellar tendon should be avoided, and another source is looked upon.

b. Preexisting patellofemoral pain: it is advisable not to go for PTB if there is history of patellofemoral pain. There may be associated chondromalacia of patella which might aggravate the pain.

c. Osgood-Schlatter disease.

5.6.2.2. Hamstring graft

5.6.2.2.1. Advantage

The principal advantage of hamstring graft is minimal donor site morbidity.

5.6.2.2.2. Disadvantages

a. Weakness of internal rotation of the tibia is associated with hamstring retrieval; however, the weakness is to a minimal extent.

b. Injury to the saphenous though rare but has been reported with it.

c. Harvesting of graft can be difficult at times.

d. Sometimes during harvesting of graft, there may occur premature amputation of the hamstrings.

e. It takes longer to heal with hamstring graft, i.e., approximately 10–12 weeks.

5.6.2.3. Central quadriceps tendon

It can be harvested with minimal morbidity and used with interference screws.

5.6.2.4. Allograft

5.6.2.4.1. Advantages

As there is no need to harvest the graft, the surgical time is greatly reduced.

5.6.2.4.2. Disadvantages

a. There is risk of disease transmission.

b. It takes a much longer time than autograft to heal.

c. The incidence of failure with allograft is higher than autograft.

5.6.2.5. Synthetic graft

5.6.2.5.1. Advantages

a. There is no graft site morbidity.

b. The graft is strong from the time of initial implantation itself.

c. There is no risk of disease transmission.

5.6.2.5.2. Disadvantages

a. There are high chances of failure with it.

b. Sometimes there is synovitis seen with the use of synthetic graft.

5.6.3. Surgical technique with harvesting of hamstring graft

A 3-cm-long skin incision is given 1 cm medial to the tibial tubercle. Subcutaneous fat and fascia are incised along the line of skin incision. The superior border of pes anserinus is palpated, and the overlying fascia is incised. A curved artery is used to lift up the semitendinosus along with gracilis. The distal end of the tendon is stripped off from the tibia, and the free end of the tendons is held with Kocher. Each tendon is individually freed from the bands that attach it to the gastrocnemius. It is imperative to remove all the bands as passage of tendon stripper may inadvertently cut the tendon short. The length of the tendon usually obtained is approximately 28–30 cm. While harvesting tendon, it is advisable to keep the free end of the tendon in tension and move the tendon stripper with gentle push.

The harvested tendon is taken over to the back table, and graft is freed from the muscle attached. The free ends of the tendons are whipstitched with no. 2 ethibond. Both tendons, i.e., semitendinosus and gracilis, are quadrupled. The width and length of the tendons are measured. A stitched is applied at 3 cm from the free end of the graft as minimum desired length of the graft in the tunnels (femoral and tibial) is 3 cm.

The femoral notch area, tibial attachment, and femoral attachment of ACL are cleared of loose tissue with the help of shaver and cautery.

Next the focus is shifted to creation of tibial tunnel. Tibial zig is set at 55–60° and introduced from the anteromedial portal. The tip of the zig is positioned approximately 7 mm anterior to PCL insertion, in line with posterior border of lateral meniscus and 5 mm lateral to the medial tibial spine. Externally the tibial zig is positioned approximately 2 cm medial to the tibial tuberosity and 4 cm below the joint line. A guide wire is then introduced through tibial zig and passed across the proximal tibia till the tip of tibial zig. Sequential reaming is carried out for passage of graft.

The femoral tunnel placement is another important aspect of ACL reconstruction. The ACL foot print can be appreciated on the medial aspect of lateral femoral condyle. The femoral notch is assumed at 12 o’clock position; hence, the femoral tunnel approaching 10 o’clock position in right knee (2 o'clock in left knee) mimics the anatomic center of posterolateral bundle of native ACL (**Figure 3**). The remnants of the torn ACL also help in placement of femoral tunnel. The mean distance between the centers of the two bundles was 6.2 mm. The distance from the center of the anteromedial bundle to the center of the femoral tunnel and the center of the posterolateral bundle to the center of the femoral tunnel was 4.2 and 4.1 mm, respectively. The placement of 7-mm offset reamer and creating a tunnel with the help of 10 mm reamer approximately reaches a midpoint between anteromedial bundle and anterolateral bundle.

The graft is then passed with the help of passer sutures through femoral and tibial tunnel. The various fixation methods used to fix femoral side of the graft are transfixation screws, endobutton, and tight rope. The tibial end of the graft can be fixed with the help of titanium or bioscrew or bone staples. Before fixing the graft, the knee should be flexed by approximately 20° in order to avoid fixation of a loose graft.

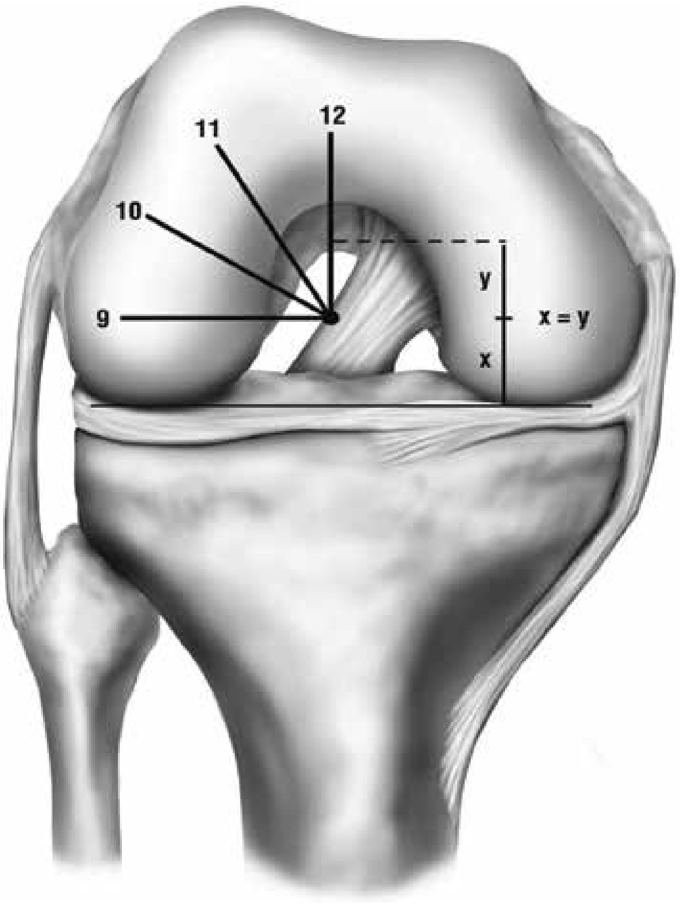

Figure 3. Diagram showing clock face superimposed on a coronal image of a right knee. It helps in coronal plane orientation in arthroscopy (reprinted with permission from Ref. [21]).

The stability of the graft should be checked with the help of probe and anterior drawer test. The wound is closed in layers, and a knee immobilizer is applied.

5.6.4. Postoperative rehabilitation protocol

The compressive stockings are applied over the limb to reduce the swelling, and cold fomentation at regular intervals is advised to the patient. Continuous passive motion (CPM) machine helps in regaining range of motion in the operated limb. The patient is allowed partial weight bearing with crutches and extension splint. The physiotherapy protocol including closed chain exercises is started immediately in the postoperative period.

The goal within 2 weeks is to achieve full extension, minimize swelling, and achieve 90° of flexion. Subsequently after 2 weeks, increase the knee flexion up to 135°, and increase the tone of the quadriceps along with hamstrings. At the end of 6 weeks, full movement of the knee is achieved along with full weight bearing with extension splint. At the end of 2 months, full weight bearing is allowed along with full functional activities like cycling, jogging, etc. At the end of 3 months, the goal is to achieve adequate hamstring and quadriceps strength along with proprioception with the help of balance board exercises. Light sports activities are allowed at the end of 4 months, and return to contact sports is permitted at the end of 6 months.

5.6.5. Complications

Every surgical procedure inherits the risk of complications so is the case with ACL reconstruction. Various factors have been implicated which lead to complications. Some of the factors are discussed below:

a. Patient selection: there are high chances of failure in cases where the patient returns to sports activity too early without following proper rehabilitation protocols.

b. Anterior knee pain: the patellar tendon bone graft should be avoided in cases with preoperative knee pain.

c. Timing of operation: the operative procedure should be delayed by few days in cases of swelling or limited range of motion of the knee.

d. Fracture of bone plug in the case of PTB graft: with careful harvesting of the graft, this complication can be avoided. It is advisable to harvest graft with the help of saw rather than osteotome. In the case of fracture of bony plug of the PTB graft, the ends of the tendon can be reversed, and the free end can be fixed with large bioscrew.

e. Dropped graft: in case the graft falls on the floor while preparation or shifting from trolley, then the option is to harvest another graft or wash the dropped graft multiple times with chlorhexidine solution and normal saline. The graft should be prepared on a separate workstation in order to avoid falling of the graft.

f. Tibial or femoral tunnel malposition: the earlier tunnel can be plugged with bone graft and new tunnel can be created. The complication can be avoided by looking for the tunnel positions with fluoroscopy.

g. Posterior blowout of femoral tunnel: in case of posterior wall blow out, the method of femoral fixation should be changed to endobutton or cortical fixation techniques. The posterior wall blow out can be prevented with accurate positioning of the femoral zig before drilling the femoral tunnel. It is preferable to flex the knee beyond 90° to create a longer femoral tunnel and prevent posterior wall blow out.

h. Loss of fixation: in case of tibial fixation, use a screw of the same or one size larger to achieve good purchase and avoid loss of fixation. This complication can be avoided with the appropriate measuring of the tunnel width and drilling it according to the graft width.

i. Patellar fracture: it can occur intraoperatively and in late postoperative period.

j. Arthrofibrosis: in cases where the patients do not follow the postoperative rehabilitation protocol, there are high chances of knee stiffness and loss of motion. Regular physiotherapy sessions can prevent this complication.

k. Residual or recurrent instability: sometimes there could be failure of fixation or tunnel widening (femoral or tibial) leading to sense of instability. Thorough workup should be carried out to ascertain the cause of residual instability.

5.7. Outcome assessment

The functional outcome of the ACL reconstruction should be done with the help of measurement scales like international knee documentation committee form (IKDC), Oxford Knee Score (OKS), etc. [22]. However, the practice of outcome assessment is followed up in very few cases by authors. If the outcome assessment is carried out on these scales, then the interpretation of results can be done easily by others. Due to complexity of these forms, the authors generally avoid these methodologies. We should strive to from a universally acceptable and easily reproducible scoring system so that the results can be interpreted with ease.

5.8. Conclusion

Anterior cruciate ligament is now increasing being treated operatively with good functional results. The choice of graft has shifted from patellar tendon bone to hamstring graft over the years. There are several other graft choices; however, the preference depends upon the surgeon and patient. The more important issue in ACL reconstruction is the correct placement of tunnels. The modern zigs and fluoroscopy help in correct tunnel formations and hence graft placement. The assessment of the functional outcome should be done by both subjective and objective measurement scales.

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Conflict of interest

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Anatomic Single-Bundle ACL Reconstruction with Remnant Augmentation Technique

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Additional information is available at the end of the chapter

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Abstract

Anterior cruciate ligament (ACL) injury is the common ligamentous injury of the knees. An ACL reconstruction is the procedure that has been proven to improve knee stability and functional outcomes and may prevent the osteoarthritic changes and subsequent meniscal injuries. The ACL reconstruction techniques have been developed in various ways. Anatomical single-bundle ACL reconstruction with remnant augmentation technique is the optimal reconstruction procedure. It may improve the clinical outcomes of biological healing, preserve the proprioceptive function, and has shown less tibial tunnel widening postoperatively. This chapter presents the step-by-step technique of an anatomical single-bundle ACL reconstruction, indication and contraindication for surgery, the preferred graft choice, fixation methods, pearls and pitfalls of the procedure, and postoperative rehabilitation. The review of literatures about the remnant preserving ACL reconstruction is also discussed in this chapter.

Keywords: ACL reconstruction, remnant augmentation, anatomic single-bundle, preserving, the ACL remnant.

1. Introduction

Anterior cruciate ligament (ACL) injury is the common ligamentous injury of the knees, especially in active, healthy patients. An ACL reconstruction is the procedure that has been proven to improve knee stability and functional outcomes. Although there have been no clear benefits and prevention of osteoarthritic changes following ACL reconstruction [1, 2], some studies have proven that this operative procedure can prevent these changes and subsequent meniscal injuries [3, 4].

The ACL reconstruction techniques have been developed in various ways. These include single-bundle reconstruction, double-bundle reconstruction, selective bundle reconstruction, single-bundle reconstruction with remnant preservation, and double-bundle reconstruction with remnant preservation. With so many techniques, there has yet to be determined as to what is the best technique that provides the greatest stability and preserves knee functions (proprioceptive sensation, range of motion).

This chapter presents one optional ACL reconstruction technique that uses anatomic single-bundle anterior cruciate reconstruction with remnant augmentation. This technique is simple, has shown improved knee stability, may preserve the proprioceptive function, may accelerate cellular proliferation and revascularization of the grafted tendon, and has shown a lower incidence of tibial tunnel enlargement postoperatively.

2. The anatomic single-bundle anterior cruciate ligament reconstruction with remnant augmentation

The functional ACL bundles consist of two parts that include the anteromedial (AM) and the posterolateral (PL) bundles. The anatomical placement of the reconstructed ACL graft has similar forces as compared to the native ACL [5]. The different techniques for ACL reconstruction aim to perform as near a normal anatomic reconstruction as possible. The double-bundle reconstruction technique has become the more popular procedure. However, the double-bundle technique is more technically demanding and more costly and has limited evidence of superior results when compared with the single-bundle reconstruction technique [6]. The centrally placed anatomic single-bundle ACL reconstruction is the common operative procedure and has been proven to restore normal knee function [7, 8].

The ACL remnants are often found during arthroscopic ACL reconstruction of the knee (**Figure 1**). A previous study reported that the mechanoreceptors that are found in the ACL remnant may contribute to the proprioception of the knee [9] and provide some biomechanical stability of the knee [10]. An immunohistochemical study [11] on the morphology and the quantity of mechanoreceptors in 40 ACL reconstruction patients shows that the time from injury to surgery was negatively correlated with the number of total mechanoreceptors ($r = -0.52$, $p < 0.01$). This study emphasizes the role of the ACL stump or ACL remnant that has a role in the preservation of proprioceptive functions of the knee.

The ACL remnant is the tissue bridge between the tibia and either the posterior cruciate ligament (PCL) or the intercondylar notch. This remnant tissue maybe developed from the synovial scar, the remnant of the ACL, and the partial rupturing of the anteromedial (AM) or posterolateral ACL bundles. Although the injured knee has the remnant of the ACL, this remnant is often in an abnormal position and could not have the normal biomechanical functions identical to an intact ACL.

The remnant-preserving technique in ACL reconstruction was introduced in 1992 [12]. This procedure has theoretical advantages that include (1) possible promotion of the revascularization and the synovial coverage of the graft, (2) improvement of knee stability, (3) preservation

Figure 1. Arthroscopic view of the left knee from the anterolateral viewing portal. The ACL remnant was found and pulled with an arthroscopic probe during the arthroscopic ACL reconstruction surgery.

of the proprioceptive function of the knee, and (4) development of a lower incidence of tunnel widening postoperatively.

The ACL reconstruction with remnant augmentation has been developed in various ways. Some of these include:

1. Selective single-bundle reconstruction of the isolated ruptured bundle (AM or PL bundle): this technique is performed if the intact bundle remains attached at its anatomical origin.
2. Anatomic center, single-bundle reconstruction with remnant-preserving technique: this technique is indicated if both ACL bundles are completely torn but retain the ACL remnant in a nonanatomical position.
3. Anatomic double-bundle reconstruction with remnant-preserving technique: this technique might be indicated as in the anatomic center single-bundle reconstruction but has a near normal ACL and may provide more stability of the reconstructed knee.

A prospective, randomized controlled trial (RCTs) study [13] was evaluated in two groups. There were 45 patients with remnant-preserving ACL reconstruction, and these were compared with 45 patients who underwent a standard ACL reconstruction. Proprioception measurements were evaluated using a passive angle reproduction test with the Biodex detector (Shirley, New York) in 80 patients preoperatively and at the last follow-up appointment. There were no differences seen between both groups at the final follow-up (mean ± SD, degree = 3.6 ± 1.8 in preservation group and 3.9 ± 2.2 in standard group, $p = 0.739$).

A systematic review of clinical outcomes of remnant-preserving augmentation ACL reconstruction [14] evaluated 13 studies including five RCTs, six case studies, and two retrospective cohort studies. The patients were 14–62 years of age and were treated with various surgical techniques (the selective single-bundle reconstruction, remnant-tensioning technique, or remnant-sparing technique) using various types of grafts. The results showed that only two of the nine studies had exhibited a small significant side-to-side difference in the remnant-preserving groups. In the standard technique group, only 1 of 13 studies showed significant higher Lysholm scores in the remnant-preserving groups. Two of 13 studies showed significantly less tibial tunnel enlargement in the remnant-preserving groups. There were no significant reported complications in both groups (including the development of cyclops lesions).

The meta-analysis of the clinical outcomes of single-bundle ACL reconstruction with and without remnant preservation [15] in 6 RCTs, 378 patients (190 remnant-preserving patients, and 188 standard ACL reconstructions) had shown no significant differences in anterior stability, the pivot shift test, knee function scores, and the development of cyclops lesions. However, two RCTs from the remnant-preserving group had a lower percentage of tibial tunnel enlargement (obvious heterogeneity, $p = 0.067$, $I^2 = 70.3\%$). The percentage of tibial tunnel enlargement was 6.6 ± 0.8% vs. 2.4 ± 0.3% in one study and 34 ± 8.9% vs. 25.7 ± 6.7% in another study with significantly different results.

The study of the clinical outcomes with an arthroscopic reevaluation following ACL augmentation [16] in 216 patients with a mean age of 25 years (73 patients with single-bundle ACL augmentation, 82 of double-bundle reconstruction, and 61 of single-bundle reconstruction) had shown significantly better synovial coverage of the graft in the augmentation group (good 82%, fair 14%, poor 4%, $p = 0.039$). The side-to-side differences measured with the KT-2000 arthrometer were significantly better in the augmentation group than in the single-bundle reconstruction group (0.4 mm [−3.3 to 2.9] vs. 1.3 mm [−2.7 to 3.9], $p = 0.013$). Moreover, in the 62 patients who were with adequate synovial coverage had revealed significant improvement of the knee proprioception in three quarter motion measurements.

From previous studies, ACL reconstruction with remnant augmentation has shown comparable results with the standard ACL reconstruction. Although ACL reconstruction with remnant augmentation may not has proven to provide the benefits in terms of stability improvement, graft healing, proprioceptive functions, and clinical outcomes, this technique has significantly less tibial tunnel widening postoperatively and no greater incidence of complications. These complications include the occurrence of the cyclops lesions.

2.1. Surgical technique

This chapter shows the technique of anatomic center, single-bundle ACL reconstruction with remnant augmentation. Indications for this surgery are active patients with clinical instability from an ACL-deficient knee. The patients must have normal alignment of the lower extremity, have no advanced knee osteoarthritic changes, and should have good knee range of motion preoperatively (more than 90° arch of motion). Obvious knee stiffness, active infection, or the patients with skeletal immaturity are relative contraindications for this procedure. If the patients have a significant malalignment of the knee, corrective osteotomy is indicated. The patients are evaluated for knee instability, with special attention to the anterior laxity using the anterior drawer, Lachman's test, and the pivot shift tests. The preoperative knee laxity was not an indicator of either the presence or lack of the presence of the ACL remnant. Associated knee pathologies such as ligamentous tears, meniscus lesions, or cartilage lesions are evaluated preoperatively. Magnetic resonance imaging (MRI) of the affected knee is obtained to evaluate the condition and associated pathologies of the ACL (**Figure 2**).

The patient is positioned supine with the operative knee flexed to approximately 90°. The procedure is done under spinal or general anesthesia depending on the patients' preference. The affected knee is draped and freely prepped from the proximal thigh to the foot. An arthroscopic examination is performed using standard anterolateral viewing and a standard anteromedial working portal (**Figure 3**). After cleaning the obstacles of fatty tissue and the ligamentum mucosum in the tibiofemoral compartment, the torn ACL and the ACL remnant are identified. Both menisci are then evaluated, and then the menisci are repaired or resected depending on the conditions found.

A quadruple semitendinosus autograft is harvested and prepared from the affected knee. The quadruple autograft length should be more than 6.5 cm, and the graft's diameter should be at least 7.5 mm. If the semitendinosus autograft is inadequate in size, an additional double or triple autogenous gracilis is also harvested. The EndoButton (Smith & Nephew, Andover, MA) is used for the graft's fixation point at the femoral side, and an interference screw (Smith & Nephew) is used for tibial fixation of the graft. Keeping in mind that the anatomic position of the tunnel is more important than the obstacle remnant of the ACL tissue, the femoral tunnel is created using a transportal technique from a standard anteromedial portal (**Figure 4**).

Figure 2. Preoperative MRI of the patient with ACL deficiency of the left knee reveals the increased signal intensity in the ACL fibers with the presence of a loose ACL remnant (yellow asterisk, *). The hypersignal of the lateral tibial plateau is represented by a valgus-impacted injury with bone bruise.

Figure 3. Patient positioning and placement of portals; the pictures show the positioning, preparation, and arthroscopic portals for arthroscopic ACL reconstruction of the left knee (AM, anteromedial portal; AL, anterolateral portal).

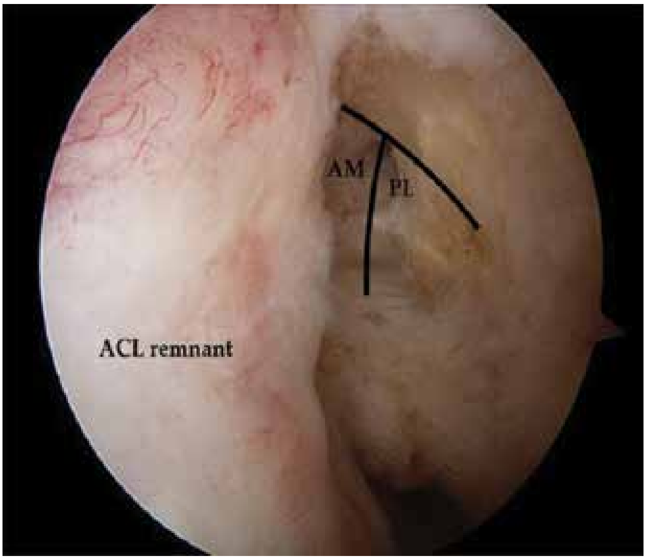

Figure 4. Arthroscopic view of the left knee from anterolateral viewing portal. After identifying the ACL femoral footprint, the femoral tunnel is created using the transportal technique from a standard anteromedial portal.

The medial femoral condyle is carefully protected during the creation of the femoral tunnel to avoid an iatrogenic cartilage injury [17]. The graft should be inserted within the femoral tunnel, and it should be at least 15 mm in length. Next, the tibial footprint of the ACL is identified. In this step, the ACL remnant at the tibial footprint often needs to be partially removed until obtaining the appropriated tibial footprint. The tibial tunnel is then created using a transtibial ACL guide pin (Acufex Director Drill Guide, Smith & Nephew) that is then inserted from a standard anteromedial working portal (**Figure 5**). If the position of the guide pin is not positioned through the center of the tibial footprint, an increment reamer is used to adjust the position of the guide pin [18].

After creating the femoral and tibial tunnels, the prepared autograft is passed from the anteromedial tibial cavity through the tibia and into the lateral intercondylar notch of the femur. The EndoButton is tested for possible dislodgement of the femoral cortex. Pretensioning of the ACL graft is performed, and the knee's motion is checked to evaluate of the graft position and the presence of an impingement (**Figure 6**). The ACL graft is then fixated at the tibia with an appropriately sized interference screw positioned eccentrically under adequate ACL graft tension in a position of nearly full extension of the operative knee (**Figure 7**). Postoperative radiographs are taken to evaluate the positioning of the implants and the femoral and the tibial tunnel positions (**Figure 8**). **Figure 9** represents the step-by-step process of a remnant-preserving ACL reconstruction of a 26-year-old woman with injury to her left knee.

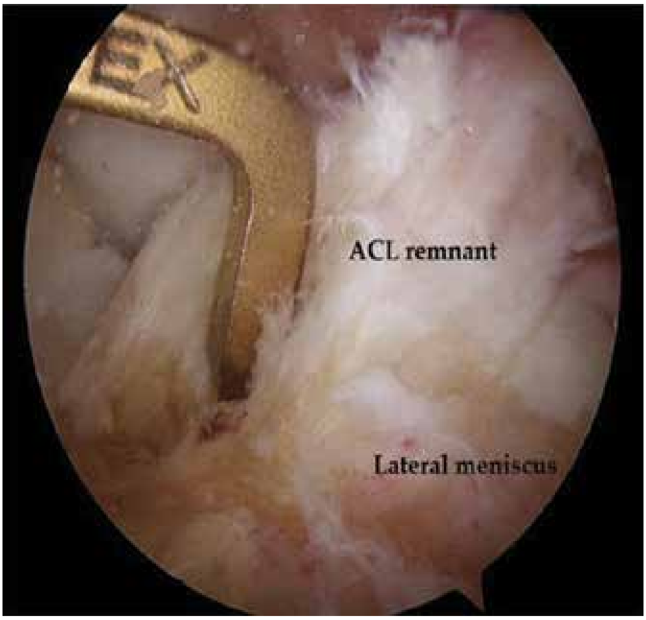

Figure 5. Arthroscopic view of the left knee from the anterolateral viewing portal. After identifying the ACL tibial footprint, a tibial tunnel is created with the use of a transtibial, ACL guide pin (Acufex Director Drill Guide, Smith & Nephew) inserted from the anteromedial portal.

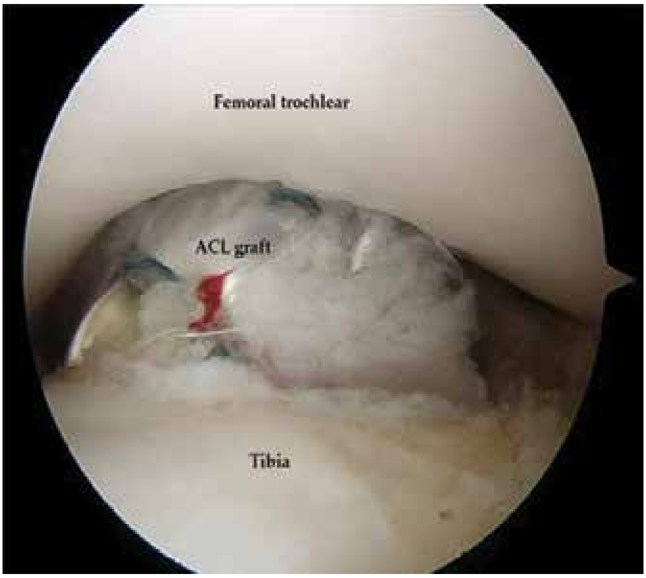

Figure 6. Arthroscopic view of the left knee from anterolateral viewing portal. The reconstructed ACL graft and positioning and impingement in full knee extension are checked.

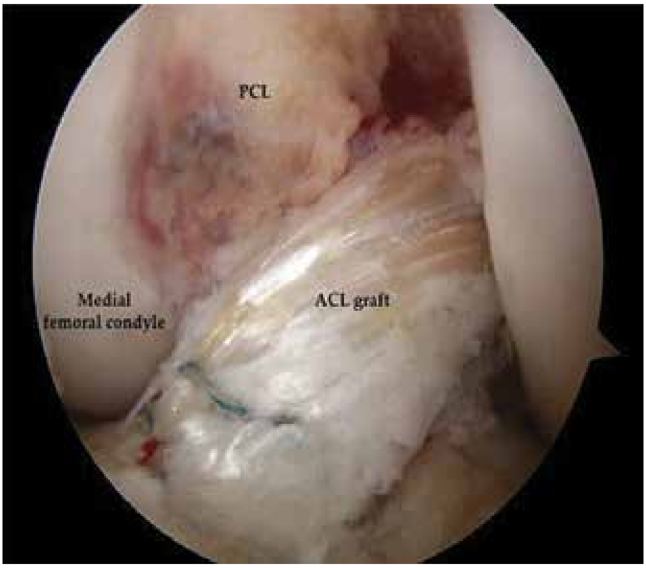

Figure 7. Arthroscopic view of the left knee from anterolateral viewing portal. Following fixation of the ACL graft, the graft, and the remnant appears to be a stable ACL reconstruct.

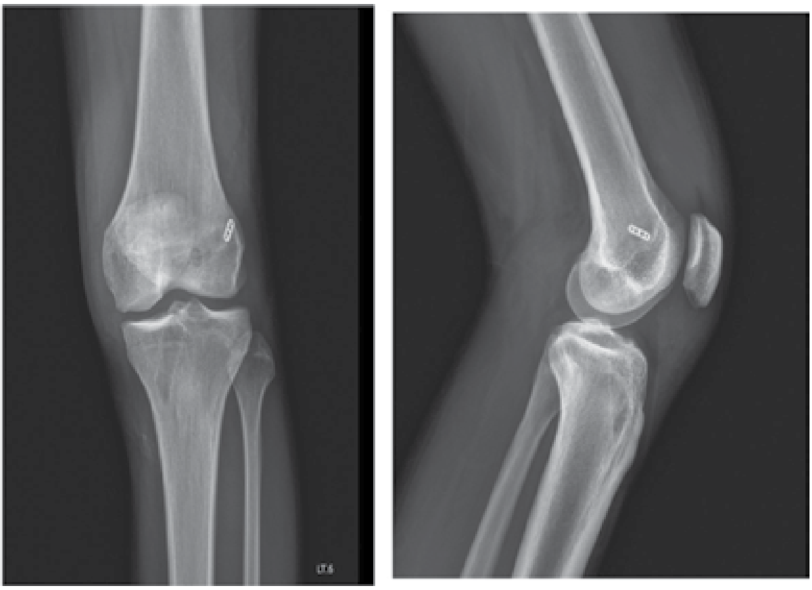

Figure 8. Postoperative radiographs of the left knee in anteroposterior and lateral views reveal the position of the EndoButton and the bony tunnels.

2.2. Postoperative rehabilitation

A small tubular drain is placed in the intra-articular area for 24 h postoperatively. An early range of motion exercises of the affected knee are encouraged as soon as possible with no limitations in knee flexion postoperatively. No knee braces or immobilization prosthetics are used. The patients can ambulate with crutches, and they are able to bear weight on the affected limb at approximately 10% of normal in the cases that had cartilage procedures done (microfracture or mosaicplasty). Approximately 50% of normal weight-bearing in the cases with meniscal repair and full weight-bearing as tolerated in cases with only ACL reconstructive surgery.

The stitches are removed 10–14 days postoperatively. Active quadriceps contraction exercises are allowed at the earliest possible time frame. Light sports activities such as jogging, swimming, and bicycling will be allowed 4 months postoperatively. Return to contact sports activities are allowed 10–12 months following the surgery.

2.3. Pearls and pitfalls

This technique is simple and processes in the same steps of a standard anatomic single-bundle ACL reconstruction. The difference is only of the preservation of the ACL remnant to get more advantages as have been discussed previously.

The pearls and pitfalls of this procedure are shown in **Table 1**.

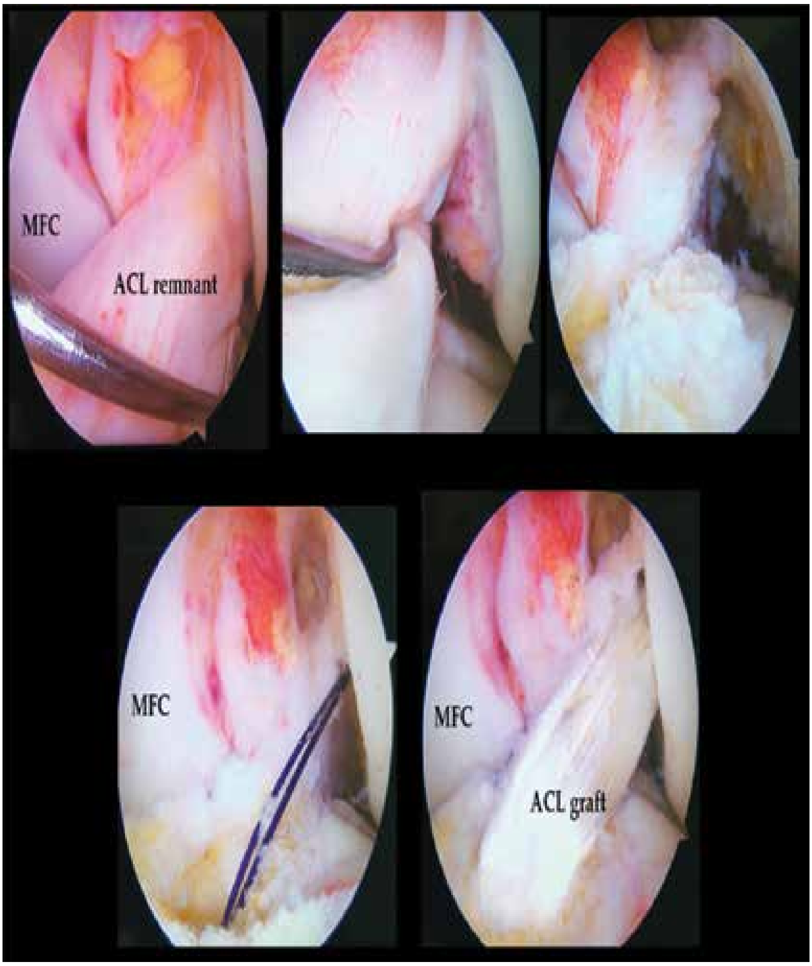

Figure 9. Arthroscopic images of a 26-year-old woman with left knee injury. The ACL remnant is observed arthroscopically. The step-by-step technique of a remnant-preserving ACL reconstruction is shown.

Pearls	Pitfalls
Simple, needs minimal technical demand as compared with the standard anatomic single-bundle ACL reconstruction	Clear identification of the center of both, the femoral and tibial footprints using bony ridges as reference
Some studies have reported achievement of greater knee stability and better proprioceptive functions	The appropriate graft position should be of greater concern than remnant preservation without anatomical graft placement
The RCTs show that the remnant-preserving ACL reconstruction has less tibial tunnel widening postoperatively	Most of the anterior tibial footprint stump of the ACL remnant should be removed to prevent anterior impingement of the graft or tissue (cyclops lesion) during full knee extension
Strict postoperative care is the key to obtaining good results	

Table 1. The pearls and pitfalls of the anatomic single-bundle ACL reconstruction with remnant augmentation technique.

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3. Conclusion(s)

The anatomical single-bundle ACL reconstruction with remnant augmentation or preservation is the optional reconstruction technique that has shown comparable results with standard ACL reconstruction. This technique has theoretical advantages in the improvement of the stability of the knee, promotion of graft healing, preservation of the proprioceptive functions, and resulting good to excellent clinical outcomes. Although the studies have shown no significant benefits, this technique has a significantly lower incidence of tibial tunnel widening postoperatively and has exhibited no additional complications, including the occurrence of cyclops lesions.

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Conflict of interest

The author declares that no conflicts of interest exist.

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Office-Based Small Bore Needle Arthroscopy of the Knee

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Additional information is available at the end of the chapter

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Abstract

Advanced imaging, such as MRI, can sometimes provide inconclusive results with knee pathology, leaving both patients and providers with a diagnostic challenge. In-office arthroscopy is a newer, low-risk, diagnostic procedure that allows the physician to use a small bore needle arthroscope to view the intra-articular anatomy of the joint. The patient and provider are provided with immediate results of the pathology found. This prevents having to undergo repeat imaging, which can be a costly, time-consuming, and inconclusive process. Ideal indications are patients who are claustrophobic, have previously undergone meniscal or chondral surgery, or whose MRI results are inconclusive. This chapter will review the background, indications, technique, and risks of this novel procedure.

Keywords: knee arthroscopy, in-office, magnetic resonance imaging

1. Introduction

Arthroscopy is currently the gold standard for diagnosing intra-articular knee pathology. While arthroscopy does allow surgeons to see within the finite pathologic area, magnetic resonance imaging (MRI) serves as a less invasive tool to diagnose injuries within the knee. MRI currently serves as the leading imaging tool to diagnose intra-articular injuries; however, studies have questioned its accuracy. Objective measures of test performance generally include, but are not limited to, sensitivity, specificity, accuracy and predictive values. To diagnose a complete anterior cruciate ligament (ACL) tear, studies show MRI to have sensitivity, specificity, accuracy and negative predictive value (NPV) of 90.9, 84.6, 88.6, and

84.6% respectively [1, 2]. Furthermore, the sensitivity, specificity, accuracy, and NPV of MRI to detect medial meniscus pathology was 100, 52.6, 64 and 100%, respectively, while detection of lateral meniscus pathology was 55.6, 83.3, 75.8 and 83.3%, respectively [1, 2]. MRI's objective measures of test performance are not perfect by any means, leading experts to question its overall reliability [3], while also seeking a superior method.

While arthroscopy is considered the gold standard for diagnosing and treating pathology of the knee, any type of surgical procedure, especially one that requires general anesthesia, presents risks that must be weighed alongside the benefits of the procedure. Arthroscopic procedures have been shown to have 30-day readmission rates of 0.92% for reasons including surgical site infections, deep venous thrombosis, pulmonary embolism, and postoperative ailments [4]. Although this percentage is low, complications do still exist. New technology geared toward obviating diagnostic arthroscopies may allow for similar diagnostic outcomes while also eliminating the surgical risk. New technology, namely mi-eye 2 (Trice Medical) has allowed physicians to perform in-office diagnostic arthroscopies.

2. Technique

The mi-eye 2™ received FDA 501(k) clearance in October 2016 for in-office diagnostic arthroscopy use (**Figure 1**). The device itself consists of a 14-gauge needle, through which the arthroscope is placed. The arthroscope is a 2.26 mm, 0° camera, which allows a 120° field of view and 5–35 mm depth of view with autofocus capability. The light source and the display monitor are also included in the packaging.

The patient should be placed in a comfortable position during the procedure; the knee should be in 90° of flexion, which can be done in a seated position or supine position with a bump under the patient's heel (**Figure 2**). Landmarks are then palpated and marked, including the medial, lateral, and inferior borders of the patella as well as the patellar tendon. The standard medial and lateral portals are marked 0.5 cm inferior to the inferior pole of the patella, just medial or lateral to the patellar tendon; a trans-patellar tendon portal, located 1 cm inferior to the inferior pole of

Figure 1. Device. The mi-eye 2 device from trice medical, which includes the tablet and disposable probe. The needle sheath is retracted by pushing back on button found on superior portion of device.

Figure 2. Patient set-up. The patient is set up with the knee at 90° in a comfortable position. This picture demonstrates the patient in a supine position. Alternatively, the patient can be positioned sitting with the knee bent to 90°.

the patella, can be marked and used as well (**Figure 3**). If further evaluation of the patellofemoral joint is necessary, standard supero-lateral or supero-medial portals can be used. Once the intended portal sites are marked, the skin is prepped in a sterile fashion and 2 cc of 0.2% lidocaine

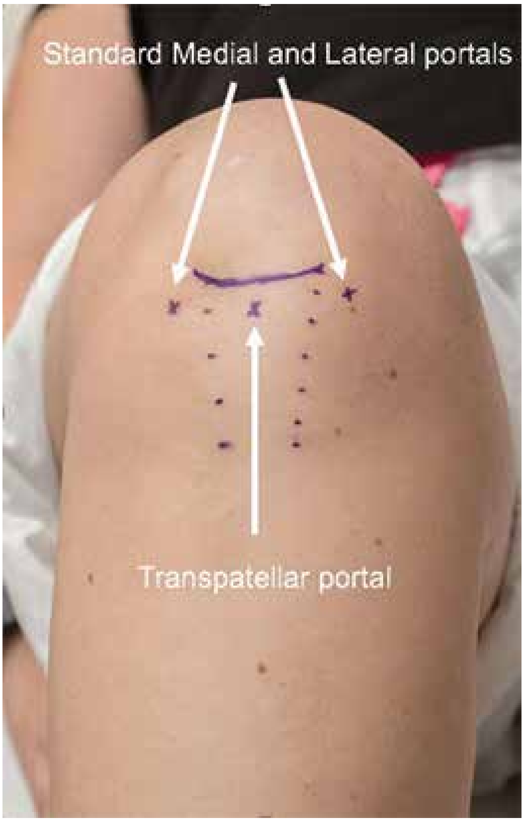

Figure 3. Portal sites. Anterolateral, anteromedial and transpatellar portal sites are marked, sterilized, and anesthetized. Additionally, superolateral and superomedial sites can be used for a more thorough visualization of the patellofemoral joint.

Figure 4. Medial knee compartment. Visualization of the medial meniscus and medial chondral surfaces using the in-office arthroscopy system.

without epinephrine is used to anesthetize the skin directly over each portal sites. An additional 20 cc of 0.2% lidocaine without epinephrine is injected intra-articularly. Allow approximately 10 minutes for the analgesia to take full effect. The skin is then sterily prepped a second time, prior to insertion of the mi-eye 2™ probe into the knee joint.

Multiple syringes of sterile saline are at hand and ready to inject into the knee joint through the mi-eye 2™ probe to obtain adequate distension for visualization; varying amounts of saline are needed but often times do not exceed 150 cc. The mi-eye 2™ is removed from its sterile packaging. The first syringe of saline (we recommend using 10 cc syringes to better control the probe) is attached to the stopcock and the probe connector is removed and handed to the assistant to be plugged into the tablet. The probe is then inserted into the medial or lateral portal sites, making sure to aim toward the notch to avoid damage to the cartilage or menisci. Once the capsule is entered, the retraction button is depressed and the needle is retracted; this will expose the probe optics. The stopcock should be opened a ¼ turn to allow for injection of saline. Slowly inject saline to distend the capsule and fill the joint to allow for adequate visualization. Bursts of fluid will be required to push away soft tissue and allow for visualization at various times during the procedure. A diagnostic arthroscopy is performed in a step-wise fashion, visualizing each compartment (medial, lateral and patellofemoral) (**Figures 4–6**), the notch (**Figure 7**), and the gutters. Certain maneuvers, including slight varus and valgus stresses, may be employed to visualize desired structures. Images and live video can be saved to the tablet device as needed.

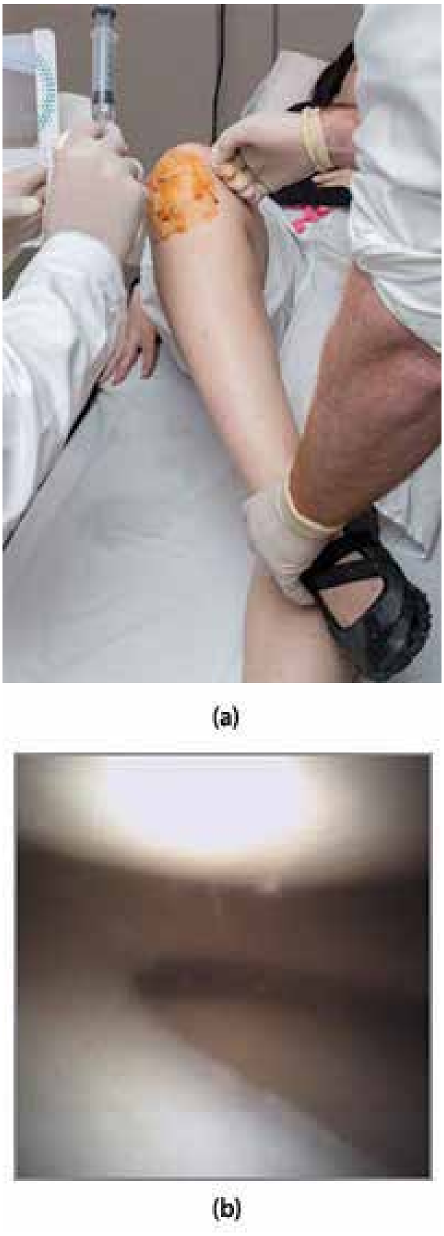

Figure 5. a) Knee position in the Figure of Four Position to gain access to the Lateral Compartment of the Knee b) Visualization of the Lateral Meniscus and the Lateral Chondral Surfaces using the in-office arthroscopy system.

After completion of the arthroscopy, the fluid in the joint can be aspirated through the same stopcock using multiple 50 cc syringes. The probe is then removed from the joint, and a compressive dressing, such as an Ace Wrap, should be applied to the knee. The images and video saved to the portal can then be reviewed with the patient immediately following the procedure. Given the minimal procedure and early mobilization, no deep venous thrombosis prophylaxis is warranted.

Figure 6. Patellofemoral knee compartment. Visualization of the patella and the trochlear chondral surfaces from the anterolateral portal using the in-office arthroscopy system.

Figure 7. The notch. Visualization of the anterior Cruciate ligament in the notch using the in-office arthroscopy system.

3. Indications and contraindications

Indications for diagnostic in office arthroscopy include patients who cannot undergo an MRI for medical or personal reasons or patients who have undergone prior arthroscopic procedures and subsequently have an inconclusive MRI. In addition, patients who are potential candidates for a meniscal transplant, osteochondral allograft, or a unicompartmental knee arthroplasty (UKA) can undergo this in office procedure to better characterize current pathology as well as aid in the preparation of a definitive treatment plan. The main contraindication to the procedure are patients with acute hemarthrosis, due to the inability to adequately flush the out the knee. Additionally, visualization can be difficult in patients who have had multiple surgical procedures resulting in significant synovial scarring.

4. Risks/limitations

While in office arthroscopy negates the anesthetic risk and greatly minimizes DVT and infection risks associated with intraoperative arthroscopy, there are limitations associated with its use. First, the surgeon must feel comfortable with the instruments, particularly the 0° scope, which may be unfamiliar. The 0° scope is used because the optics do not allow for the more commonly used 30° scope; however, the development of the 30° scope is in progress. Second, while direct visualization of intraarticular pathology is possible, the images are not as clear as an operative arthroscopy.

5. Discussion

In-office arthroscopy has been available since the early 1990s, yet, over the years, this technology has evolved, allowing for high quality intra-articular images to be obtained in an office setting [5, 6]. Historically, MRI has been used to diagnose a variety of intra-articular pathologies, due to its superiority to other imaging studies in identifying chondral, ligamentous and meniscal pathologies; reported accuracy rates hover around 90% [7, 8]. While imaging studies often play a substantial role in the decision to treat a patient conservatively or surgically, these studies are not perfect and can sometimes miss, under-diagnose, or over-diagnose intra-articular knee pathologies [8–10]. In-office arthroscopy allows the physician to directly visualize the knee through high-quality, real-time images. In an unpublished, current study, the accuracy of in-office arthroscopy in comparison to MRI is 91.5 versus 61.3% for all pathologies [11].

In addition to the accurate diagnostic potential, in-office arthroscopy provides further benefits to both the patient and the physician. The patient, who is seeking a medical opinion, can receive not only a more definitive and accurate answer regarding the nature of their pathology but this diagnosis can eliminate a possibly unnecessary diagnostic arthroscopy performed in the operating room under general anesthesia. The physician, who is providing a medical opinion, can be more definitive in their diagnosis of intra-articular pathology, leading to a more definitive and accurate treatment plan. In-office arthroscopy is a purely diagnostic tool; simple procedures, like loose body removal, are not yet possible.

The risk associated with in-office arthroscopy, as compared to diagnostic arthroscopy, is minimal. Diagnostic arthroscopy requires patients to undergo general anesthesia, adding both risk and cost to the patient, while in-office arthroscopy uses local anesthetic. Furthermore, both procedures allow patients to go home the same day, yet the time constraint of in-office arthroscopy is significantly decreased, since a diagnostic arthroscopy requires more time due to preoperative evaluation, anesthetic induction, the procedure itself, and time in the post-anesthesia care unit after surgery.

Advantages	Disadvantages
Minimal risk (compared to standard arthroscopy)	Surgeon unfamiliarity using 0° scope
No risk of anesthesia	Visualization not as clear (compared to standard arthroscopy)
Can be used when MRI contraindicated due to medical reasons, claustrophobia	Contraindicated with acute hemarthrosis (unable to flush out knee)
Improved accuracy (compared to MRI)	Scar tissue from prior surgeries limits excursion of small-bore needle
Allows visualization of prior repair	
Cost effective	
Cost savings	

Table 1. Advantages and disadvantages of in-office arthroscopy.

The potential cost savings associated with in-office arthroscopy is also worth noting. Studies have shown that in-office arthroscopy procedures are responsible for a net $151 million per year in cost savings while being used over MRI [12]. Furthermore, the avoidance of unnecessary future surgical procedures has the potential for cost saving, yet this topic has not yet been critically analyzed. Although the procedure in novel, it appears that insurances are reimbursing for the diagnostic arthroscopy code. Advantages and disadvantages of in-office arthroscopy are listed in **Table 1**.

While in-office arthroscopy is not required in every patient presenting with symptoms of knee pain, its use in specific situations can greatly improve and expedite patient care, as well as save patients the cost and morbidity of an unnecessary procedure. In-office arthroscopy offers the surgeon another diagnostic tool that can be valuable in a multitude of clinical settings.

Conflict of interest

The authors have no conflict of interest or financial interest regarding this product.

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Chapter 5

Arthroscopic Technique to Treat Articular Cartilage Lesions in the Patellofemoral Joint

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Additional information is available at the end of the chapter

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Abstract

Cartilage lesions are frequent in routine knee arthroscopy (63%). Among these injuries, 11–23% are located in patella and 6–15% in the trochlea. Treatment of cartilage lesions in patellofemoral joint (PFJ) represents a challenge because of its complex access, high axial loading, and shearing forces. These factors explain the 7% of good results in the PFJ versus 90% in femoral condyles for autologous chondrocyte implantation (ACI). Microfracture (MF) as the first line of treatment has revealed limited hyaline-like cartilage formation in comparison to ACI. This fibrocartilage deteriorates with the time resulting in inferior biomechanical properties. Important issues that enhance the results of cartilage repair procedures in PFJ are associated with the restoration of the joint balance as unloading/realigning techniques. In the literature, there is no description of any convenient *arthroscopic technique* for ACI. The reported techniques usually require to set up the patient in prone position to perform the arthroscopy making it difficult to treat associated knee malalignment or instability. Others are open techniques with more risk of morbidities, pain, and complications and longer recovery time. In this chapter, we will describe a novel all-arthroscopic technique to treat cartilage lesions in the patella that permits the correction and treatment of associated lesions in the same patient position.

Keywords: cartilage lesions, patellofemoral joint, arthroscopic treatment, autologous chondrocyte implantation, knee

1. Introduction

The patella is the biggest sesamoid bone in the body. The main functions of the patella are to direct forces of the quadriceps and to protect the deeper knee joint and the quadriceps tendon from frictional forces [1, 2]. Posteriorly the patella is covered by a thick hyaline cartilage which decreases friction in the PFJ and allows a correct and smooth flexion of the knee. The patella contact area changes when knee flexion increases showing maximum contact between 60 and 90° of flexion.

The patellofemoral pain syndrome is very common in the general population. It is often seen in young people with high physical activity level in both competitive and recreational sports. Patellar malalignment and instability with or without articular cartilage lesions (ACL) are usually the source of pain. Repetitive microtrauma as well as acute severe trauma can lead to damage of the articular cartilage of the patella and when those lesions are not treated produces severe pain, disability, and poor quality of life. The accurate detection and treatment of ACL are essential for the proper function of the knee. However, when those lesions are left untreated, it can alter normal distribution of weight-bearing forces and may lead the development of early osteoarthritis (OA) [3].

Articular cartilage injuries are commonly found in knee arthroscopies (61–63%). The majority of these lesions are found in the medial femoral condyle (58%), while chondral lesions affecting the patella are the second most common (11%) location [4, 5]. Hielle et al. found that 17% of patients having arthroscopy had an articular cartilage injury located in the patella or trochlea [4]. Nomura et al. also found 35 patients with severe articular cartilage injuries in the patella out of 37 patients with a first-time acute patellar dislocation [6]. Articular cartilage lesions of the PFJ can be especially challenging because of the complex biomechanical environment and the significant forces experienced within this compartment during weight-bearing activity. Given the poor intrinsic capacity of cartilage to heal, surgical intervention is often necessary for symptomatic relief.

Basic nonsurgical management is recommended as an initial treatment modality to treat chondral lesion of patellofemoral joint for at least 6 months [7]. This option is recommended for patients without significant pain and without mechanical symptoms. Anti-inflammatory medications, activity modification, weight loss, and muscle strengthening have been shown to improve pain [8, 9]. However, surgical management is recommended when symptoms are persistent despite the nonsurgical treatment and when the function is limited by symptoms. Surgical options depend on the lesion size, depth, location, and status of the underlying subchondral bone. Microfracture, ACI, DeNovo juvenile chondrocyte implantation, osteochondral autograft transfer, and osteochondral allograft transplantation are considered cartilage restoration procedures for PFJ.

Autologous chondrocyte implantation is currently the preferred and most effective procedure in the management ACL. Microfractures have shown great short-term results for well-contained lesions less than 2 cm^2; however, 47–80% of patients have shown functional deterioration between 18 and 36 months after microfracture technique. Some authors attribute this decline to incomplete defect filling and poor integration with the surrounding normal cartilage as well as an inferior capacity of the fibrocartilage to resist articular stress [10–14]. ACI is considered a first-line surgical treatment in large lesions (>4 cm^2) and in secondary treatment for patients with persistent symptoms following treatment with another procedure [15]. However, outcomes of ACI in PFJ have shown mixed results. Pascual-Garrido et al. reported a statistically significant improvement in patients treated with isolated ACI on the basis of several functional scoring systems as well as a 71% satisfaction rate in patients [16]. In a follow-up by Brittberg et al., 81% of the patients had good to excellent results at 2 years and 83% at 5–11-year follow-up [17].

ACI performed in conjunction with anteromedialization (AM) of the patella for the correction of malalignment has shown better results with significant improvements in functional and satisfaction outcomes [16].

As with most orthopedic procedures, less invasive procedures such as arthroscopy are being preferred because of the decreased associated comorbidity and the accelerated postoperative rehabilitation for earlier return to full physical function [18]. Biant et al. found that the viability of cells in ACI technique was 16 times higher for open approach-delivered implants than those delivered arthroscopically. However, no clinical outcomes were evaluated since it was a cadaveric experiment [19]. On the other hand, Edwards et al. showed that patients with arthroscopic ACI required a significantly shorter hospital stay after their procedure and presented fewer post-surgery complications than those who underwent ACI performed through a mini-open arthrotomy [20].

Recent advances in our understanding of focal chondral lesions, surgical techniques, and surgical technology have provided a new array of treatment options for symptomatic patients with cartilage lesions of the PFJ. The aim of the present chapter is to describe a surgical procedure for the arthroscopic ACI in the patellofemoral joint.

2. Arthroscopic chondrocyte implantation in the PFJ

Before implantation surgery, a knee arthroscopy was performed for biopsy. Two to three osteochondral cylinders of 4-mm diameter were taken from a non-weight-bearing area of the knee (**Figure 1**). Samples were processed in the laboratory for chondrocyte isolation, in vitro expansion, and cell-polymer construct formation as Masri et al. described [21]. In a second arthroscopic procedure, the constructs with cultured chondrocytes were implanted.

After regional anesthesia the patient was settled in supine position; the knee was prepared and draped in a conventional manner. A tourniquet was placed around the proximal thigh, although normally it was not insufflated. A conventional longitudinal anterolateral portal was established for arthroscopic examination of the knee joint using a superolateral portal for irrigation. The articular cartilage injury was identified, measured, and prepared for construct implantation.

2.1. Arthroscopic chondrocyte implantation in the trochlea

Cartilage lesion was measured and debrided to leave stable walls (**Figure 2A**). When the lesion was in the medial trochlea, an oblique anteromedial portal was established over the lesion to have perpendicular access. If the lesion was on the lateral trochlea, the anterolateral portal was extended proximally or distally to allow perpendicular access. A 2-mm hole

Figure 1. Osteochondral biopsy harvesting. (A) An osteochondral harvester (COR; DePuy Mitek, Raynham, MA) was used to get one to three 4-mm diameter biopsies in a non-weight-bearing area adjacent to the intercondylar notch (B and C).

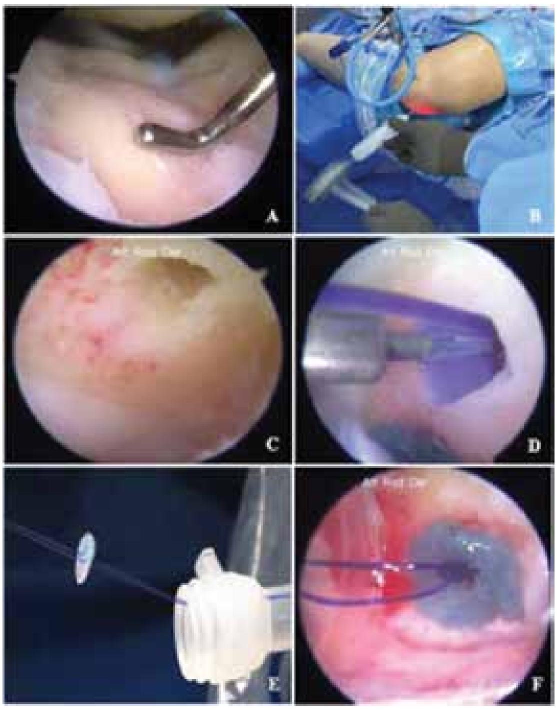

Figure 2. Matrix chondrocyte implantation in trochlear lesions. (A) Cartilage lesion is measured and debrided with a curette to leave stable walls. (B–D) A 1.7-mm hole was made in the center the lesion, and an absorbable anchor charged with 0-PDS suture is inserted. (E) The implant is fixed with self-locking arthroscopic sliding knot and two or three additional half-hitch knots.

was made in the center of every centimeter of cartilage lesion. An absorbable 1.9-mm anchor (MINILOK, Depuy Synthes Mitek, Raynham, MA) with 0-PDS suture (Ethicon, Somerville, NJ) was inserted through the anteromedial or anterolateral portal (**Figure 2B–D**). The cell-scaffold disk was prepared on the side table. An 8-mm transparent cannula was then inserted through the portal directly over the lesion, and the sutures from the anchor were pulled outside the joint through an arthroscopic cannula (**Figure 2E**). The anchor sutures were passed in the construct through two needles (20 G × 32 mm); the construct was slide into the joint to place it in the bottom of the cartilage lesion. A self-locking arthroscopic sliding knot was used to fix the implant (**Figure 2F**). Once the construct was sitting in place at the bottom of the lesion, the knot was tightened by pulling on the wrapping limb of the suture, and two additional half-hitch knots were tied with the assistance of a knot pusher. The sutures were then cut flush to the knot and the cannula was retrieved. Stability of the implant was then tested with the probe, and the knee was taken through a range of motion to verify the stability and permanence of the implant at the repair site.

2.2. Arthroscopic chondrocyte implantation in patella

Implantation of constructs in patella is performed with the use of an anterior cruciate ligament tibial guide (ACUFEX; Smith-nephew, Andover, MA) with different grades of angulation. Standard arthroscopy evaluation is done to evaluate additional lesions.

The cartilage lesion is identified, measured, and debrided. The tibial guide is introduced either through medial or lateral portal to have easy access to the lesion (**Figure 3A**). Using the elbow aimer of the tibial guide, the angle was adjusted depending on the better position of the tip over the center of the lesion (**Figure 3D**). Two holes are drilled with a cable wire (Kirschner 0.062″) from the anterior cortex of the patella to the subchondral bone (**Figure 3B** and **E**); the holes are placed in the center of every 10 mm of cartilage lesion. The cable wires

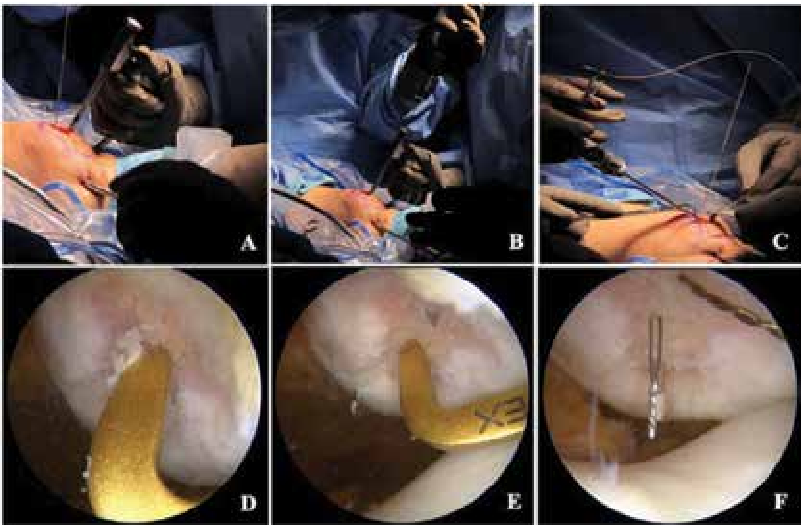

Figure 3. Arthroscopic chondrocyte implantation in patella. (A and D) The ACL tibial guide is introduced by the portal that permits better position to the center of the lesion. (B and E) Two holes are drilling from the anterior cortex of the patella to the subchondral bone at the center of the lesion. (C and F) An anterior skin incision is made over the patella; deep direction is necessary to visualize the entrance of both cable wires. Cable wires are removed with the drill, and a chia passer is inserted in every hole until it is visible into the joint space.

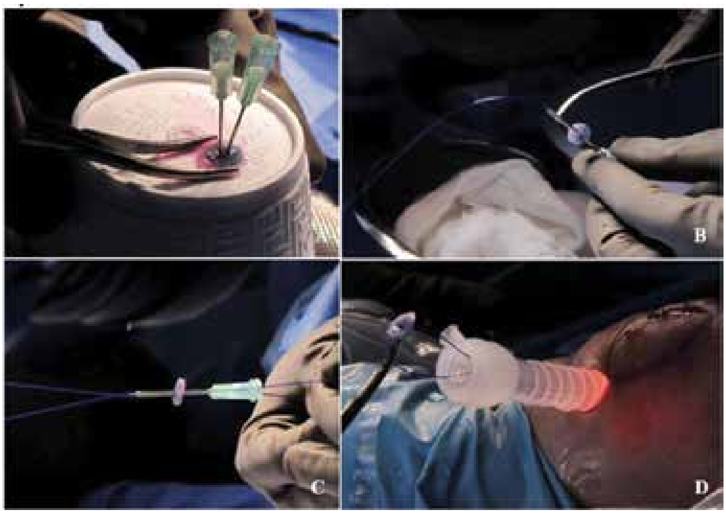

Figure 4. Preparation of the chondrocytes construct with a 0-PDS suture. (A) Two needles (20 G × 32 mm) are inserted in the center of the construct leaving 2 mm of distance. (B and C) The ends of 0-PDS are passed tin the through the needles. (D) Once the PDS is placed in position, needles are removed, the ends of the PDS are introduced in the loop of every chia passer, and the construct is pulled slowly through a 10-mm cannula.

are left in place, while the tibial guide is removed from the joint. A 15-mm skin incision is performed anterior to the patella connecting the two cable wires (**Figure 3C**). Deep dissection is performed until the periosteum to identify the cable wires; then those are removed with the drill, and a wire passer (CHIA PERCPASSER, Suture Passer Depuy Synthes Mitek, Raynham, MA) is inserted in every hole from anterior cortex of the patella to the inside until the chips are visible and accessible into the joint space by the scope (**Figure 3F**). The chia tip is advanced into the joint and is grabbed with a grasper from either medial or lateral portals.

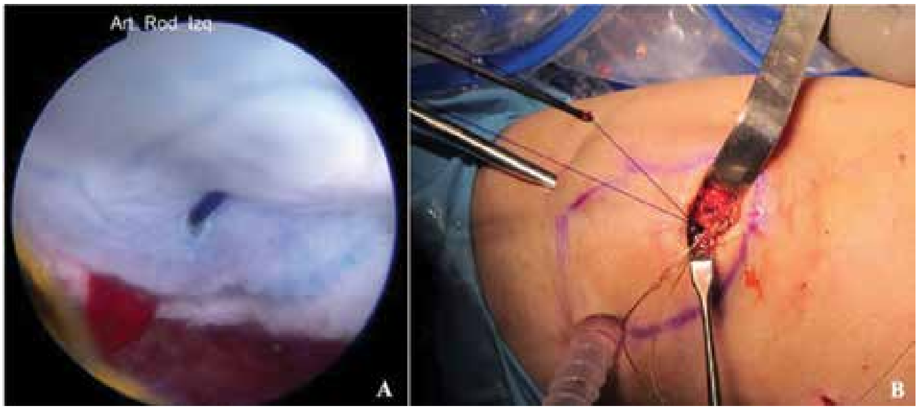

Figure 5. Fixation of the construct. (A and B) Once the construct is placed in the bottom of the lesion, three to four sliding knots are tied over the anterior cortex of the patella. Notice that different to trochlear implantation in patellar technique the knots are out of the articular space.

In the back table, the construct was prepared before using two percutaneous needles (20 G × 32 mm) that were inserted in the center (**Figure 4A**). One 0-PDS suture is folded, and its ends are passed in the construct through the needle tips (**Figure 4B** and **C**). Once PDS is placed in the center of the construct, needles are removed.

A 10 mm cannula is placed in the chosen portal where the chia passers were grabbed; every end of the 0-PDS suture with the construct is introduced in the loop of the wire passer and then pulled to introduce the construct into the joint (**Figure 4D**). Once the construct is placed in the bottom of the lesion (**Figure 5A**), a non-sliding knot was performed and tied over the anterior cortex of the patella outside the joint (**Figure 5B**). Steps are repeated if more than one construct is needed. Portals and accessory incision are closed in the traditional manner.

3. Conclusion

Arthroscopic autologous chondrocyte implantation in the PFJ is a reproducible and safety technique that permits the early recovery of the patient and the treatment of concomitant lesions as patellar realignment and/or ligament reconstruction.

3.1. Take-home points

- The described technique is recommended for focal cartilage lesions with healthy and stable cartilage around the lesion.
- During the lesion debridement, it is necessary to leave stable walls of normal cartilage and take out the calcified layer.
- Correction of associated lesions as instability or malalignment is mandatory to enhance better results in the treatment of cartilage lesions of PFJ.

Acknowledgements

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Conflict of interest

The authors declare that there is no conflict of interest with respect to the research, authorship, and/or publication of this chapter.

A. Appendices and nomenclature

Indications for proposed technique in PFJ cartilage lesions

Lesion	Technique
Focal lesion medial facet + patellar dislocation	Arthroscopic ACI + MPFL reconstruction
Focal lesion medial facet + patellar dislocation + lateral patellar inclination	Arthroscopic ACI + MPFL reconstruction + lateral retinacular release
Focal lesion lateral facet + lateral patellar inclination	Arthroscopic ACI + lateral retinacular release
Focal lesion lateral facet + lateral patellar inclination + lateral hiperpresion	Arthroscopic ACI + lateral retinacular release + Tibial Tuberosity Osteotomy

Postoperative management and rehabilitation

Stage	Week	Process	Indication
Cellular proliferation	4–6	Chondrocyte stimulation	Continuous passive motion (6–8 h a day)
			Full weight bearing in patients with PFJ lesions
	4		Weight bearing with toe or heel-touch for femoral condyle defects
	8–12		Weight bearing for poorly contained lesions and patients with multiple lesions
Transition	16–24	Matrix expansion	Strength within 80–90% of contralateral extremity
Remodeling	24–48	Cartilage hardens	Perform ADL

Important considerations

Surgical treatment for cartilage lesions in PFJ is recommended when patient has persistent symptoms despite conservative treatment

Satisfactory results are reported in the treatment of isolated cartilage lesions in the patella with ACI (65%); however, when ACI was combined with unloading tibial tubercle osteotomy (AMZ), better results are found (85%)

Clinically both microfracture and autologous chondrocyte implantation improve significantly over time after treatment. However, studies have demonstrated that quantitative assessment with T2-mapping in ACI is more similar to native cartilage than microfracture after 12 months.

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Section 2

Shoulder

Chapter 6

Subscapularis Tendon Tears: Classification, Diagnosis and Repair

Laurent Baverel

Additional information is available at the end of the chapter

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Abstract

Rotator cuff tears include a panel of tendon lesions, and superior cuff tears are often combined with subscapularis lesions that are more difficult to repair. We propose in this chapter to describe the Lafosse subscapularis tears classification and to describe the arthroscopic repair that can be performed easily with a needle as shuttle. The advantages of these surgical techniques are simplicity, safety and quickness. The procedure is performed under general anaesthesia with the patient in beach chair position. A classic arthroscopic posterior portal is used to perform glenohumeral exploration, and cuff tendons are analysed. Once subscapularis tear is confirmed, the tendon must be released after repair with anterolateral portal. Then, a triple-loaded anchor is positioned at the edge of the bicipital groove to perform both biceps tenodesis and subscapularis repair.

Keywords: subscapularis tendon, rotator cuff tear, Lafosse classification, needle shuttle, biceps tenodesis

1. Introduction

The subscapularis (SSC) muscle is one of the four components of the rotator cuff along with the supraspinatus, infraspinatus and teres minor muscles. The first SSC tendon tears have been reported in 1834 by John Gregory Smith. In 1954, Hauser reported two cases of full-thickness tears repaired with an open approach using trans-osseous sutures [1]. In 1960, McLaughlin reported an SSC tear associated with recurrent anterior shoulder instability. More recently, the first major series with 16 patients including isolated SSC tears were described by Gerber in 1991 [2]. Early studies of rotator cuff tendon tears focused on the supraspinatus tendon. However, SCC tendon tears have garnered increasing attention over the last decade: clinical exam and

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radiographic imaging occurred in a better diagnosis of SSC tears, and recent improvements in arthroscopic instrumentation allow easier repair of the SSC tendon.

Misdiagnosed SSC tendon tears may result in rotator unbalanced force couple, leading to persistent shoulder pain and weakness after cuff repair. SSC tendon tears can be difficult to diagnose on clinical examination, and lesions may be hidden on arthroscopy, essentially in the presence of an intact biceps pulley or rotator interval [3]. The aim of this chapter is to update the classification of SSC tendon tears, better identify SSC tears on specific clinical exam and radiographic imaging, and their arthroscopic management. Even if lesions are well recognized, arthroscopic SSC repair is a technically demanding procedure with a long learning curve [4]. This could be linked to the narrow subcoracoid space making the repair difficult and to the close presence of neural structures at the anterior border of the muscle belly that should be preserved.

2. Anatomy

The SSC tendon is the only anterior tendon of the rotator cuff, and the SSC is the largest of the rotator cuff muscles. The SSC muscle is the major internal rotator of the shoulder and contributes more to shoulder elevation strength than the supraspinatus or infraspinatus tendons [5, 6]. It is important in passive and active stabilization of the glenohumeral joint [7]. The SSC is inserted between the scapula and the humerus.

The scapula attachment is a wide surface area of the subscapularis fossa. The directions of the muscle fibres are anteriorly and laterally towards the humeral lesser tuberosity medially to the bicipital groove. There are three distinct layers in the muscle belly that are well seen with ultrasound or magnetic resonance imaging (MRI) sagittal views. The SSC humeral insertion is tendinous in the two superior thirds and muscular in the lower third. The two superior thirds and the inferior third of the SSC muscle are innervated, respectively, by the upper and lower subscapularis nerves, which are both branches of the posterior chord of the brachial plexus. Electromyographic studies have shown differences in neural activity between the upper and lower portion of the SSC muscle, suggesting that they could work as two different muscular units during shoulder movements [8].

The SSC tendon contributes to the formation of an anatomical space called the rotator interval, which is a tendinous gap in the rotator cuff, exclusively covered by fibrous capsule made of blended fibres coming from the SSC and supraspinatus tendons. It is a triangular-shaped space bordered inferiorly by the superior edge of the SSC tendon and superiorly by the anterior edge of the supraspinatus tendon. The medial base is delimitated by the coracoid process, and the lateral apex is the intertubercular sulcus [9]. The coracohumeral ligament, the superior glenohumeral ligament and the superior fibres of the SSC tendon reinforce the lateral rotator interval and act as a pulley system for the long head of the biceps tendon (LHBT) to prevent its dislocation [10–12]. That may explain why pathologies of the SSC tendon and LHBT are intimately connected [13–18], and why SSC should always be assessed and repaired in patients with rotator cuff tears including the SSC tendon.

3. Pathogenesis

The SSC tendon tears can have either a traumatic and/or a degenerative aetiology. In most cases, the two aetiologies are intricate: an acute traumatic event is reported, on a previous degenerate and fragile tendon. In young patients however, traumatic SSC tears are usually secondary to a forced external rotation in high-energy trauma, with or without combined posterosuperior cuff lesion. In more elderly patients, a SSC traumatic tear can be a consequence of a shoulder dislocation, and associated rotator cuff tears or neurologic injury must be assessed.

In cases with degenerative aetiology, two theories are classically described. The extrinsic aetiology is related to the subacromial impingement syndrome that is the most common disease of the shoulder joint after the sixth decade of life, particularly in overhead workers [19]. Even if its prevalence is high, the aetiology of this syndrome and the histologic and ultrastructural changes in the rotator cuff are not well known. The friction and pressure in the narrow subacromial space probably result in tendon micro-traumatism. In degenerative SSC tears, a subcoracoid impingement may injure the anterosuperior portion of the rotator cuff involving the SSC tendon, the LHBT or all the other rotator cuff tendons. Some anatomic studies reported the close relation of the medial glenohumeral ligament (MGHL) to the upper SSC near its humeral footprint [20]. Based on arthroscopic findings, the MGHL may abrade against the upper edge of the SSC medial to its insertion [21].

The intrinsic theory is that the subacromial pain is multifactorial and could be attribute to the chronic inflammation and degeneration of the rotator cuff and the subacromial bursa [22]. Farfaras found that degenerative histological changes in the form of fibrils with smaller diameters were present in the SSC tendon in patients with subacromial impingement syndrome [23].

4. SSC tear classification

There is no consensus or clear classification regarding SSC tears. We used the classification of Lafosse to classify the SSC lesions into five types [24].

Type 1 is an isolated and partial separation of the SSC tendon fibres from the lesser tuberosity with a normal bicipital sling, regardless of the appearance of the LHBT.

Type 2 is a separation of the SSC tendon fibres from the lesser tuberosity and partial tear in the bicipital sling without involvement of the anterior LHBT pulley or tendinous slip. The probe introduced through the partial sling tear (consisting very often in a cleft in the anterior wall) can lift the superficial SSC layer separated from the lesser tuberosity.

Type 3 is a complete separation of the SSC tendon fibres from the lesser tuberosity and complete tear in the anterior wall of the bicipital sling. The anterior LHBT pulley is normal, distended or, rarely, completely torn. The tendon retraction is minor because the superficial tendon layer is normally attached to the bicipital sling and connected to the superficial fibres of the supraspinatus (superficial layer of the rotator interval, which produces the comma sign after separation from the bony structures).

Type 4 is a complete separation of the SSC tendon fibres from the lesser tuberosity leaving a free edge that can remain continuous with the fibrous scar tissue attached either to the humerus or to the subacromial bursa. The degree of retraction varies, but the stump may reach the level of the glenoid labrum. At this stage, the comma sign is readily identified and connects the subscapularis to the supraspinatus if this last is torn.

Type 5 can be considered as a complete SSC tear combined with an anterior and superior humeral head translation, combined with coracoid impingement and SSC muscle fatty infiltration. This classification is useful to assess the reparability and the risk of retear.

5. Clinical assessment

The shoulder pain related to a SSC tendon tear may be more anterior compared to the typical pain observed in patients with superior rotator cuff tear, essentially when SSC tears are associated with biceps dislocation. Weakness in internal rotation and difficulty to touch the lumbar spine with the hand may also be reported by the patients but are nonspecific of a SSC tear. The three more sensitive and specific clinical tests to assess SSC tendon are the lift-off test, the belly-press test and the bear-hug test.

The lift-off test described by Gerber is performed by placing the hand behind the back at the level of the lumbar spine and asking the patient to lift the hand posteriorly from the back. It is positive when the patient is not able to raise the hand. The examiner can also place the patient's hand raised and ask the patient to maintain the position. The test is positive if the patient is not able to maintain the hand raised and beat up his back.

The belly-press test starts with the elbow slightly anterior to the body and flexed to 90°. The patient is asked to press the hand against his belly without elbow movement. The test is considered positive if the pressing force is weaker than contralaterally.

The bear-hug test is performed with the palm of the hand of the affected side on the opposite shoulder, the fingers extended and the elbow ahead of the body with the shoulder flexed to 90°. The patient is asked to keep the position while the examiner attempts to pull the hand of the patient away from the opposite shoulder by applying a force in external rotation perpendicular to the forearm. The test is positive when the patient cannot keep the hand on the opposite shoulder or the strength in internal rotation is impaired compared to the opposite side.

These tests are however subjective. The SSC strength can be assessed using a dynamometer, providing objective values and allowing force comparison with the contralateral shoulder.

6. Radiographic imaging

A full shoulder series of plain radiographs is useful to assess evidence of trauma (bony avulsion), acromioclavicular or glenohumeral arthritis, lateral acromial morphology (critical shoulder angle), humeral head subluxation and any changes at the SSC humeral footprint [25, 26].

Ultrasonography is a noninvasive diagnosis method allowing a dynamic exam. It is accurate and sensitive for detecting of rotator cuff tears but could be more limited for evaluation of the size of tears, in particular, for the detection of small tears [27]. Ultrasound is useful to assess muscle fatty infiltration, LHBT dislocation or degenerative biceps tendon and subcoracoid impingement.

MRI or computed tomography arthrogram is more reliable compared to ultrasonography for cuff assessment, LHBT (**Figures 1–3**) and fatty muscle belly infiltration (**Figure 4**). In some cases however, it could fail to diagnose the presence of SSC tears [28], indirect signs, as LHBT subluxation must be analysed (**Figure 5**). Diagnostic accuracy could be improved with MR

Figure 1. Axial view of computed tomography arthrogram showing the LHBT in the groove.

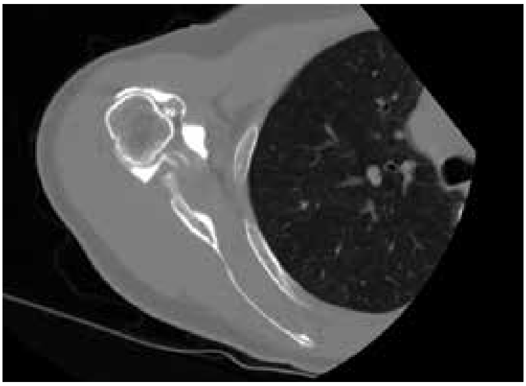

Figure 2. Axial view of computed tomography arthrogram showing a medial subluxation of the LHBT, related to a SSC tear.

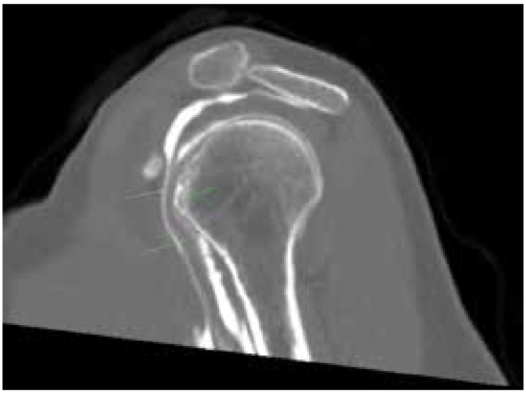

Figure 3. Sagittal view of computed tomography arthrogram showing medial subluxation of the LHBT, related to a SSC tear. The LHBT is in front of the lesser tuberosity.

Figure 4. Axial view of computed tomography arthrogram with muscle analysis. No fat infiltration of the SSC belly muscle.

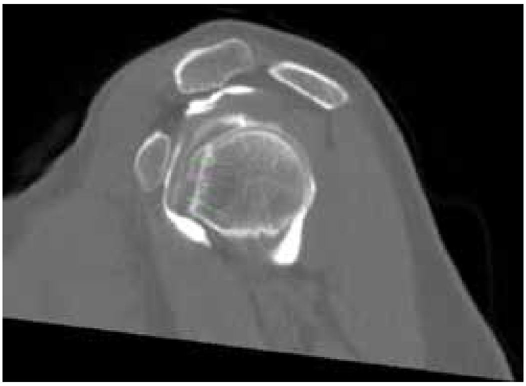

Figure 5. Sagittal view of computed tomography arthrogram showing medial subluxation of the LHBT (two upper arrows), related to a SSC superior third tear. The inferior part of the SSC tendon is well inserted (inferior arrow).

arthrography in assessing rotator cuff tendon tears [29], essentially in the evaluation of SSC tears [30]. Lee recently reported that T1 SPIR is a more sensitive and accurate imaging sequence compared to T2 TSE in detecting SSC tendon tear on 3 T MRA [31].

7. Indications of arthroscopic repair

Repair of a torn SSC tendon restores the internal rotation strength of the shoulder and could stabilize the joint providing a fine balance between internal and external rotator muscles. Indications for arthroscopic SSC repair include patients with a painful shoulder combined with evidence of SSC tear, without fatty muscle degeneration on imaging. In young patients with traumatic tear, there is no place for medical treatment: surgical repair (open or arthroscopic approach) should be quickly performed to avoid both tendon retraction and fatty infiltration that lead to lower clinical outcomes. In older patients with degenerative tear, the medical treatment must be first attempted with corticosteroid injections that are well known to be effective on pain [32]. Contraindications to repair are major glenohumeral arthropathy, fatty SSC muscle infiltration stage >2, active infection and significant medical comorbidities. Regarding patients with rotator cuff combined with frozen shoulder, the author recommends to not repair as long as the shoulder is stiff. The medical treatment should be first initiated with injections and rehabilitation until the complete range of motion is recovered. Once the shoulder has passive full motion, then SSC repair can be performed depending on the patient's complaints.

8. Arthroscopic repair procedure

The surgery may be performed in the beach chair or lateral position, under general anaesthesia in combination with interscalene regional nerve block, to decrease postoperative pain. The beach chair position allows mobilization of the arm during the procedure, as shoulder internal rotation or the Burkhart posterior lever push is applied (the assistant applies a lever from anterior to posterior). However, arm mobilization is not systematically required, and SSC repair may also be performed using a light superior limb traction, exactly as superior rotator cuff repairs.

Standard arthroscopic instruments are required to perform a successful repair of the SSC tendon: angled arthroscopic elevators, electrocautery, ablation wands, suture retrievers, knot pushers and shuttling instruments for passing of the suture through the tendon, like a spinal needle. The author prefers to use a 30° arthroscope; however, the use of a 70° arthroscope may improve the joint view in difficult cases. Instead of 70° arthroscope, switching sticks could be used during SSC repair procedures to change the viewing portal. This makes the visualization of the SSC tendon in subcoracoid space and its release easier, through an anterior-lateral viewing portal easier. Although the authors use no cannula during SSC repair, it can be helpful for young surgeons to manage all the sutures.

According to Burkhart, the author recommends to perform arthroscopic SSC repairs following a meticulous order of steps, whatever SSC tear patterns [33]:

1. Perform a glenohumeral diagnostic arthroscopy.
2. Perform biceps tenotomy or tenodesis, depending on surgeon's habit.
3. Clear the rotator interval.
4. If the subscapularis tendon has adhesions, perform a skeletonization of the coracoid process and perform a three-sided (anterior, posterior and superior) release.
5. Perform a coracoplasty if the subcoracoid coracohumeral distance is <7 mm.
6. Prepare the humeral SSC footprint.
7. Repair the subscapularis tendon.

8.1. Glenohumeral diagnostic arthroscopy.

To perform the glenohumeral diagnostic arthroscopy, a standard posterior viewing portal is first established. Then, two instrumental portals are planned with a spinal needle. An anterior-superior portal is performed by evaluating the optimal direction of the future suture anchor that will be positioned in the bicipital groove, using the needle. This portal is easily performed in patients with a full-thickness anterior supraspinatus tendon tear combined to the SSC tear. In cases with intact supraspinatus tendon, the needle may be inserted immediately anterior at the anterior border of the supraspinatus tendon through the rotator interval. This portal allows lateral-row suture of the SSC tendon and can be used as a viewing portal. Then, the anterior portal is performed along the lateral edge of the coracoacromial ligament using also the needlepointing (**Figure 6**). This instrumental portal allows access to the medial part of the SSC footprint and the SSC medial-row suture. Thus, three portals are enough to perform an arthroscopic SSC repair. The author recommends performing the two instrumental portals before the joint exploration that requires sometimes a shaver to wash or cauterization of a

Figure 6. Preoperative view showing the anterior portal.

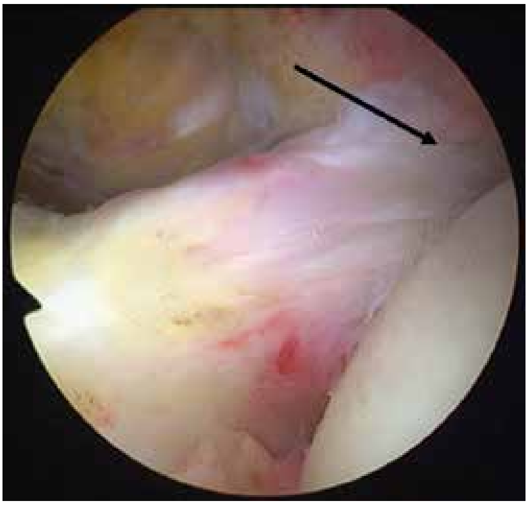

Figure 7. Preoperative view showing an SSC superior third tear.

bleeding vessel. The diagnostic arthroscopy allows analysing the glenoid and humeral articular surfaces, the shoulder ligaments, the labrum and the LHBT, the posterior and superior rotator cuff and the SSC tendon (**Figures 7** and **8**).

8.2. Long head of the biceps management

In patients with rotator cuff tears and particularly in cases with SSC tears, the LHBT requires a specific assessment. The viewing aspect of the LHB is analysed (normal, partial or complete

Figure 8. Preoperative view showing an SSC superior third tear combined with a medial subluxation of the LHBT that is delaminated.

Figure 9. Preoperative view showing an SSC superior third tear combined with a medial subluxation of the LHBT that is degenerative.

degeneration), and then using a stick, the stability at the pulley is assessed by pushing a medial force to dislocate the tendon from the groove above the SSC tendon (**Figure 9**). Sometimes the tendon is already torn. LHBT tenotomy or tenodesis at the groove is indicated in most patients before the SSC tendon repairs to increase the SSC view and make repair easier. The author performs the biceps tenodesis using a triple-loaded anchor that is impacted at the top of the bicipital groove in order to reattach the LHBT in its anatomical position. Thus, one of these sutures is used for the biceps tenodesis with a loop suture technique (the two other sutures will be used later for the lateral row of the SSC repair) (**Figure 10**). In younger patients, the biceps tenodesis should be performed with an interference screw [34]. Some authors described other techniques of biceps tenodesis according to the bone fixation: the tendon can be tenodesed beneath the pectoralis tendon and removed entirely from the bicipital groove [35]. Controversies still exist regarding the best localization for the biceps tenodesis [36–42].

8.3. Rotator interval debridement and SSC release.

Using an ablation wand through the instrumental anterior and anterior-lateral portals, the rotator interval is cleared: first the anterior capsule is resected, then the MGHL, and more medially until the coracoid process. It is easy by following the superior border of the SSC tendon to find the lateral and inferior borders of the coracoid process. There is no danger of nervous injury when the dissection is performed laterally to the pectoral minor tendon. If the SSC tendon is retracted, it can be loaded with a traction wire that may temporarily favour the reduction and assess the tendon reducibility. The three-sided release corresponds to an anterior, posterior and superior release. The superior release is performed during the coracoid process exposition (**Figure 11**). The anterior release is performed using an ablation wand between the SSC tendon and the conjoint tendon (**Figure 12**). It exposes to neurologic injury (axillary and musculocutaneous nerves) if performed too medially. The posterior release is safe

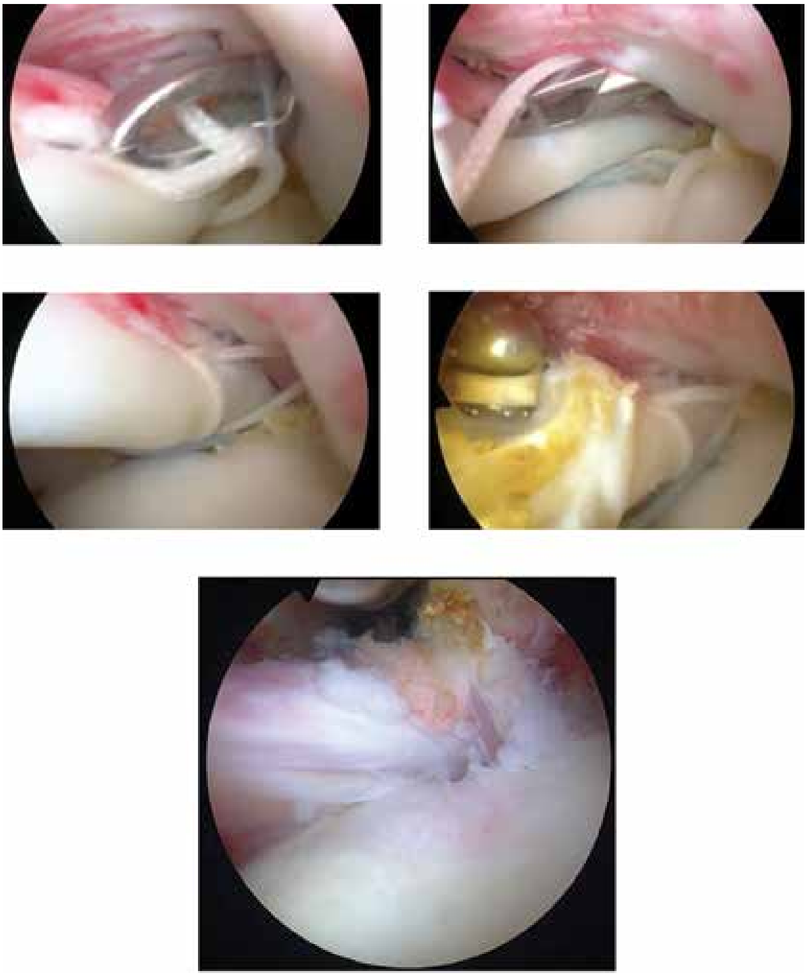

Figure 10. (a) Biceps tenodesis using lasso loop technique; (b) biceps tenodesis using lasso loop technique; (c) biceps tenodesis using lasso loop technique; (d) biceps tenodesis using lasso loop technique. The section before the fixation allows undertension of the biceps; and (e) final aspect after biceps tenodesis.

and performed by introducing a 15° elevator between the posterior SSC tendon and the anterior glenoid neck. If there are combined SSC and supraspinatus tears, it is important to preserve the comma sign [43]. It corresponds to tissue composed of the humeral attachments of the superior glenohumeral and coracohumeral ligaments that concomitantly tear and remain attached to the superolateral corner of the subscapularis. The comma sign is pathognomonic of a combined SSC and supraspinatus tear [44]. Once the SSC is repaired, this tissue helps to reduce and suture the posterosuperior rotator cuff.

8.4. SSC suture

A single-row technique or a double-row technique can be used. The author recommends that type 4 lesions require a double-row technique that could be biomechanically advantageous

Figure 11. SSC superior release, with exposition of the coracoid process.

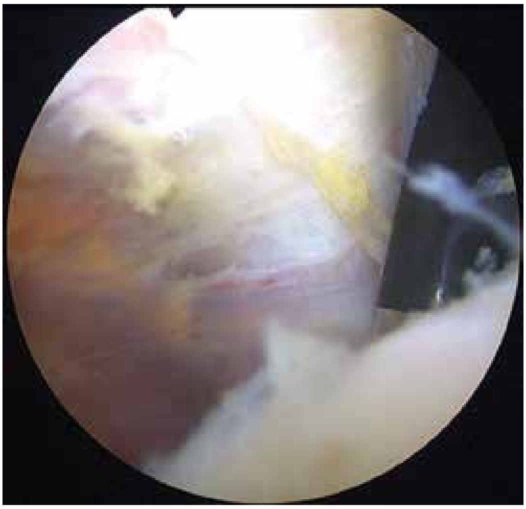

Figure 12. SSC anterior release, with exposition of the conjoint tendon.

regarding postoperative strength and iterative tears [45]. In most cases with SSC tear stages 1–3, a single-row repair may be enough. The principles are similar as for all cuff repairs: decortication of the footprint using a burr through anterior and/or anterior-superior instrumental portals to create a bleeding base (**Figures 13** and **14**). The lateral border of the lesser tuberosity corresponds to the bicipital groove within the biceps tendon previously tenotomised or tenodesed. If the SSC tendon release does not create enough lateral excursion for an anatomic repair, a 5–7 mm medialization of the footprint may be performed without decrease in functional outcomes [46]. Knotless anchors or bridging sutures can be alternatively used; the number of anchors may vary

Figure 13. Decortication and exposition of the SSC footprint.

Figure 14. Decortication and exposition of the SSC footprint using a burr.

from 1 to 4 depending on the extent of the lesion and the type of repair procedure. In patients requiring a double-row suture, the author inserts the medial anchor through the anterior portal in the medial part of the SSC footprint and the lateral anchor through the anterosuperior portal in the bicipital groove. Thus, the same anchor can be used for both the biceps tenodesis and the lateral row of the SSC repair. The same tools used to repair the rotator cuff may be used to pass the sutures, using small instruments, which pass within the tendon itself. Considering the narrow subcoracoid space, it is not easy to pass the sutures through the SSC tendon. The author performs the double-row sutures with 5.5 mm BioComposite Corkscrew FT, Arthrex. The medial suture is passed through the SSC tendon with a shuttle needle with a loop inside, which seems to be a noninvasive technique compared to BirdBeak (**Figure 15**). The lateral suture can be performed with a classic suture pass (FastPass Scorpion, Arthrex).

Chernchujit recently described arthroscopic SSC repair by a double-row knotless technique performed with an extra-articular SSC view [47]. The patient is placed in the beach chair position with an assistant to hold the arm. He uses a standard arthroscopic posterior portal with a 30° scope for glenohumeral diagnostic, and the arthroscope is shifted to the subacromial space. Through an anterior-superior portal, subacromial decompression, acromioplasty and

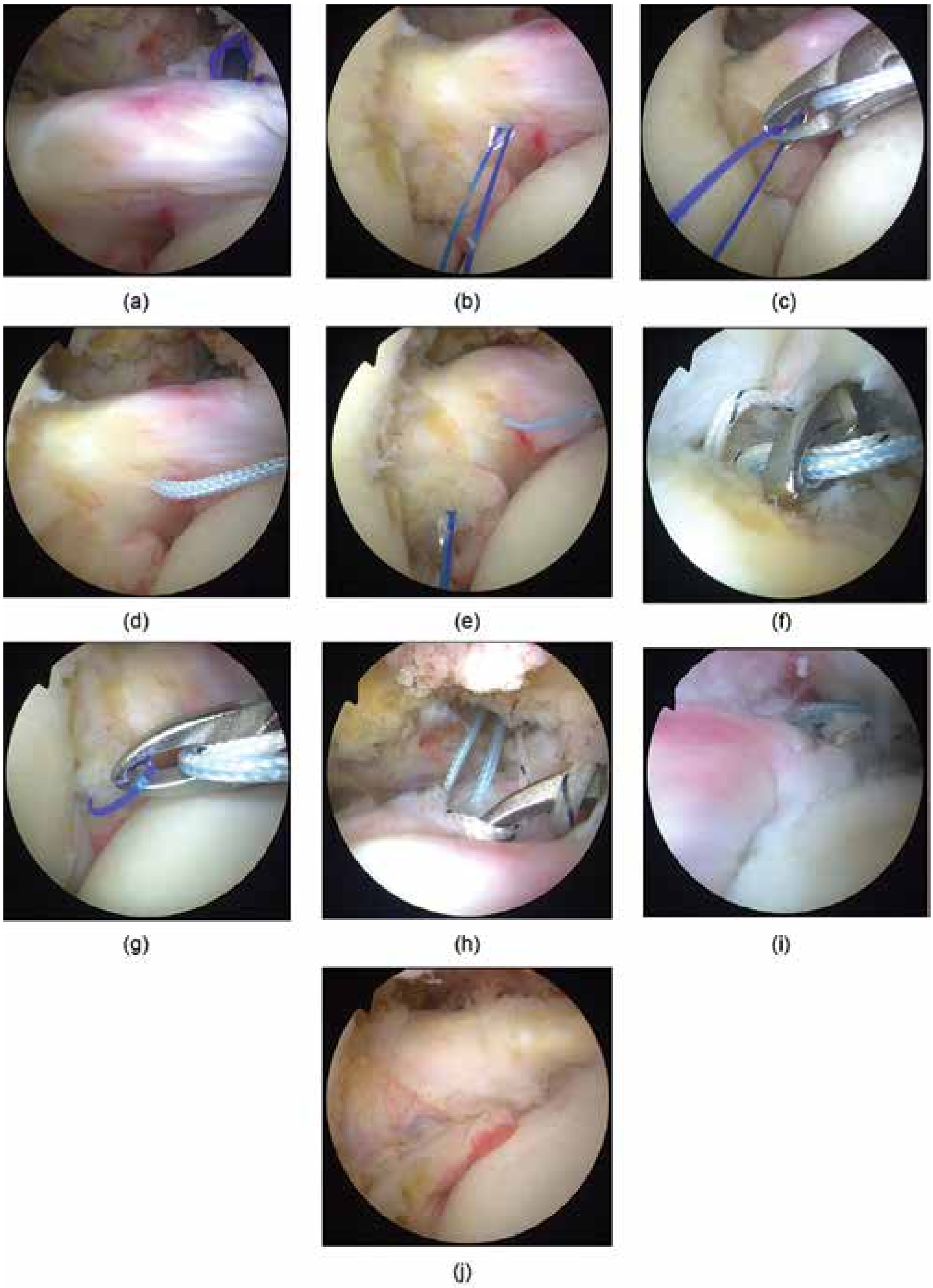

Figure 15. (a) (b) A shuttle needle with a loop inside is introduced from anterior to posterior through the SSC tendon; (c) one suture of the anchor is retrieved with the loop through the anterolateral portal; (d) outside, the surgeon passes the suture inside the loop, and the loop is pulled from posterior to anterior. The suture goes through the SSC tendon; (e) this technique is repeated as many times as required; (f) (g) two sutures of the anchor can be retrieved at the same time; (h) SSC suture; (i) (j) final aspect.

bursectomy are performed to improve visualization and make the SSC suture easier. The anterior portal is established in the rotator interval region. A cannula is inserted through the anterior portal, and a 70° arthroscope is used for the SSC repair. The rotator interval is cleared, the biceps tenotomy is performed, and SSC tendon is released to obtain a good reduction. The SSC footprint is prepared by microfracture, and two anchors are inserted to form the medial row. Suture loops are passed through the SSC tendon using a specific device. The suture bridge technique is then performed, with arm rotated externally. Knotless anchors are inserted on the lesser tuberosity to form the lateral row of the SSC repair. Special attention will be devoted to adequate tensioning.

When performed at early stages, arthroscopic repair is highly successful [48], whereas in patients with irreparable tears (tendon retraction to the level of the glenoid with grade III or IV fatty muscle infiltration) tendon repair is not indicated. To restore shoulder mechanics, some nonanatomic techniques have been reported in the literature such as pectoralis major or latissimus dorsi tendon transfers [49, 50]. These procedures have, however, a high rate of iterative ruptures and complications [51]. Allograft used to repair SSC irreparable tear has also shown fair clinical outcomes and tendon healing on postoperative imaging [52]. More recently and on the model of irreparable supraspinatus tear, superior capsule reconstruction was used in patients with irreparable SSC tears. Anterior capsule reconstruction technique using a human acellular dermal patch requires an open approach, eventually after an arthroscopic diagnosis confirmation of SSC irreparable tear [53, 54]. A standard delto-pectoral incision is made starting to the coracoid process tip. The cephalic vein is exposed and retracted laterally or may be ligated if necessary. The conjoint tendon is identified, and its lateral border is dissected. The subscapularis muscle and anterior capsular deficiency are exposed. After vertical arthrotomy, a Fukuda retractor may be placed into the joint to retract laterally the humeral head exposing the glenoid and the anterior glenoid rims. After anterior labral debridement, three 3.0 mm knotted anchors are inserted into the anterior glenoid rim at the 5-, 3- and 1-o'clock positions. On the humeral footprint, a double-row bridging repair may be performed using four anchors. A 3.5 mm thick human acellular dermal patch is then prepared at the matching size of the SSC tear and then sutures to the glenoid and humeral anchors. Marking several parallel lines perpendicular to the length of the graft for reference could be useful to ensure that the final graft shape is still rectangular.

Cartaya and Valenti described an alternative technique for irreparable tears of the upper two-thirds of the SSC tendon, an arthroscopic-assisted pectoralis minor transfer with a bone chip from the coracoid process [55]. The patient is positioned in the beach chair position, without upper limb traction, to easily mobilize the arm during the procedure. A shoulder diagnostic examination through the standard posterior viewing portal confirms the presence of an irreparable SSC tendon tear. The SSC is released by clearing the rotator interval and excising the coracohumeral ligament; the MGHL and the LHBT are tenotomised. Compared to arthroscopic Latarjet, the coracoid process with conjoint tendon, coracoacromial ligament and pectoral minor are dissected. This stage requires switching the arthroscope from posterior to anterior-superior portal to increase pectoral minor visualization and to create a superior coracoid expanded portal. This instrumental portal allows performing the osteotomy of the medial wall of the coracoid process with the PM tendon using a 10 mm chisel. The bone chip is exteriorized through the same portal and sutured to a double-button device. The footprint is prepared with a burr to create a concave zone matching the shape of the bone chip. An eyelet drill pin is positioned at the centre of the SSC footprint from anterior to posterior until the posterior subcutaneous tissue. The pin is then drilled across all the humeral head, through the posterior humeral cortex to create a complete bone tunnel. After the sutures are loaded in the eyelet of the drill pin, the pin is then retrieved posteriorly through a small skin incision. The sutures are carefully pulled to apply the button over the humeral posterior cortex and to obtain a good compression of the bone chip on the lesser tuberosity, under arthroscopic control. Clinical outcomes after this procedure could be better compared to other techniques according to the use of bone-to-bone fixation. Nevertheless, the author advises to have extensive knowledge of the anatomy to avoid nervous injury (musculocutaneous or axillary nerves).

8.5. Open approach SSC repair

In some patients, particularly in young 12–14 year-old patients, during traumatic event with forced external rotation, a bony avulsion of the lesser tuberosity occurs without tendon tear. Clinical exam finds positive SSC test, and radiographic imaging confirms this isolated SSC lesion. In that case, the author recommends an open delto-pectoral approach. The avulsed fragment is found below the coracoid process, released and removed from the soft tissue and synthetized on humerus after bone decortication. Needle anchors or screw may be used, depending on the bone fragment size. Arthroscopic management is quite possible in these cases, but the author does not recommend this approach, because it is technically demanding, with difficult exposure and repair.

9. Postoperative care and rehabilitation

The patient is usually discharged on the same day after recovering from anaesthesia. Cryotherapy is initiated in the immediate postoperative period. Rehabilitation of subscapularis tears follows the same principles of rotator cuff rehabilitation, using brace for 6 weeks. However, pendulum exercises are immediately initiated, as well as early passive- and active-assisted motion, first performed in supine position and progression to the sitting and standing position. Strengthening activities are authorized after 3 months, and return to manual work or to sports intensively are not allowed before 6 months, to avoid iterative SSC rupture. In general, the rehabilitation program should carefully consider the extent of the tissue retraction and the tendon condition in terms of resistance and elasticity.

10. Conclusion

When a SSC tendon tear is clinically suspected with specific tests, surgeons should confirm and assess its reparability on preoperative MR imaging or arthro-CT. During arthroscopic cuff repair, the concept of "à la carte" surgery is applicable, meaning that surgeon may repair all tendon torn in the same procedure to restore anatomy. The clinical outcomes of recent studies confirm that successful arthroscopic repair of the tendon can lead to an improvement in shoulder function and strength, as well as a reduction in pain. We recommend arthroscopic single or double-row repair using spinal needle as shuttle, after biceps tenotomy or tenodesis.

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Diagnosis and Treatment of the Meso-Acromion of the Shoulder

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Additional information is available at the end of the chapter

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Abstract

The failed fusion between two acromial apophyses, called an os acromiale, is often asymptomatic and found incidentally during evaluation for unrelated shoulder pathology. Though this is frequently not the primary pain source, a mobile os acromiale fragment can cause inflammation at the pseudarthrosis site, rotator cuff impingement, or AC joint arthritis. Varying operative techniques exist with good to satisfactory results for symptomatic patients. Several operative techniques have been described including open excision, open reduction-internal fixation (ORIF), arthroscopic acromioplasty or subacromial decompression, and arthroscopic excision. Open excision of a meso-acromion can lead to persistent pain and deltoid weakness and atrophy. The management of a meso-acromial fragment with ORIF can also result in persistent pain and deltoid weakness and atrophy with non-union of the fragments. Arthroscopic excision of the meso-acromion is described as a viable alternative for surgical candidates.

Keywords: shoulder arthroscopy, os acromiale, meso-acromion, surgical technique, acromion

1. Introduction

An os acromiale is usually found incidentally during the evaluation for unrelated shoulder pathology as most patients are often asymptomatic for this condition [1]. The acromial apophysis develops from four main classification centers: (1) the pre-acromion, (2) the meso-acromion, (3) the meta-acromion and (4) the basi-acromion [2]. The os acromiale represents a failure of fusion between two of these apophyses [2]. The types of os acromiale are defined by the unfused segment immediately anterior to the site of nonunion [3]. For example, failed fusion between the meta-acromial and meso-acromion ossification centers is called a meso-acromiale [3]. Although the reported prevalence of os acromiale in skeletally mature shoulders has ranged from 1.3 to 30% [2–4], it is not frequently diagnosed as a cause of pain [2, 4, 5]. The great majority of os acromiale are meso-acromions (**Figure 1**). Pre-acromial fragments occur much less frequently and a meta-acromiale is rare [3].

A mesotype of os acromion is uncommon shoulder pathology but when symptomatic, presents the surgeon with a diagnostic dilemma with inconsistent outcome treatment options with various surgical techniques. It is not frequently diagnosed as a cause of pain [2, 4, 5] but when other factors have been ruled out, such as impingement or other shoulder pathology, what is the best treatment option is dependent on the age of the patient and their activity level.

The condition can be symptomatic secondary to pain or inflammation at the pseudarthrosis site from the mobile fragment impinging on the rotator cuff [5, 6] or arthritic changes of the acromioclavicular joint due to hypermobility of the os [2]. The diagnosis of a symptomatic os acromiale can be difficult but can be made by the presence of pain and local tenderness over the anterior acromion and the nonunion site [3, 5] a hyper-mobile fragment at the anterior acromion [3], positive impingement signs [5, 7], and positive local injection tests [3].

The area of fibrous union or non-union of the os acromiale fragment may become painful after the patient has minor trauma [1] or from repetitive overhead activities of the shoulder. The persistent pain may be due to acromioclavicular (AC) joint arthropathy as a result of motion of the os acromiale site or from local inflammation at the non-union site [5]. Because there are multiple potential causes of shoulder pain, it is important to rule out other sources of shoulder pain. A thorough clinical examination is needed to define the source of the pain.

When non-surgical treatment fails, surgical management is warranted. A number of surgical techniques have been widely described such as open fragment excision [8], arthroscopic acromioplasty [1, 7, 9, 10], open reduction and internal fixation (ORIF) [2, 3, 5, 6, 11–13], or arthroscopic excision [14, 15]. The excision of a pre-acromion arthroscopically or open is

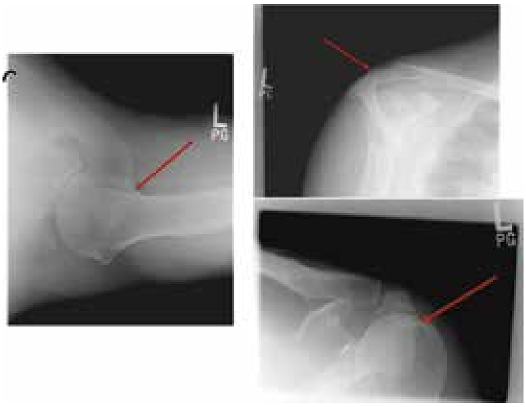

Figure 1. Radiograph views showing a meso-acromion: axillary lateral (A), supraspinatus outlet (B), and anterior-posterior view of the glenohumeral joint.

usually satisfactory [14, 15]. However, open excision of a symptomatic meso-acromion has led to poor results with residual pain, weakness, and deltoid dysfunction [5, 8, 16]. Arthroscopic subacromial decompression has led to good results in many studies, but the satisfaction rate has ranged from 0 to 85% [1, 7, 9. 10]. However, in those studies many of the patients had subacromial impingement and the os acromiale was asymptomatic. ORIF has also led some mixed results with many different surgical techniques described [2, 3, 5, 6, 11–13, 17]. Hardware complications, nonunion, and the need for hardware removal are common after ORIF even when radiographic union has occurred [1–3, 5, 11, 13].

There are some patients who are not candidates for open reduction and internal fixation or for arthroscopic subacromial decompression because of many reasons including concomitant AC joint osteoarthritis, history of previous arthroscopic subacromial decompression with recurrence of pain, or advanced age and the risk of nonunion or the unwillingness to undergo a second surgery for hardware removal, which is very common after ORIF. Arthroscopic excision of the meso-acromion is described as a viable alternative for surgical candidates.

2. Diagnostic imaging

Plain radiographs are the mainstay of diagnostic imaging. An axillary view should be made routinely to diagnose and confirm the presence of an os acromiale. More frequently, the diagnosis is made incidentally. Lee and colleagues [18] described the double-density sign on a standard anteroposterior radiograph of the shoulder and a cortical irregularity on the supraspinatus outlet view which was highly suggestive of an os acromiale (**Figure 1**). MRI or

Figure 2. MRI left shoulder that shows an intact rotator cuff, healing of the previous SLAP repair, moderate AC joint osteoarthritis, and a meso-acromion with sclerotic changes and soft tissue swelling at the meso-acromion site.

CT scan can also be used to confirm an os acromiale and to determine if there are any sclerotic or inflammatory changes at the site which may be indicative of degeneration or symptomatic findings. Bone scans may help illustrate the inflammatory response at the non-union site [5]. MRI and MR arthrogram are also helpful to determine if there is any other intra-articular (SLAP lesion) or other pathology (partial or full thickness rotator cuff tear) which may be a source of pain (**Figure 2**).

3. Nonsurgical management

Nonsurgical treatment for an isolated symptomatic os acromiale is generally recommended as the initial approach [19]. Rest and restriction of activities accompanied by a structured physical therapy program along with a course of nonsteroidal anti-inflammatory medications similar to a typical impingement protocol is a reasonable approach [19]. A subacromial corticosteroid injection can also be used and may help or eliminate the pain due to impingement or subacromial bursitis.

A selective injection into the os acromiale site with lidocaine (lidocaine injection test of 5 cc's of 1% lidocaine with reexamination 10 min later) as a diagnostic tool or with a corticosteroid can also help to determine whether or not the os acromiale is the source of the pathology and may also help relieve the symptoms and surgery may not be necessary.

4. Surgical options

Once the os acromiale or, in particular, the meso-acromion, has been determined to be the source of pain and non-operative treatment options have failed, there are a number of different surgical options ranging from acromioplasty to open resection, open reduction and internal fixation, and arthroscopic resection. The results in the literature vary considerably and are controversial. Depending on the type of os acromiale, the age of the patient, and their activity level, the best surgical options vary for each individual patient. For the sake of this discussion and review for surgical options, we will only address the most common type of os acromiale: the meso-acromion.

4.1. Open excision

Open fragment excision of the symptomatic meso-acromion has had mixed results in the literature due to residual deltoid weakness and dysfunction post-operatively [19]. Mudge and colleagues [8] reported on 6 patients with an os acromiale who underwent open fragment excision but all of them also had associated rotator cuff tears which were repaired with an open technique. Four had excellent results, but two had poor results which may have been due to the severity of the rotator cuff tear or possibly due to the excision of the os acromiale. It is also unclear from their research what type of os acromiale was present as the pre-acromion represents only a small portion of the os acromiales whereas the meso-acromion represents a much larger portion.

The results of an open excision for a meso-acromion from other authors are poor. Armengol and colleagues [20] reported on a case series of 41 patients with an os acromiale in conjunction with rotator cuff tears. Five patients had open fragment excision and all five had poor results. Warner and colleagues [5] reported on 3 patients who underwent fragment excision, one with a pre-acromion who had an excellent result, but the other two had meso-acromions, which were openly excised. These two patients had poor results with persistent weakness and pain. It is likely that the pain and weakness they had after surgery was due to the loss of the normal acromial fulcrum for function of the deltoid. Open fragment excision has limited indications and is recommended for a symptomatic pre-acromion with a relatively small fragment or as a salvage procedure after a failed ORIF [19].

4.2. Open reduction and internal fixation

There are many studies that deal with open reduction and internal fixation of symptomatic meso-acromions using different techniques including the use of tension-band wires, sutures, or cannulated screws with or without bone graft. Internal fixation is technically difficult and has led to frequent nonunion rates and often requires hardware removal as a result of postoperative irritation [12]. Aboud and colleagues [1] reported on 19 patients with a meso-acromion, 8 (42%) which were treated with open reduction and internal fixation. Even though all 8 patients achieved union of the fragment, only 3 of these 8 (38%) patients achieved a satisfactory result.

Peckett and colleagues [13] reviewed 26 patients with symptomatic meso os acromiale that were treated with either K-wires or screws and a tension band. If bone stock was adequate, local bone graft was placed in the pseudarthrosis site but there was no mention in how many cases this was performed. The rate of union was 96% (25 of 26) and 24 of 26 were satisfied with their results. However, no objective or subjective shoulder scores were reported. There were two postoperative fractures and eight patients had postoperative pain that was subsequently relieved by wire or screw removal.

Ryu and colleagues [17] reported on 4 patients with symptomatic meso-acromions treated with diagnostic arthroscopy followed by open reduction and internal fixation using partially threaded, 3.5 mm cannulated screws, such that compression could be achieved across the fibrous union site. All of the patients reported complete satisfaction with the procedures with an average postoperative UCLA rating score of 35, a maximum score of 35 indicates that patients were pain-free and had returned to their previous activities without restriction. All regained full range of motion and full strength without any complications or reoperations for symptomatic hardware.

Warner and colleagues [5] reported on 11 patients (12 shoulders) who underwent ORIF with iliac crest bone grafting comparing two fixation techniques. Each technique incorporated debridement of the nonunion site with incorporation of iliac crest autograft spanning the debrided nonunion site. Five shoulders in 4 patients underwent ORIF with a tension-band procedure including the use of pins and wires. Four of these 5 shoulders (80%) resulted in persistent nonunion. The other 7 patients had an ORIF using cannulated screws and an 18-gauge wire passed through the screws in a figure of 8 fashion. Six of 7 were successful unions. Nine of the 12 shoulders treated with ORIF required hardware removal. Two patients who failed ORIF had open excision of a grossly unstable meso-acromion with persistent pain and weakness following the procedure.

Hertel and colleagues [21] reported on 15 shoulders in 12 patients who underwent ORIF for unstable os acromiale fragments using tension band wiring with the use of bone grafting. Two surgical approaches were used. An anterior deltoid-off approach was used on 7, whereas the other 8 shoulders were approached trans-acromially to preserve the deltoid origin. Union occurred in 3 of 7 cases approached anteriorly and in 7 of 8 shoulders repaired without detachment of the deltoid. The investigators concluded that fusion was more successful when the vascularity of the acromial epiphysis was maintained, likely through the acromiale branch of the thoracoacromial artery.

The techniques and approaches associated with the most successful types of ORIF include those with rigid internal fixation and preservation of the blood supply of the os acromiale fragment [21]. However, even in cases of successful union, patients may still have hardware discomfort requiring hardware removal [19].

4.3. Arthroscopic subacromial decompression and acromioplasty

Arthroscopic subacromial decompression and acromioplasty is used primarily when impingement with or without a rotator cuff tear is present and the nonunion site of the os acromiale is nontender and considered to be incidental [19]. As with other treatment options, the results are variable. Wright and colleagues [7] reported on 13 patients following an arthroscopic acromioplasty of a meso-acromion and found no decrease in anterior deltoid strength and no occurrence of deltoid detachment. None of these patients had pre-operative symptoms or signs localized to the os acromiale pseudo-arthrosis site. Good or excellent results were found in 11 of the 13 cases with an average UCLA shoulder rating scale of 31.

Hutchinson and colleagues [9] reported on 3 cases of impingement syndrome with an associated os acromiale treated with arthroscopic subacromial decompression. Each had good or excellent results in the early post-operative period but the pain returned each case requiring additional surgical intervention. Repeat arthroscopic debridement and excision of the fragment resulted in a good result in one patient while the other two patients the os acromiale was not removed. Both patients had residual pain with impingement like symptoms and pain with overhead activities following the second procedure.

4.4. Arthroscopic excision

Arthroscopic excision can be a better option with a larger os acromiale such as a meso-acromion. Campbell and colleagues [14] reported on 28 patients with 31 os acromiale. Three patients had a pre-acromion and 28 patients had a meso-acromion. After failing conservative management, the patients were taken to surgery and arthroscopic excision of the pre-acromions and meso-acromions was performed in 14 shoulders (45%) using a 4.5 mm flat acromionizer burr, leaving the periosteal sleeve and deltoid attachment. A rotator cuff tear was identified in 16 (52%) of the 31 shoulders. Arthroscopic repair was performed in 9 shoulders and a mini open repair (lateral deltoid splitting) in 7 shoulders. Eighty-nine percent had good or excellent results with little difference in deltoid strength and in subjective or objective change in the appearance or contour of the anterior deltoid in those patients in which the meso-acromion was removed.

Pagnani and colleagues [15] reported on 12 patients (14 shoulders) with persistent shoulder pain that interfered with athletic participation. Symptoms included impingement-like pain with overhead activity and weight lifting, night pain, and an inability to sleep on the affected side. All had tenderness at or near the meso-acromion. All were males between the age of 18 to 25 years and all were engaged in competitive athletics. Eleven of the twelve patients were elite collegiate or professional athletes. Nine patients (11 shoulders) were treated with arthroscopic excision of the anterior acromial fragment. Using an arthroscopic technique, the acromial fragment was carefully shelled out and the deltoid fascia insertion onto the remaining acromion was preserved to prevent deltoid disruption. With a minimum of two-year follow-up with a range of 2–6.5 years and an average follow-up of 3.72 years, all patients were able to return to full athletic participation by 14 weeks after surgery. No deltoid function was compromised by the procedure and there was no evidence of deltoid weakness or cosmetic deformity post-operatively.

Reviewing the literature, the studies of Pagnani [15] and Campbell [14] are the only ones dealing with the arthroscopic excision of symptomatic meso-acromions. The surgical technique requires no special instrumentation and may be reproducibly performed by those familiar with arthroscopic techniques of the shoulder. The advantages include more rapid rehabilitation, better range of motion and shorter surgical times [12]. There is also no need for a second surgery for symptomatic metal removal. Even though both studies reported excellent results, most orthopedic surgeons are reluctant to recommend or perform an arthroscopic excision for fear of resultant muscle weakness, cosmetic deformity and/or perhaps the technical difficulty of performing such a procedure.

4.4.1. Surgical technique for arthroscopic excision

A shoulder diagnostic arthroscopy should be performed in the lateral decubitus position while the patient is under general anesthesia. A 15-point diagnostic arthroscopy of the glenohumeral joint is performed, addressing any intra-articular pathology including loose body removal, labral debridement or repair, capsular release, and evaluation and debridement of the articular side of the rotator cuff. The subacromial space is entered into and the arthroscopic shaver is introduced through a separate lateral incision. Then, the subacromial space is examined, addressing bursitis, impingement, and bursal sided rotator cuff tears. The soft tissues are then taken off of the undersurface of the acromion and the coracoacromion (CA) ligament is released but not cut. A radiofrequency device is preferred versus a shaver as it causes less bleeding and allows for better visualization (**Figure 3**). The anterior and lateral edges of the acromion are then identified along with the pseudoarthrosis or synchondrosis site of the meso-acromion (**Figure 4**).

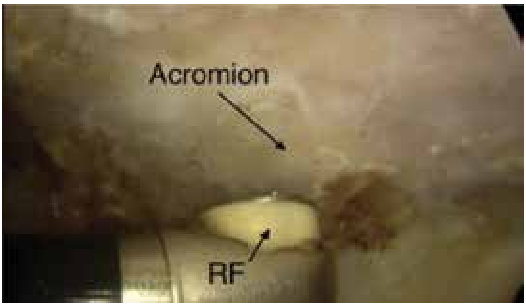

Figure 3. Viewing anteriorly from the posterior portal in a left shoulder in the lateral decubitus position, a radiofrequency device (RF) (Arthrocare 90 degrees wand) is inserted into the sub-acromial space through a lateral portal. This device is used to strip all the soft tissues off the undersurface of the acromion.

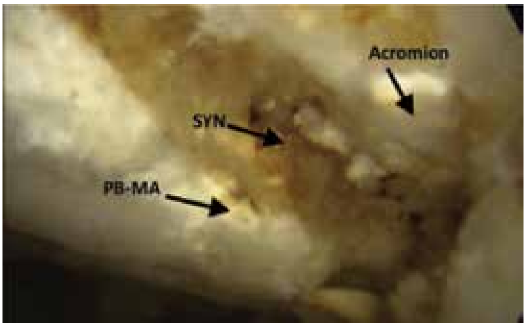

Figure 4. Viewing the subacromial space anteriorly from the posterior portal in a left shoulder in the lateral decubitus position, the radiofrequency device has removed all the soft tissues from the undersurface of the acromion. The posterior border of the meso-acromion (PB-MA), the synchondrosis site (SYN), and the acromion are all visualized.

The entire meso-acromion should be identified and stripped of all soft tissues, using an oval burr via the lateral portal while viewing posteriorly (**Figure 5**). Arthroscopic excision using a burr is performed with careful attention not to damage or disrupt the deltoid fibers, which are attached to the remaining portion of the acromion. Meticulous technique is required to prevent disruption of the deltoid fibers (**Figure 6**). Once this is completed, co-planning of the distal aspect of the clavicle should be performed if there is any evidence of arthritis. The soft tissue shaver can then be reinserted to debride any residual soft tissue and ensure complete removal of the meso-acromion. (**Figure 7**).

4.4.2. Post-operative care for arthroscopic excision

X-rays should be taken post-operatively to assure adequate resection of the meso-acromial fragment (**Figure 8**). Patients should be placed into a sling for 2 weeks to allow the incisions to heal and are instructed on active elbow flexion and extension exercises, active gripping exercises of a small exercise ball with gentle, pendulum exercises. After 2 weeks, the patient's sling should be discontinued and are placed into an aggressive physical therapy program for active assisted range of motion, followed by a strengthening program. Post-operative visits should be

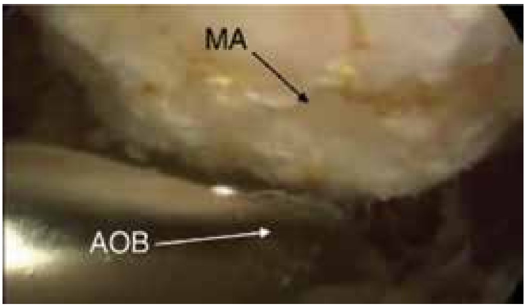

Figure 5. Viewing the subacromial space anteriorly from the posterior portal in a left shoulder in the lateral decubitus position, the arthroscopic oval burr (AOB) (4.5 mm Dyonics; Smith & Nephew) is inserted through the lateral portal. The meso-acromion (MA) can be visualized superior to the burr.

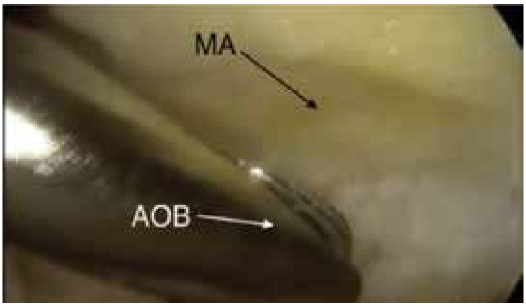

Figure 6. Viewing the subacromial space anteriorly from the posterior portal in a left shoulder in the lateral decubitus position with the burr in the lateral portal, arthroscopic burring is performed by sweeping the arthroscopic oval burr (AOB) along the undersurface of the meso-acromion (MA) from posterior to anterior with meticulous technique to prevent disruption of the deltoid fibers.

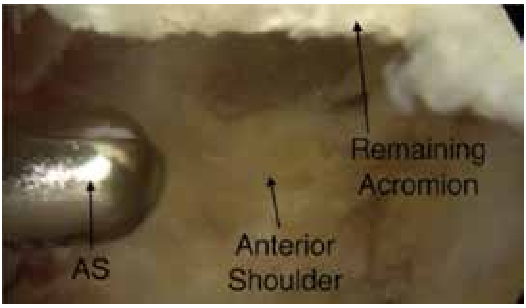

Figure 7. Viewing the subacromial space anteriorly from the posterior portal in a left shoulder in the lateral decubitus position, the arthroscopic shaver (AS) is introduced through the lateral portal to remove any residual soft tissues from the remainder of the acromion and to make sure that the entire meso-acromion has been removed. The remaining acromion can be visualized superiorly.

Figure 8. Post-operative X-rays showing complete excision of the meso-acromion: supraspinatus outlet (A), axillary lateral (B), and AP of the glenohumeral joint (C).

Figure 9. A (left) and B (right) shows no evidence of any cosmetic deformity from resection of the meso-acromion.

regularly scheduled, assessing improvement in range of motion and strength. Particular attention should be focused on the deltoid, looking for evidence of weakness or atrophy. After the patient is fully recovered, the cosmetic appearance of the shoulder should not be appreciably different (**Figure 9**).

4.5. Author's indications for surgery and preferred technique

The senior author (WBS) has been treating shoulder patients for over 20 years. As discussed here in this chapter, many meso-acromions are incidental findings on x-ray and are asymptomatic and should be left alone. If there is ever a question of whether the meso-acromion is the source of a patient's shoulder pain, we prefer the technique of a local injection of 5 cc's of 1% lidocaine into the synchondrosis of the meso-acromion and if that gives pain relief, it is usually diagnostic for a symptomatic meso-acromion that needs to be addressed surgically. We will also often follow the local lidocaine injection with a corticosteroid injection into the area as this can give some patients long lasting pain relief.

Once the meso-acromion has been determined to be the cause of the pain, the senior author recommends arthroscopic excision using the techniques described in this book chapter. At the time of surgery, the meso-acromion is most often loose and the synchondrosis is easily identified arthroscopically and removed. In our experience, we have not seen any evidence of deltoid weakness or atrophy in the patients we have treated with arthroscopic excision and all have been able to resume normal overhead activities with virtually no pain and no subjective or objective evidence of weakness.

5. Summary and conclusions

Symptomatic os acromiale are uncommon shoulder pathology but have several management options. When conservative management fails, operative management is warranted. Arthroscopic excision is a much better option than open resection or even ORIF. ORIF of meso-acromial fragments has led to mixed results [1, 2, 5, 13] and is not a good option in patients who are older or who have AC joint osteoarthritis. We prefer arthroscopic excision of the os acromiale/meso-acromion fragment and have found it to be a reliable technique that gives good long term patient satisfaction with no loss of strength. Future studies need to be done to address and analyze the surgical option of the arthroscopic excision of symptomatic os acromiale and in particular, meso-acromion, in certain patient populations. This could lead to a better understanding and treatment options of this difficult and challenge clinical shoulder problem.

Conflict of interest

The authors have no conflicts of interest to report.

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Section 3

Hip

Chapter 8

Hip Arthroscopy Made Simple, Easy, and Elegant. A Novel Variant of the Outside-In Technique

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Jacek Macek

Additional information is available at the end of the chapter

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Abstract

Hip Arthroscopy (HA) is considered to be a demanding surgery with a steep and slow learning curve. Adequate HA instrumentation is required to perform a reproducible surgery. The technique most commonly used to access the hip is through the central compartment or from the "Inside-Out" with continuous distraction and specialized access equipment. Newer techniques start from the peripheral compartment called "Outside-In" techniques, these techniques have a safer access with a more controlled environment avoiding iatrogenic scuffing of the acetabulum, labrum or femoral head. The purpose of this surgical and novel variant technique from the "Outside-In" which we call *simple, easy*, and *elegant* is an excellent choice and can be part of the armament for young surgeons who are initiating in hip arthroscopy and preservation, our technique has been very reproducible and reliable with good to excellent results with very few complications.

Keywords: hip arthroscopy, peripheral compartment first, hip arthroscopy without fluoroscopy, simple hip arthroscopy, outside-in technique for hip arthroscopy

1. Introduction

The hip joint anatomy is known to be surrounded by a strong soft tissue mantle and muscles; this deep and constrained anatomy makes hip distraction very difficult. Hip arthroscopy (HA) is considered to be a demanding surgical procedure compared to other joint arthroscopies and is known to have a steep and very slow learning curve (**Figure 1**) [1, 2].

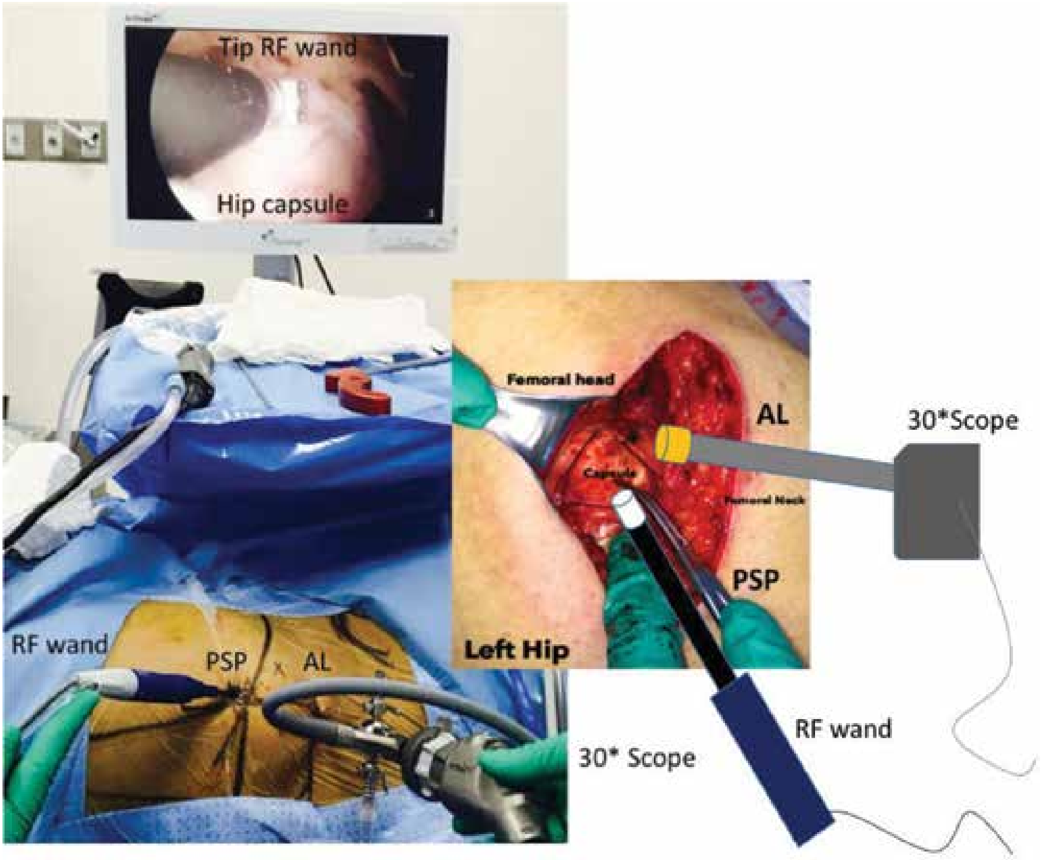

Figure 1. Left hip arthroscopy demonstrating the hip capsule. Observe the radiofrequency (RF) wand placed in the peritrochanteric space portal (PSP) and the 30° scope placed in the anterolateral portal (AL). Observe an open left hip (right quadrant picture) demonstrating the hip capsule, where the instruments are placed to perform the capsulotomy.

Hip arthroscopy is a unique specialty, which initiated in the nineteenth century. The last decade has seen an exponential rise in the number surgeries performed worldwide [3]. The procedure itself has evolved throughout this years.

Michael Burman was responsible for first cases describing hip arthroscopy in cadavers in 1931. He had developed a device comprised of a 4 mm trocar and a 3 mm arthroscope. Burman used this to examine 20 hip joints and after this, He then stated “it is manifestly impossible to insert a needle between the head of the femur and acetabulum.” He could never entry to the central compartment of the hip as all his surgeries were without traction. Later, Takagi in 1939 reported the first clinical application of hip arthroscopy in four patients: two with Charcot’s joint, one with tuberculosis, and one with septic arthritis [4].

Hip arthroscopy is a rapidly expanding procedure that has been gaining popularity in the medical field since the 1980s. Initially, the indications for hip arthroscopy were much more limited than for other joints because the hip joint anatomy which is known to be surrounded by strong soft tissue and muscles, which presents additional challenges to access and have adequate maneuverability inside the hip. With improved instruments, hip distractors, patients positioning, equipment, hip capsular management and hip exposure techniques, the indications for hip arthroscopy have greatly expanded. In experienced and trained hands, this minimally invasive procedure may offer the potential for reduced iatrogenic neurovascular lesions [5, 6].

The most used arthroscopic surgical technique and worldwide used is the called "Inside-Out technique" which enters the hip joint through the central compartment (CC), with continuous distraction. This technique needs the aid of hip cannulated needles, a specialized hip access system, fluoroscopy and a hip fracture table (HFT) or distractor, adequate distraction is important in HA to avoid surgical iatrogenic complications like labral penetrations, labrum resections and also scuffing of the femoral head cartilage [7, 8].

Newer techniques have been published in performing HA from the "Outside-In" to approach the hip joint extra-articularly and starting from the peripheral compartment (PC) first, other techniques do not use specialized cannulated needles or a hip access system; and others have developed radiographic and anatomic landmarks to approach the anterior capsule without fluoroscopy (**Figure 2**) [7, 9, 10].

This "Outside-In" techniques have been developed to perform HA simple, safely, reproducible and more reliably; but what is most important they have been developed to avoid iatrogenic cartilage lesions while accessing the hip joint. As we all know HA has the disadvantage of being difficult and demanding because of his steep learning curve, is a very tedious procedure to perform and the operating room staff must be familiarized positioning the patient on a hip fracture table. Another very important factor is that this procedure has too much radiation burden from fluoroscopy [11].

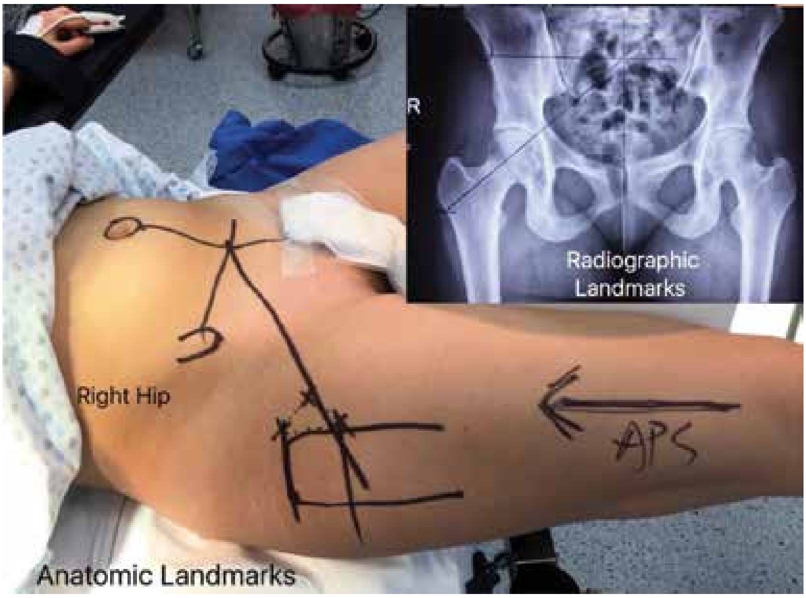

Figure 2. Radiographic landmarks (right upper corner X ray) and anatomic landmarks plotted in the patients right hip.

Performing HA reproducibly in third world countries has been challenging and the struggle in getting access to all HA equipment has made surgeons develop newer techniques; we developed this "Outside-In" technique which we call, *Simple*: Because we do not use any specialized access equipment or cannulated dilators or obturators to access the hip joint, *Easy*: Because we do not use fluoroscopy to aim the hip, instead we use radiographic and anatomic landmarks to approach the anterior capsule and *Elegant*: Because 90% of the case the operative hip is placed in a simple mayo table, which allows to perform a complete range of motion of the hip (flexion, extension, internal and external rotation) and allows access to almost every portion of the femoral head.

We started performing hip arthroscopy with this technique in January 2015–May 2017, 230 patients underwent HA, 116 patients with cam impingement, 55 Pincer impingement, 23 with mixt FAI, 4 internal snapping hips, 3 traumatic dislocation of the hip, 8 GII hip arthritis, 14 patients with avascular necrosis of the femoral head, 2 hip dysplasia, 3 Leg-Calve-Perthes and 2 patients with subspine impingement. Complications presented where, 1 patient with HA and core decompression presented erectile dysfunction who recovered at 6 weeks, 1 patient with numbness at the lateral thigh region who lasted 2 weeks, 1 patient presented a transitory femoral nerve palsy for 1 week, 1 patient developed a knee hematoma from traction, 1 patient developed a catastrophic supero-lateralization of the femoral head who underwent an uneventful THA (she had arthritis grade III and dysplasia), no infections, no instability. The follow-up of our patients was made at 2 years postoperatively.

2. Surgical technique

HA is performed in the modified supine position, with the patient supported on a conventional hip fracture table (HFT) (MAQUET Gmbh, Rastatt, Germany), under general anesthesia, no muscle relaxants are used, although they may be added. Knee and shoulder instruments are used through the entire case (**Figure 3**). The padded counter traction post is applied against the proximal femur deliberately lateralizing this post, both feet and shins are also well padded. The foot of the operative hip is taking out the HFT clamp and afterwards positioned over the mayo table (Medical products Monterrey, Mexico) [12]. Radiographic landmarks are routinely marked in a simple AP pelvis and reproduced on the patient's operative hip with anatomic landmarks. Portals are established to access the PC and CC: A anterolateral portal (AL) used for vision, immediately anterior to the trochanteric tip, a peritrochanteric space portal (PSP) used as a working portal, situated 3 cm distally from the AL and over the anterior trochanteric border, and a new modified mid- anterior portal which is located 1.5 cm above and between AL and PSP, which we call the trochanteric triangle portal (TTP) (**Figures 4** and **5**). A hip bursa resection is performed with a shaver or a radio frequency (RF) wand and posteriorly a longitudinal capsulotomy is performed to access the head–neck junction to perform a femoral osteochondroplasty (FOC) for the cam morphology, if there is a pincer impingement acetabuloplasty is performed without distraction. Afterwards an arthroscopic dynamic impingement test (ADIT) is performed with the help of the surgical assistant, fellow or nurse, and it will be useful to evaluate FOC. After finishing on the peripheral compartment a surgical assistant will place the free foot and attach it to the HFT clamp, this to distract the hip under

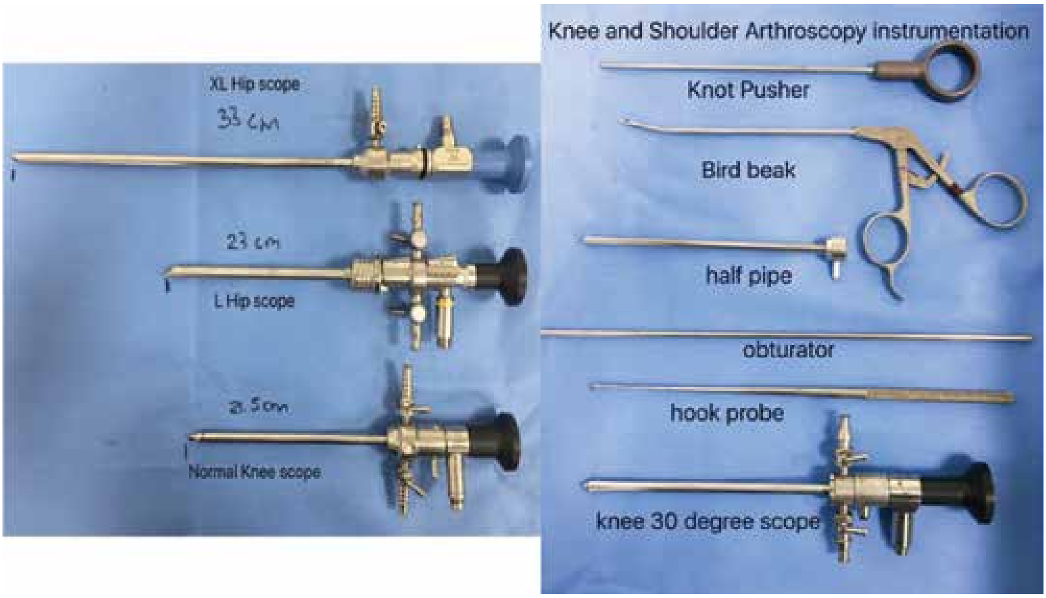

Figure 3. Three different arthroscopes and sheaths in different lengths, knee and shoulder instruments are used in every case. The 30° scope is used in 90% of the case to work in the peripheral compartment.

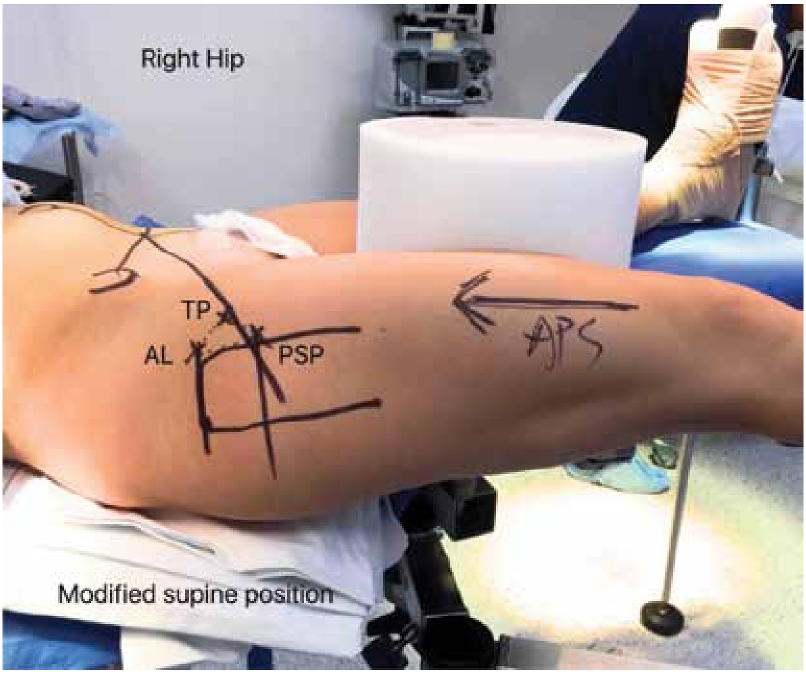

Figure 4. Right hip in the modified supine position. Observe the vision portal (AL) and the working portals (peritrochanteric space and triangle portal).

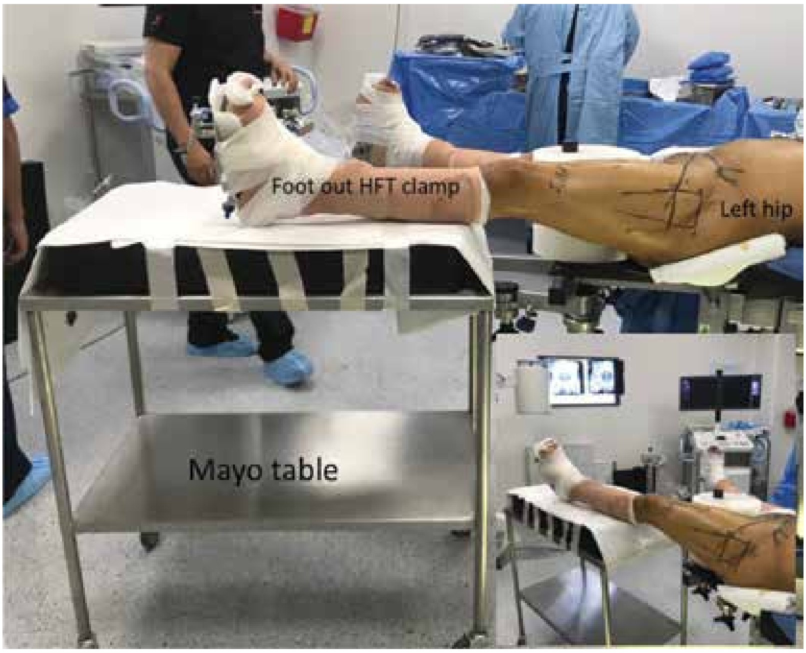

Figure 5. The left foot (operative hip) is out of the hip fracture table (HFT) clamp 90% of the case. Posteriorly clamped for hip distraction. Observe the left foot/hip over the cushioned mayo table, which allows the surgeon to manipulate and perform maximal hip range of motion.

controlled arthroscopic vision. A thorough evaluation in the CC is performed. Labral repair is tackle from the TTP portal if needed, ligamentum teres injuries or tears are also treated. A capsule closure is performed if the patient presents with generalized ligamentous laxity. A 30° arthroscopic lens is used throughout the peripheral compartment to perform a femoral osteochondroplasty, an exchange to a 70° arthroscope is done to enter the CC and if a labral repair is needed. The entire case of HA is performed without fluoroscopy.

3. Results

Two hundred and thirty patients underwent an uneventful HA through the same surgical approach from the outside-in technique which we call “simple, easy, and elegant,” none of the patients presented with iatrogenic scuffing of the femoral heal, labral resection or penetrations, no infections, avascular necrosis or instability was presented.

4. Discussion

HA is evolving tremendously over these past years, more reliable and reproducible techniques are being described and published with excellent results; this described arthroscopic technique has allowed us to create a more practical environment outside and inside the hip joint, better maneuverability to the hip when the boot/foot is out of the HFT clamp, we have found easier access to the hip with no needles or cannulated obturators, also less iatrogenic chondral damage and cero radiation to the surgical team. Dienst et al. has mentioned that portal placement to the hip joint is probably the most demanding step during HA and extreme care must be taken in these critical steps which are related to the thick soft-tissue mantle; less force of traction is applied when the capsulotomy is done prior distraction, their published results demonstrated that soft tissue injuries and nerve dysfunction are extremely rare. Doron et al. describes an extracapsular technique for the non-distractable hip, but they still use fluoroscopy to establish the AL portal. Salas AP. describes a technique accessing the anterior capsule fibers with radiographic and anatomic landmarks without using a fluoroscope, performing a capsulotomy to tackle the cam morphology [13].

The author (APS) started HA with the "Inside-Out" technique and difficulty was encounter in every case due to lack of arthroscopic disposables, materials and access systems; but the passion in performing HA and to develop a simple, reproducible and reachable technique for all surgeons was the goal. Our technique called *Simple, Easy* and *Elegant*: **A Novel Variant of The Outside-In Technique** is now our daily battle horse to approach the hip and the vast majority of its pathologies and morphologies.

Care should be considered in dysplastic hips with generalized ligamentous laxity because iatrogenic instability can occur, a labral repair, capsule closure or tightness is recommended in this cases. With this developed technique we want to demonstrate that HA is accessible and it can be performed in a simple and safely way, that the expensive hip disposables and hip instrumentation are not a barrier to start HA.

5. Conclusion

Hip Arthroscopy is difficult and becomes a challenge to the young Orthopedic Surgeons, this technique made *Simple, Easy* and *Elegant*: **A Novel Variant of The Outside-In Technique** is an excellent choice in hip arthroscopy and preservation and can be part of the armament for hip surgeons; our technique has been very reproducible and reliable with good to excellent results.

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Section 4

Elbow

Chapter 9

Neurological Complications of Elbow Arthroscopy

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Abstract

Elbow arthroscopy is an increasingly common procedure performed in orthopedic surgery. However, due to the presence of several major neurovascular structures in close proximity to the operative portals, it can have potentially devastating complications. The largest series of elbow arthroscopies to date described a 2.5% rate of post-operative neurological injury. All of these injuries were transient nerve injuries resolved without intervention. A recent report of major nerve injuries after elbow arthroscopy demonstrated that these injuries are likely under-reported in literature. A review of our records from 1998 to 2014 revealed six patients who had undergone elbow arthroscopy and developed neurological injury post-operatively. While complications after elbow arthroscopy are rare, the most common permanent nerve palsy post-operatively is the posterior interosseous nerve (PIN) followed by the ulnar nerve. Because of the surrounding neurovascular structures, familiarity with the normal elbow anatomy and portals will decrease the risk of damage to important structures. The purpose of this chapter is to review important steps in performing elbow arthroscopy with an emphasis on avoiding neurovascular injury. With a sound understanding of the important bony anatomic landmarks, sensory nerves, and neurovascular structures, elbow arthroscopy can provide both diagnostic and therapeutic intervention with little morbidity.

Keywords: elbow arthroscopy, neurological complications, posterior interosseous nerve, ulnar nerve, neurovascular injury

1. Introduction

Elbow arthroscopy is a technically demanding procedure, which requires extensive hands-on training and supervised experience to acquire proficiency [1, 2]. When performed with appropriate judgment and technique, elbow arthroscopy is an excellent tool for the correction of many lesions of the elbow joint with minimal risk [3]. However, it poses greater technical challenges and neurological risks than knee or shoulder arthroscopy. Arthroscopy of the elbow joint is perhaps the most hazardous due to the potential for causing injury to important nearby nerves and vessels. The reason for this relates to the complex relationship of these structures to the joint (**Figure 1**) [4]. Because of the surrounding neurovascular structures, familiarity with the normal elbow anatomy and portals will decrease the risk of damage to important neurovascular structures [5]. With a sound understanding of the important bony anatomic landmarks, sensory nerves, and neurovascular structures, elbow arthroscopy can serve as an opportunity for both diagnostic and therapeutic intervention with little morbidity.

Due to the proximity of several neurovascular structures to the established portals, the risk of neurological injury during elbow arthroscopy is higher as compared to other joints [6]. Additionally, the complications after elbow arthroscopy have been reported to be 10%, compared to a rate of ~3% after knee arthroscopy [1]. Multiple anatomical studies have documented the relationship and location of the nerves crossing the elbow to the commonly used arthroscopic portals [7–12]. Not surprisingly, injuries to every nerve about the elbow have been reported after arthroscopy [13–18]. Despite these concerns, the three largest consecutive series of elbow arthroscopy to date have reported a low incidence of neurological

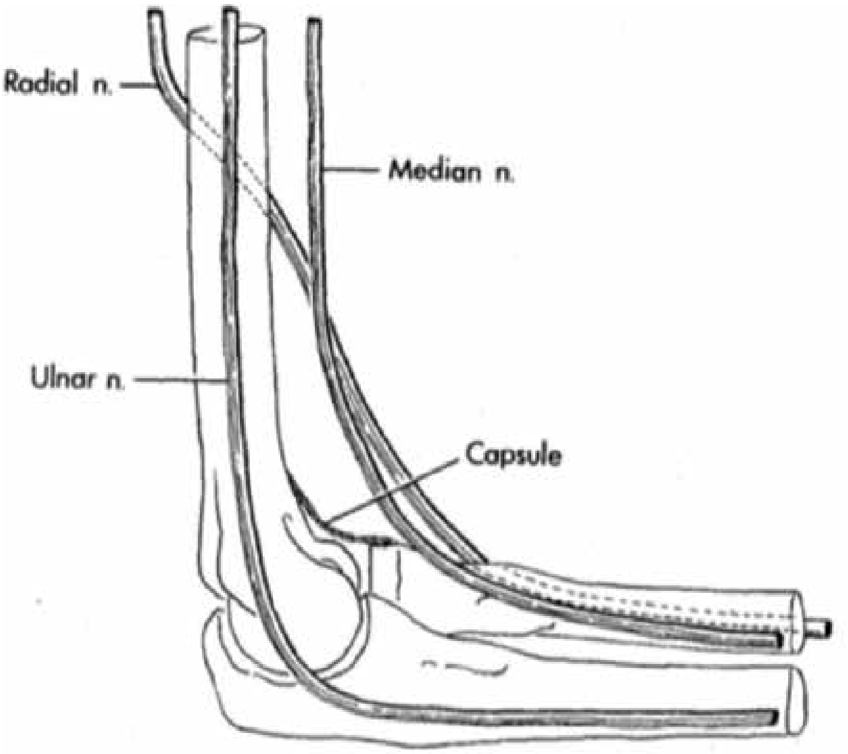
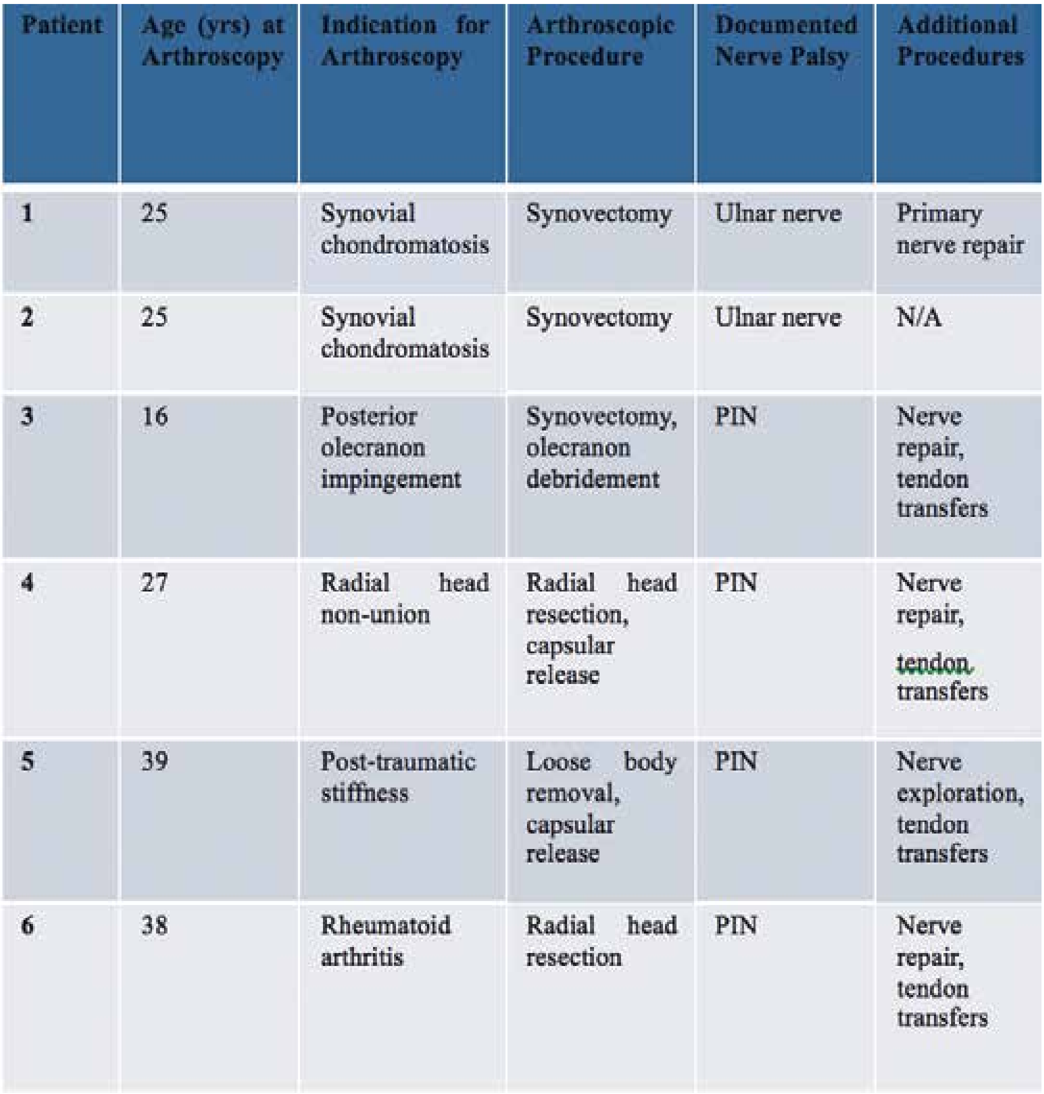


Figure 1. The antecubital fossa with important neurovascular structures.

complications [1, 2, 18]. The first large series of consecutive elbow arthroscopies reported one laceration of the ulnar nerve in 187 consecutive cases (0.5%) [19]. The largest series reported a 2.5% rate of neurological injury after elbow arthroscopy in 473 consecutive cases with ulnar nerve dysfunction being the most common [1]. All of the reported injuries in this series resolved spontaneously without intervention.

In the most recent series, a 1.7% rate of neurological injury was reported in 417 consecutive elbow arthroscopies [2]. As with the previous series, all of the reported injuries were transient in nature. From these studies, it can be inferred that a permanent neurological deficit is an



Patient	Age (yrs) at Arthroscopy	Indication for Arthroscopy	Arthroscopic Procedure	Documented Nerve Palsy	Additional Procedures
1	25	Synovial chondromatosis	Synovectomy	Ulnar nerve	Primary nerve repair
2	25	Synovial chondromatosis	Synovectomy	Ulnar nerve	N/A
3	16	Posterior olecranon impingement	Synovectomy, olecranon debridement	PIN	Nerve repair, tendon transfers
4	27	Radial head non-union	Radial head resection, capsular release	PIN	Nerve repair, tendon transfers
5	39	Post-traumatic stiffness	Loose body removal, capsular release	PIN	Nerve exploration, tendon transfers
6	38	Rheumatoid arthritis	Radial head resection	PIN	Nerve repair, tendon transfers

Table 1. Neurological complications following elbow arthroscopy.

extremely rare occurrence, despite the risks highlighted in the anatomical studies. However, a recent online survey of members of the American Society for Surgery of the Hand reported a much higher incidence of major nerve injuries after elbow arthroscopy indicating that this is not a rare occurrence [20].

Review of our medical records revealed six patients with documented nerve palsies after elbow arthroscopy. All of these patients were referred to our institutions; their index procedures were performed at other facilities and no cases of neurological injury were found at our institutions. The complete results are presented in **Table 1**. The indications for the arthroscopies performed included synovial chondromatosis [3], stiffness after elbow trauma [3], posterior olecranon impingement [2], and stiffness due to rheumatoid arthritis [2]. All patients underwent arthroscopic synovectomy in the anterior and posterior compartments to improve range of motion, two patients underwent radial head resection, two patients underwent capsular release and one patient underwent posterior olecranon debridement. Four patients demonstrated isolated posterior interosseous nerve (PIN) palsies (66%) with inability to extend all digits and radial deviation with wrist extension. In these four patients, the anterior lateral portal used was found to be at or distal to the radiocapitellar joint. Two other patients demonstrated isolated ulnar nerve palsies (33%). All nerve injuries were confirmed by EMG/NCS or by direct visualization during surgical exploration. None of the neurological injures demonstrated recovery without further surgical intervention.

Five out of the six patients underwent additional surgical procedures to address their nerve palsies. Four patients underwent attempted repair of the lacerated nerve (3 PIN, 1 ulnar), with only one demonstrating any improvement in function at 1 year (1 ulnar). All four patients with PIN palsy underwent modified Brandt tendon transfers (flexor carpi radialis to extensor digitorum communis, palmaris to extensor pollicis longus) to restore finger and thumb extension successfully. In this chapter, we will provide a step-by-step process for performing elbow arthroscopy in order to minimize the risk to neurovascular structures.

2. History and physical examination

Before proceeding with elbow arthroscopy, a comprehensive history should be taken including the occupation of the patient, whether they are right or left handed, the location of their pain, and the duration of their symptoms. It is also important to determine the details of whether their symptoms started with a single traumatic event or from repetitive activities. Symptoms in the lateral region of the elbow may be indicative of radiocapitellar chondromalacia, osteochondral loose bodies, radial head fracture, osteochondritis dissecans (OCD) lesions, and most commonly lateral epicondylitis. Symptoms in the medial region of the elbow most commonly present as medial epicondylitis, but MCL sprains, ulnar neuritis, ulnar nerve subluxation, or even a medial epicondyle avulsion fracture should also be considered.

The differential diagnosis for symptoms of the anterior elbow includes distal biceps tendon rupture, which can be partial, or complete, an anterior capsular strain, and a brachioradialis muscle strain [21]. Symptoms in the posterior compartment can reflect valgus extension overload syndrome, posterior impingement, osteochondral loose bodies, triceps tendonitis, triceps tendon avulsion, or olecranon bursitis [22]. A careful neurovascular history is also important, as ulnar nerve paraesthesias can be the result of cubital tunnel syndrome, a subluxing ulnar nerve, or a traction injury from valgus instability [23]. A careful physical examination of all three compartments of the elbow is critical to determine the correct diagnosis. Each compartment should be examined individually in order to fully evaluate the elbow.

3. Diagnostic imaging

Routine diagnostic radiographs include an anterior posterior (AP) view with the elbow in full extension and a lateral view with the joint in 90 degrees of flexion. An axial view can also be obtained to outline the olecranon and its medial and lateral articulations. When there is a history of trauma, an oblique view should also be done to rule out occult fractures.

Magnetic resonance imaging (MRI) is useful for evaluating osteochondral lesions in the radiocapitellar joint [24, 25] and for demonstrating early vascular changes which are not yet apparent on plain radiographs and can be used to assess the extent of the lesion and displacement of fragments [23]. MRI is also helpful for evaluating the soft tissue structures of the elbow including the tendinous insertions of the flexor and extensor musculature to help in diagnosing medial and lateral epicondylitis, the triceps insertion, and associated musculature to evaluate for triceps tendonitis, and the medial and lateral collateral ligaments for possible tears. Magnetic resonance arthrography with saline contrast or gadolinium can increase the sensitivity for detecting undersurface tears of the ulnar collateral ligament and has now become the test of choice to detect these tears [26].

4. Operating room setup and positioning

We typically perform this procedure under general endotracheal anesthesia in the prone position. This procedure can also be performed with the patient in the lateral decubitus position [27], but the prone position is our preference. We prefer the prone position as it allows easy access to the both the anterior and posterior compartments of the elbow joint. Similar access can be achieved in the lateral decubitus position but we prefer the prone position as we find it easier to gain access into both compartments. We strongly advise against the supine position, as access to the posterior compartment is difficult and can lead to unintentional neurovascular injury.

We prefer general anesthesia as it allows proper positioning of the patient, which is key to avoiding neurological and vascular injuries although a regional block is possible. After an appropriate level of anesthesia (general endotracheal or axillary block) has been achieved, the patient is placed in the prone position, using two large chest-rolls under the torso to raise the patient's torso up from the operating table. These are made of operating room blankets rolled up and taped together. These chest rolls are very important and must be firm so that it elevates the chest wall off of the operating room table. We advise against the pre-made devices used by spine surgeons for prone positioning, as it does not elevate the patient high enough off of the operating room table.

In the prone position, an arm-board is placed on the operative side of the table and parallel to it. A sandbag, block, or firm bump of towels is placed under the shoulder to further elevate the arm away from the table and increases the mobility of the upper extremity. If the chest rolls are not high enough or firm enough, the chest is not elevated far enough away from the operating room table and the shoulder will be placed in hyper-abduction, which can place unnecessary stress or strain on the shoulder capsule or surrounding structures. The forearm is then allowed to hang in a dependent position over the arm-board at 90° (**Figure 2**). A sterile tourniquet may be placed around the proximal aspect of the arm to help to control bleeding during the procedure, but it is not always necessary to inflate when using a mechanical irrigation system [3]. The forearm is prepared from the proximal arm to the tip of the fingers and then the extremity is wrapped with an elastic bandage from the fingers to just below the elbow to minimize fluid extravasation into the forearm [28]. After the extremity is prepped and draped, a large sterile "bump" is placed under the arm proximal to the elbow to keep the shoulder abducted to 90° and the elbow at approximately 90 degrees of flexion (**Figure 3**).

Figure 2. The prone position with the right elbow resting over an arm board, which is parallel to the operating room table. A non-sterile U-drape is placed proximally. A sterile bump is placed under the arm for support after the extremity is prepped.

Figure 3. A left elbow is shown in the prone position. Anesthesia is at the head (left) of the patient and all equipment is on the opposite side of the table. Note the sterile bump under the arm which helps stabilize the elbow during the procedure. This rests on the arm board, which has been placed parallel to the table.

5. Portal placement and diagnostic arthroscopy

5.1. Anterior compartment

After prepping and draping the extremity, all bony landmarks are then outlined including the olecranon, the medial and lateral epicondyles, the radiocapitellar joint and the course of the ulnar nerve (**Figure 4**). The proximal anteromedial portal is located approximately 2 cm proximal to the medial epicondyle and just anterior to the intermuscular septum (**Figure 5**) and is established first. If close attention is paid to anatomic landmarks, joint insufflation is not necessary. Prior to establishing this portal, the location and the stability of the ulnar nerve should be assessed. If there is any history of a previous ulnar transposition or a question of a subluxing ulnar nerve, this portal incision should be extended the ulnar nerve dissected out and identified before portal placement (**Table 2**).

If the course of the ulnar nerve is not in question, then blunt dissection is carried through proximal anterior medial portal with a straight Kelly instrument until the anterior aspect of the humerus is palpated. This is the key step. If the portal is placed too anterior then the neurovascular structures in the antecubital fossa are at risk. If the portal is posterior to the

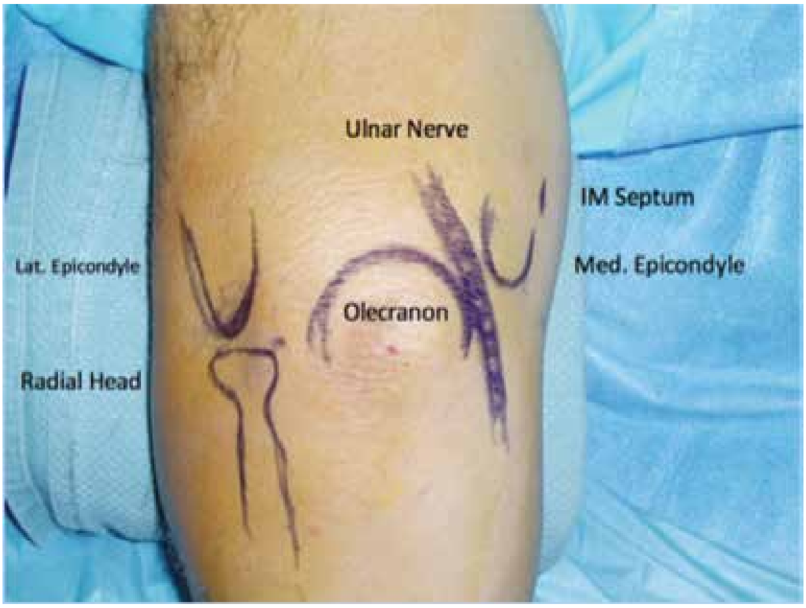


Figure 4. Anatomic landmarks are identified of the left elbow in the prone position including the medical epicondyle (right), the lateral epicondyle (left), the radial head, the olecranon, and the ulnar nerve (dark blue line on right). The intermuscular septum is also identified on the medial aspect of the elbow, just anterior to the medial epicondyle.

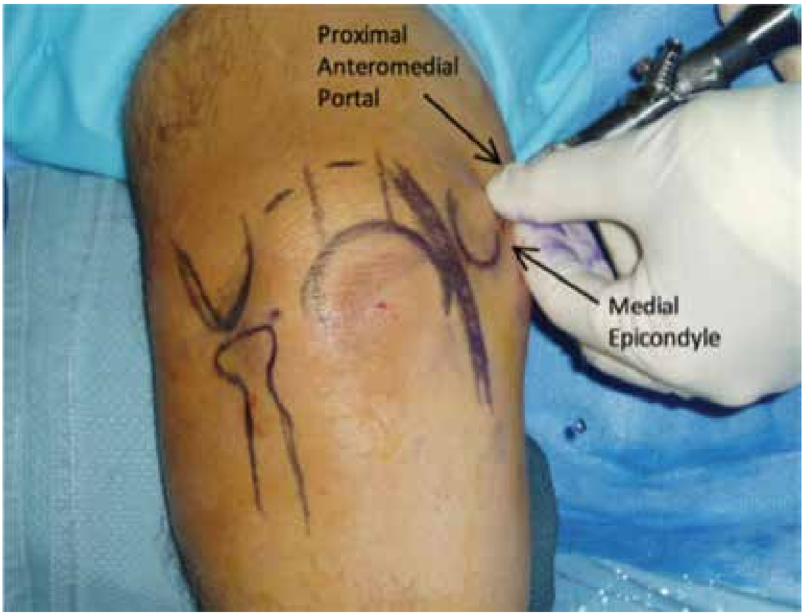
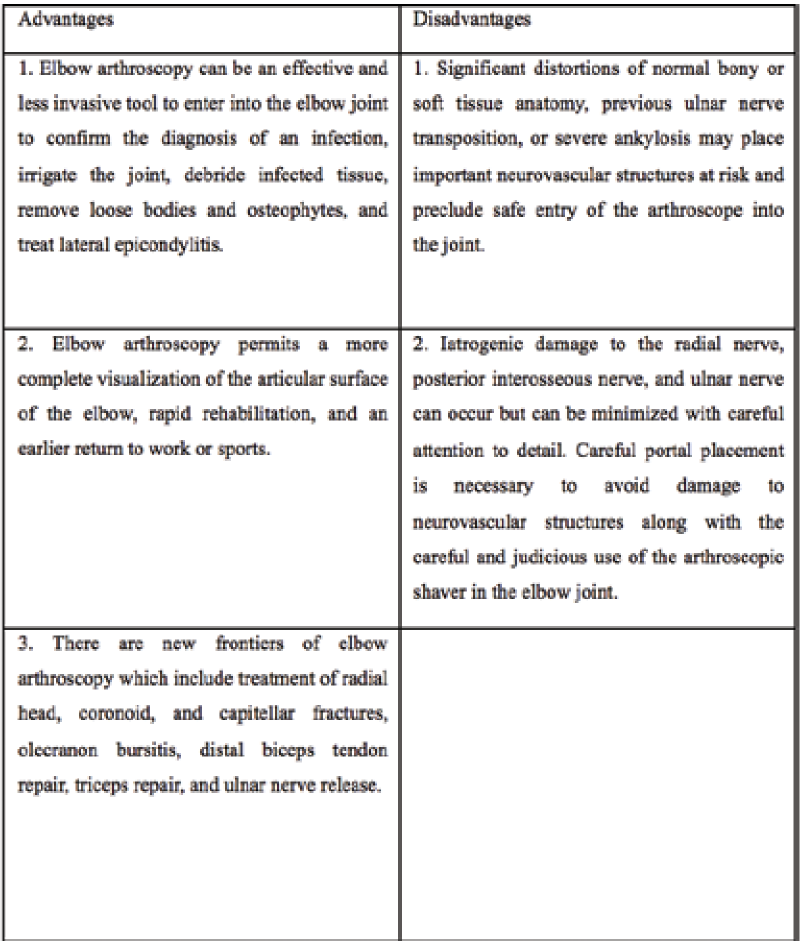


Figure 5. The proximal anteromedial portal is the first to be established, it is located just anterior to the intermuscular septum and two centimeters proximal to the medial epicondyle.



Advantages	Disadvantages
1. Elbow arthroscopy can be an effective and less invasive tool to enter into the elbow joint to confirm the diagnosis of an infection, irrigate the joint, debride infected tissue, remove loose bodies and osteophytes, and treat lateral epicondylitis.	1. Significant distortions of normal bony or soft tissue anatomy, previous ulnar nerve transposition, or severe ankylosis may place important neurovascular structures at risk and preclude safe entry of the arthroscope into the joint.
2. Elbow arthroscopy permits a more complete visualization of the articular surface of the elbow, rapid rehabilitation, and an earlier return to work or sports.	2. Iatrogenic damage to the radial nerve, posterior interosseous nerve, and ulnar nerve can occur but can be minimized with careful attention to detail. Careful portal placement is necessary to avoid damage to neurovascular structures along with the careful and judicious use of the arthroscopic shaver in the elbow joint.
3. There are new frontiers of elbow arthroscopy which include treatment of radial head, coronoid, and capitellar fractures, olecranon bursitis, distal biceps tendon repair, triceps repair, and ulnar nerve release.	

Table 2. Pearls and pitfalls of elbow arthroscopy.

humerus and posterior to the intermuscular septum, the ulnar nerve can be damaged. We have seen iatrogenic ulnar nerve damage from improper portal placement and so meticulous attention to detail is important to avoid this complication.

The arthroscopic cannula and sheath is then inserted anterior to the intermuscular septum while maintaining contact with the anterior aspect of the humerus and directing the trocar toward the radial head. Use of the anterior surface of the humerus as a constant guide helps to prevent injury to the median nerve and the brachial artery, which are anterior to the capsule. The ulnar nerve is located approximately 3 to 4 mm from this portal, posterior to the intermuscular septum (**Figure 6**). Palpating the septum and making sure that the portal is established anterior to the intermuscular septum minimizes the risk of injury to the nerve while providing excellent visualization of the radiocapitellar joint, the humeroulnar

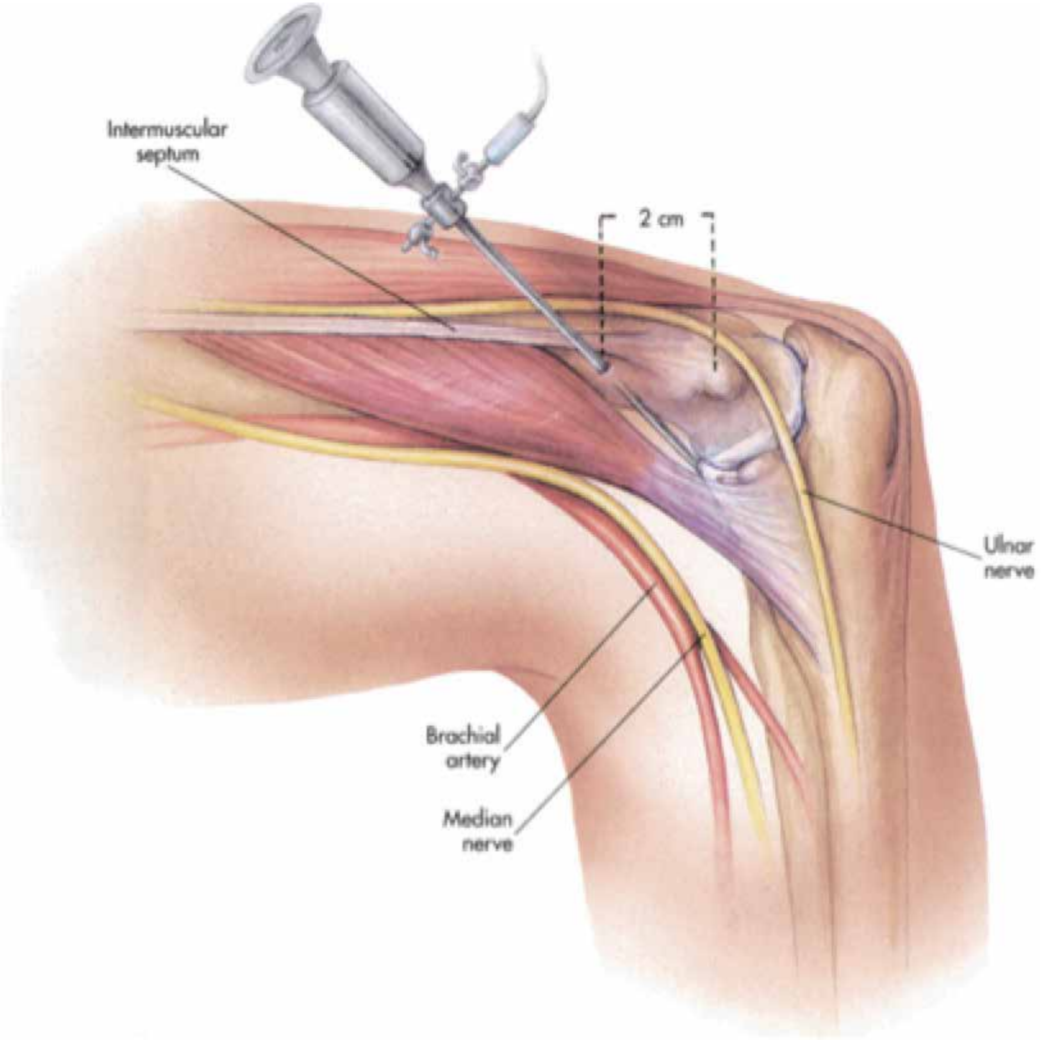


Figure 6. The arthroscope is inserted two centimeters proximal to the medial epicondyle and just anterior to the intermuscular septum on the medial aspect of the arm. In the prone position, the brachial artery and median nerve fall away from the joint capsule allowing for safe portal placement.

joints, the coronoid fossa, and superior joint capsule [3, 23]. We prefer establishing the proximal anterior medial portal first, as there is less fluid extravasation when starting medially because this portal traverses predominantly tendinous tissue and a tough portion of the forearm flexor muscles [29, 30]. The thicker tissues minimize fluid extravasation more effectively than the softer, thinner, radial capsule laterally [29, 30]. Finally, most elbow disorders are located in the lateral compartment, which is best visualized from the proximal anteromedial portal [23] including the lateral capsule, the radiocapitellar joint and the distal aspect of the humerus (**Figure** 7).

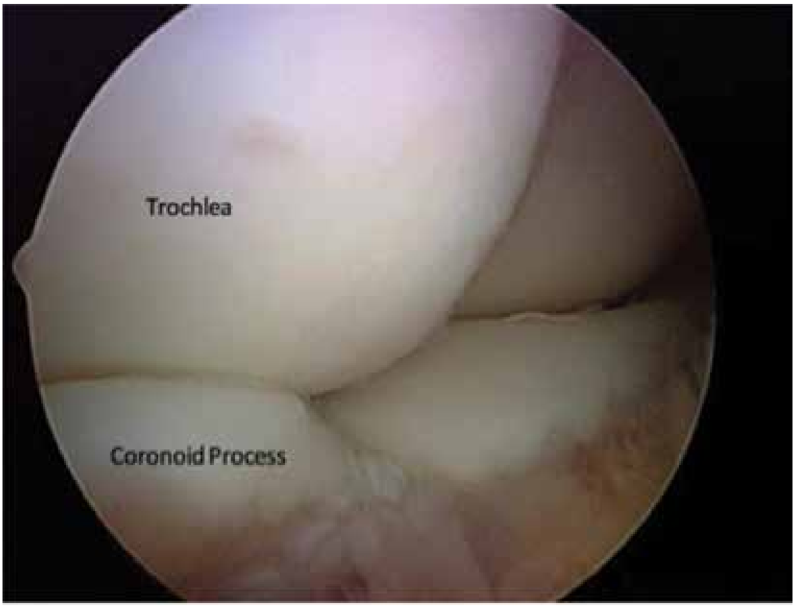


Figure 7. The trochlea (top left) and the coronoid process (lower left) can also be seen from the proximal anteromedial portal.

After creating the proximal anteromedial portal, we establish the proximal anterolateral portal using an outside-in technique localizing the position with a spinal needle. This portal is created 2 cm proximal and 1 cm anterior to the lateral epicondyle, as described by Field and coworkers [31]. If this portal is created too far distally near the radiocapitellar joint or even further distally near the radial neck, it places the posterior interosseous nerve at significant risk. Non-fenestrated cannulas are used to prevent extravasation of the fluid into the subcutaneous tissues.

Visualizing from the proximal anteromedial portal, one can visualize the lateral capsule and palpate the skin to localize the exact location of the spinal needle for accurate portal placement (**Figure 8**). It is important to direct the cannula toward the humerus while penetrating the capsule so that the portal placement is not too far anterior and medial [5]. The proximal anterolateral portal is often a working portal and is ideal for arthroscopic lateral epicondyle release and debridement of the radiocapitellar joint. Viewing from this portal permits visualization of the anterior compartment, and is particularly good in evaluating medial structures, such as the trochlea, coronoid tip, and the medial capsule (**Figure 9**).

5.2. Posterior compartment

For evaluating the posterior compartment, the straight posterior portal is usually created first and is located 3 cm proximal to the tip of the olecranon and can be used as a viewing portal or as a working portal. When it is the first portal created, a cannula with a blunt trocar is

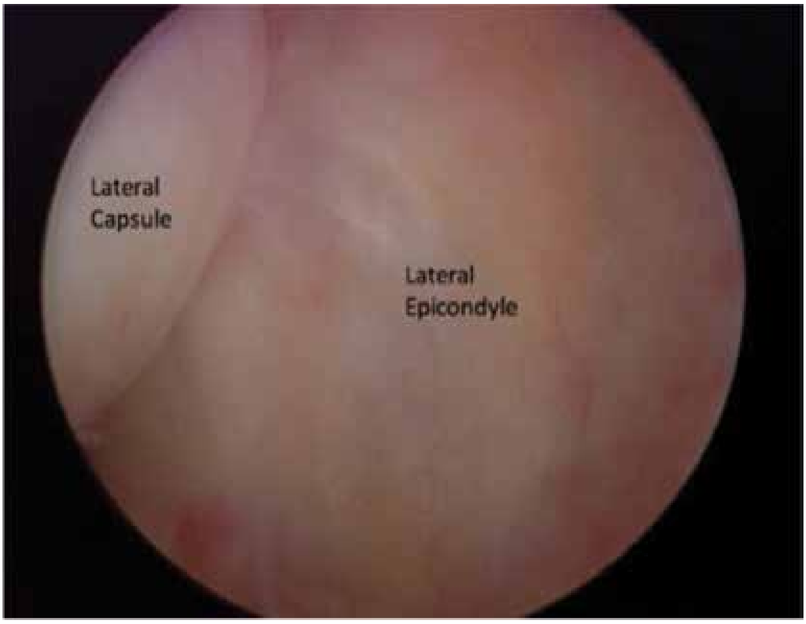


Figure 8. The lateral capsule is seen from the proximal anteromedial portal. This is the location where a spinal needle is introduced for the proximal anterolateral portal.

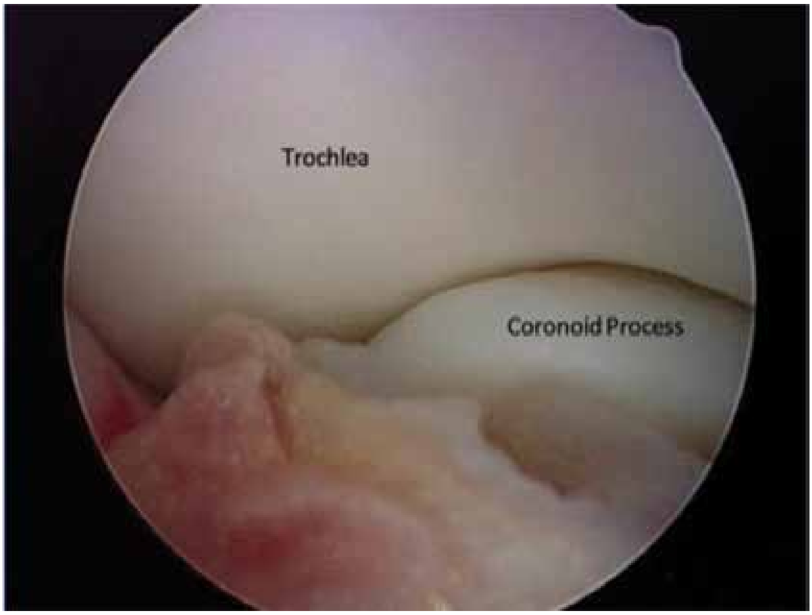
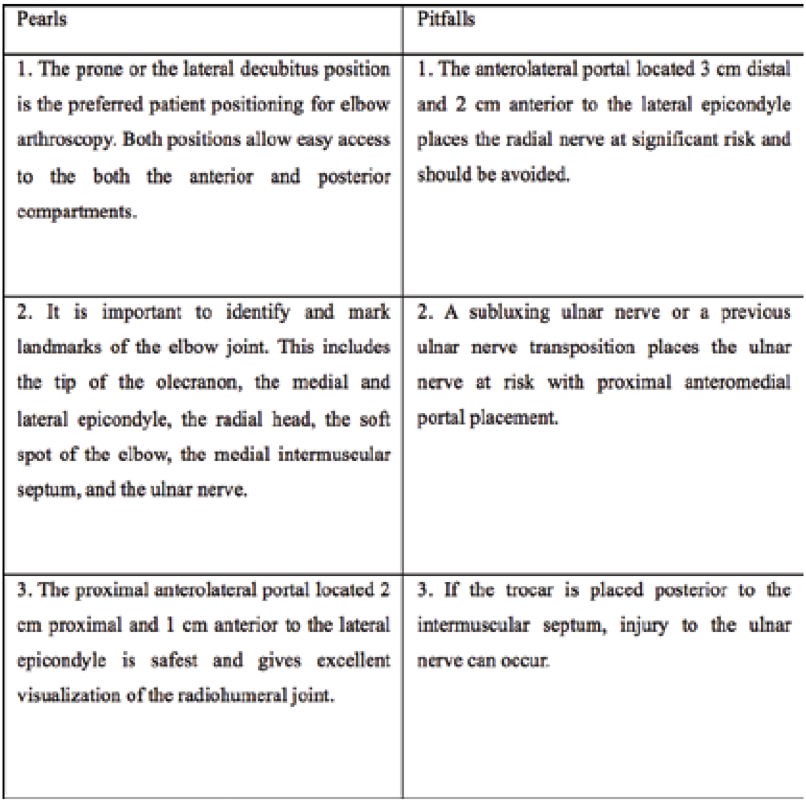


Figure 9. Viewing from the proximal anterolateral portal, the trochlea and the coronoid process can also be seen.

inserted. The cannula pierces the triceps muscle just above the musculotendinous junction and is bluntly maneuvered in a circular motion manipulating the soft tissues from the olecranon fossa for better visualization. When used as a working portal, it is helpful for removal



Pearls	Pitfalls
1. The prone or the lateral decubitus position is the preferred patient positioning for elbow arthroscopy. Both positions allow easy access to the both the anterior and posterior compartments.	1. The anterolateral portal located 3 cm distal and 2 cm anterior to the lateral epicondyle places the radial nerve at significant risk and should be avoided.
2. It is important to identify and mark landmarks of the elbow joint. This includes the tip of the olecranon, the medial and lateral epicondyle, the radial head, the soft spot of the elbow, the medial intermuscular septum, and the ulnar nerve.	2. A subluxing ulnar nerve or a previous ulnar nerve transposition places the ulnar nerve at risk with proximal anteromedial portal placement.
3. The proximal anterolateral portal located 2 cm proximal and 1 cm anterior to the lateral epicondyle is safest and gives excellent visualization of the radiohumeral joint.	3. If the trocar is placed posterior to the intermuscular septum, injury to the ulnar nerve can occur.

Table 3. Advantages and disadvantages of elbow arthroscopy.

of impinging olecranon osteophytes and loose bodies from the posterior elbow joint (**Table 3**) [32]. The straight posterior portal passes within 25 mm of the ulnar nerve and within 23 mm of the posterior antebrachial cutaneous nerve [29].

The posterolateral portal is located 2–3 cm proximal to the tip of olecranon at the lateral border of the triceps tendon. This is created while visualizing from the straight posterior portal using a spinal needle directed toward the olecranon fossa (**Figure 10**). Initial visualization of the posterior compartment can be impeded by synovitis, scar tissue, and fat pad hypertrophy. A trocar is directed toward the olecranon fossa, passing through the triceps muscle to reach the capsule. A shaver is then introduced to improve visualization of the posterior compartment. This portal permits visualization of the olecranon tip, olecranon fossa, and posterior trochlea. It may also be used as a working portal to remove osteophytes and loose bodies from the posterior compartment (**Figure 11**). The medial and posterior antebrachial cutaneous nerves are the two neurovascular structures at most risk, residing an average of 25 mm from this portal [33]. The ulnar nerve is also at significant risk near the medial epicondyle and the medial gutter. Careful direct visualization of the arthroscopic shaver is important when in this area, and judicious use of the suction of the shaver can prevent iatrogenic injury to the ulnar nerve. At no time should the arthroscopic shaver be used "blind" in this area as the ulnar nerve can be inadvertently sucked into the shaver tip and cause significant and possible irreversible damage to the nerve.

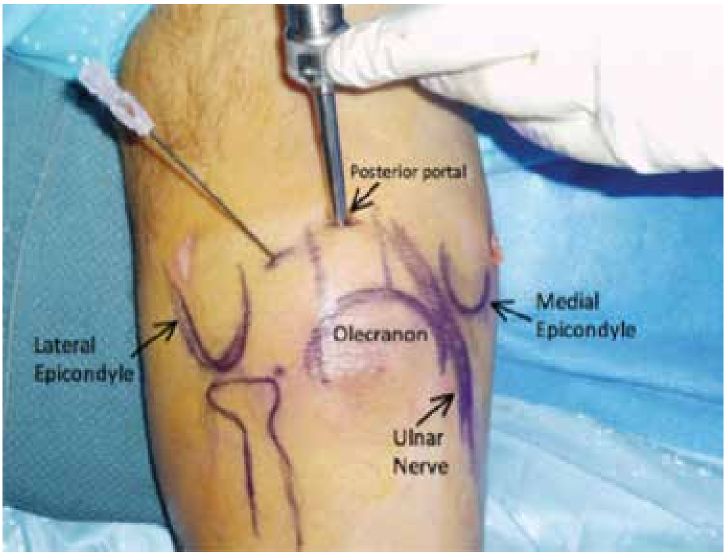


Figure 10. The arthroscope is introduced into the posterior compartment using a straight posterior portal, 3 cm proximal from the tip of the olecranon. A spinal needle is introduced lateral to the triceps tendon toward the olecranon fossa for the posterolateral portal.

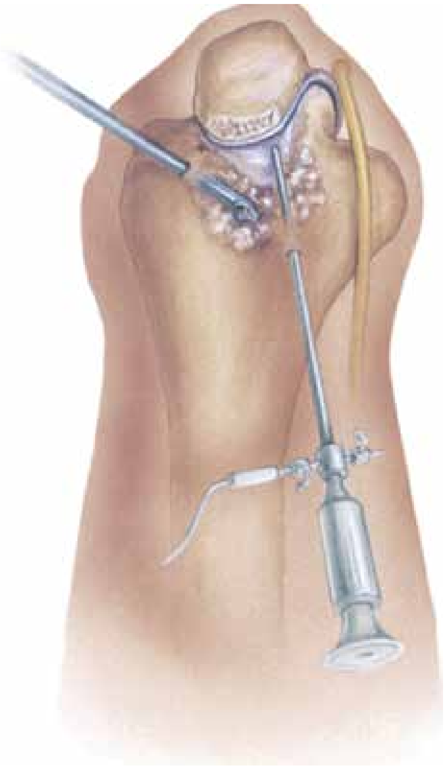


Figure 11. The posterior lateral portal is used as a working portal to remove osteophytes and loose bodies from the posterior compartment.

The direct lateral portal is located at the "soft spot" which is the triangle formed by the radial head, lateral epicondyle, and olecranon. It is developed under direct visualization using a spinal needle and may be used as either a viewing portal for the posterior compartment and radiocapitellar joint or a working portal for radial head resection [34]. This is the only portal that provides easy access to the posterior capitellum and radioulnar joint and can be useful for lesions of the radiocapitellar joint [22]. Altering the portal position along the line between the posterolateral portal and lateral soft spot changes the orientation of the portal relative to the joint [28]. These portals are particularly useful for gaining access to the posterolateral recess.

6. Summary and conclusions

The several published consecutive series of elbow arthroscopies performed demonstrated extremely low rates of neurological complications. Taken in the aggregate, these studies demonstrated one permanent nerve palsy out of over a thousand elbow arthroscopies. The vast majority of the nerve palsies reported in these series was transient, sensory deficits.

However, a recent survey of members of the American Society for Surgery of the Hand received 322 responses and a total of 222 nerve injuries were reported. There were 107 major nerve injuries, which were defined as those requiring surgical intervention. The most common nerve involved was the ulnar nerve (38%), followed by the radial nerve (22%) and the posterior interosseous nerve (PIN) 19%). It is obvious from this report that the risk of neurological complications after elbow arthroscopy has likely been under-reported in the literature [20].

At our institutions where we have been referred patients with neurovascular complications following elbow arthroscopy, we have found that the PIN palsy is the most common injury after elbow arthroscopy followed by ulnar nerve palsy. Many of these complications could have been avoided with proper portal placement. In particular, each of the patients with PIN palsies or lacerations had lateral portal placements either at the level of the radiocapitellar joint or distal to it. Staying at least 2 cm proximal to the lateral epicondyle will minimize or even eliminate this risk. This is important when performing an anterior capsule release or a radial head resection.

For the anterior-medial portal, it is very important to stay anterior to the intermuscular septum, which protects the ulnar nerve. Palpation of the intermuscular septum is key, and the inability to locate it can cause inadvertent placement of the arthroscopic cannula and trocar posteriorly and damage the ulnar nerve. Blunt dissection anterior to the intermuscular septum and anteriorly to the anterior aspect of the humerus is critical. Use of the anterior surface of the humerus as a constant guide helps to prevent injury to the median nerve and the brachial artery, which are anterior to the capsule. It also prevents posterior placement of the portal posterior to the humerus, which can place the ulnar nerve at risk. As mentioned previously, if there is a question of a subluxing ulnar nerve or if there is a history of a previous ulnar nerve transposition, the portal incision should be enlarged both proximally and distally and the ulnar nerve should be dissected out and identified before portal placement.

In the posterior compartment, the ulnar is also at greatest risk and can be injured with the use of the arthroscopic shaver in the medial gutter, so careful attention must be used when the shaver is used in this region. It is paramount that there is direct visualization of the shaver tip at all times and that there is never "blind" shaving in the medial gutter.

Elbow arthroscopy is a technically demanding procedure. Attention to detail, including careful portal placement, is necessary to avoid iatrogenic injury to neurovascular structures around the elbow joint. In every clinical case, the bony anatomy should be drawn on the patient's elbow and an 18-gauge spinal needle should be used to confirm correct portal location before introducing larger arthroscopic instruments [20]. As with any operative procedure, careful preoperative planning, including a detailed history and physical examination, along with proper imaging studies, and sound clinical judgment, is necessary to ensure a successful procedure.

Conflict of interest

The authors have no conflicts of interest to report.

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This book is aimed at providing an overview of arthroscopic joint surgery involving major joints in the body. It discusses all aspects of arthroscopy including complex surgical procedures, feasibility of performing surgery as an OPD procedure, and complications associated with these surgeries. The chapters are organised in regional basis and presented in an easy-to-understand format. This book will benefit all sports medicine physicians, orthopaedic surgeons and trainees, physiotherapists, and all clinicians involved in treating joint diseases. The combination of the authors' shared experiences with facts and presentation of figures and photographs will help the reader in understanding the complex principles involved. This can be used as a text for an individual or a "must have" reference book for any medical library.

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