Technical Note

# Arthroscopic Untethering of the Fat Pad of the Knee: Release or Resection of the Infrapatellar Plica (Ligamentum Mucosum) and Related Structures for Anterior Knee Pain

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**Abstract:** Anterior knee pain (AKP), a multifactorial symptom complex, can be successfully treated surgically. A specific diagnosis often cannot be made, but the pain is linked to an unrecognized common factor in most patients: the mechanical behavior of the non-isometric contents of the anterior compartment of the knee—the fat pad (FP) and infrapatellar plica (IPP). The objective of this presentation is to describe an effective arthroscopic technique that treats AKP by addressing this common factor. The operation consists of release or resection of the IPP, or ligamentum mucosum, which tethers the FP. These highly innervated tissues act together as a hydraulic shock absorber, filling the anterior compartment. They stretch and deform at the extremes of knee motion because of constraint centrally by the non-isometric IPP. These dynamic changes in shape are eliminated when the plica is released or resected. Pain perception is from perturbed nociceptive nerves: pain relief results from de-tensioning these contained nerves by untethering the fat pad. Ascribing pain causation is problematic because morphologic change, such as inflammation, fibrosis, or contracture of these structures, is only present in a minority of cases. Nonetheless, AKP is both physically linked to these central, pain-sensitive structures and relieved by this operation.

Anterior knee pain (AKP), as discussed by Grelsamer et al.[1] (2009), is an unsolved problem in orthopaedics, best treated as a symptom complex without relying on a specific diagnosis or cause.[2] It is very common, with incidence rates far exceeding those of osteoarthritis: it is found in 1 in 14 adolescents and 1 in 10 military members.[3] It is characterized by a deep parapatellar ache, usually associated with squatting, weight-bearing activities, and prolonged sitting. It is often transiently worse during the first few steps after arising, and it may be accompanied by crepitation, weakness, giving way, and catching. The most common physical finding is a positive Hoffa test, and 80% of patients have pain with squatting.[4] It can coexist with, and indeed mimic, other pathology in the knee and is likely multifactorial.[1] No specific investigation is diagnostic. Recent literature has increasingly suggested that there are few structural abnormalities[5-7] and that the cause of pain is likely neural damage as the "provoking factor."[5] This article describes a simple, safe operation that addresses AKP associated with derangement of the infrapatellar plica (IPP) and fat pad (FP) in terms of perturbation of the nerves contained in this structural unit. The procedure has a high probability of eliminating the pain, with a complication rate as low as that of diagnostic arthroscopy.[8]

Several authors have suggested that the long-term outcome of AKP, believed by many to be untreatable surgically,[5,6,9,10] may not be benign.[2,11-14] The natural history of adolescent AKP has been studied. In many

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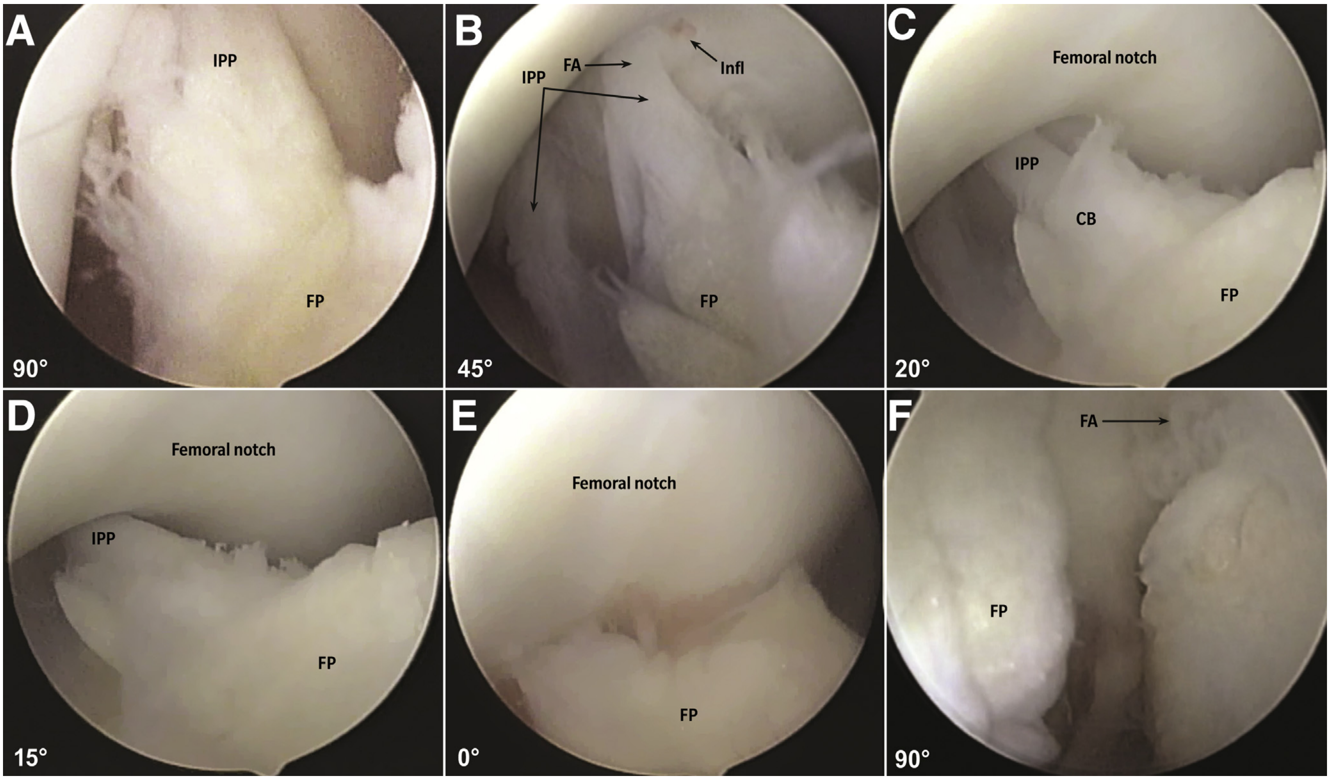


**Fig 1.** Non-isometric mechanical behavior of infrapatellar plica (IPP), viewed arthroscopically (screenshots from Video 1). Arthroscopic views of the notch from the anterolateral portal (A-E) and anteromedial portal (F) are shown in the right knee of a 16-year-old patient with anterior knee pain for 4 years, with an insidious onset, undergoing release and resection of the IPP at its femoral attachment (FA). (A) At 90° of knee flexion, the IPP, of normal structure, is vertical and taut. (B) At 45° of knee flexion, the IPP has 2 parallel elements, classified as "split." The leading edge is a curved arc suggesting laxity. (C) At 20° of knee flexion, the leading edge straightens as the IPP approaches the apex of the notch; the FA has rotated posteriorly out of view. (D) At 10° to 15° of knee flexion, the IPP contacts and indents the articular surface at the notch; with further extension, the apex of the notch acts as a pulley. From kinematic videos, the IPP increasingly elongates with further extension. The apposing aspect of the IPP and the central body attachment of the fat pad (FP) are compressed against the articular surface of the trochlea, potentially inducing surface reactive change. (E) At 0° of knee flexion and in full extension, the IPP and the central body attachment of the FP to the IPP have rotated out of view and the FP apposes the trochlear articular surface. (F) At 90° of knee flexion, with viewing from the anteromedial portal, the IPP has been released. The FP seen on the left, floating free of the central attachment, is no longer tethered by the IPP at the FA. (CB, central body attachment of FP to IPP; FA, femoral attachment; Infl, small zone of possible inflammation.)

adolescents, the condition is benign and self-limited; however, in 25% to 45%, pain becomes chronic with long-term sequelae, both physical and mental.[2,3,13,15-18] These patients may have higher levels of mental distress and perceive lower levels of health[19]; they may adopt the coping skills of chronic pain patients.[20,21] The adult population may be equally affected, given that more than half the patients with patellofemoral pain reported long-term pain and disability after adequate conservative management.[22] AKP, when prolonged, can be a life-changing condition worthy of further study.[3] Our suggested clinical approach offers a simple arthroscopic procedure, which is safe, potentially allowing a return to normalcy, even after years of AKP.

The procedure involves release or resection of the IPP, or ligamentum mucosum, effectively untethering the FP. It was performed for the first time by the senior author (T.V.S.) during arthroscopy in an adult patient with chronic, disabling AKP. No images were preserved at the time (1990); however, the first clinical case, presented in Video 1, showed remarkably similar arthroscopic findings, as shown in Figure 1. Pristine articular surfaces and menisci were present, with a small zone of inflammation adjacent to the femoral insertion of a normal-appearing, rope-like IPP, which showed subtle changing tension with knee motion. This observation suggested that the structure, rather than being an embryologic remnant of no clinical significance,[23-26] had an actual function related to this non-isometric mechanical behavior. The IPP was released at its femoral attachment (FA), with rapid and permanent pain relief. This led to the described surgical approach to AKP, as well as the subsequent

**Table 1.** Surgical Principles for Untethering of Fat Pad by Release or Resection of IPP and Related Structures

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|---|
| First principle: Untether the fat pad, eliminating any central restraint; release and/or resect the IPP and any other attached structure that interferes with the freely reversible deformation and stretch of the fat pad (such as anomalous bands). |
| Second principle: Restore, as much as possible, the anatomic contours of the borders of the anterior compartment, eliminating interference with the fat pad as it deforms with knee motion. This implies removal of local pathology, which is uncommon, such as the following: |
| Cyclops lesion attached at the base of the reconstructed ACL |
| Arthrofibrotic scarring |
| Attached tissues—which may be osseous, cartilaginous, or both (osteochondromatous)—or other soft-tissue lesions (cysts, focal PVNS, or any soft-tissue tumor) |
| Third principle: Because the fat pad is a structure of multiple functions, disturb it as little as possible. |
| Fourth principle: Because the IPP—fat pad complex is a potential pain generator, consider untethering the fat pad every time arthroscopy is performed on a knee for undiagnosed pain. |

ACL, anterior cruciate ligament; IPP, infrapatellar plica; PVNS, pigmented villonodular synovitis.

investigations seeking to explain how this operation actually works.[27-30] The approach has been applied to AKP associated with the growth spurt in adolescence; AKP associated with acute overuse, underuse, and trauma; knee surgery, including anterior cruciate ligament (ACL) reconstruction, arthroscopy, meniscectomy, lateral release, total knee replacement, and insertion of femoral and tibial intramedullary rods; as well as AKP after hip surgery (total hip replacement or decompression for avascular necrosis). This clinical experience, spanning 28 years and hundreds of patients from 9-year-old children to elderly patients, is consistent with several reports in the literature of small numbers of patients in whom AKP has been relieved by release of the IPP at its FA.[23,31-33]

## Surgical Technique

This section outlines how to perform this operation. As detailed in Table 1, the principles are to untether the fat pad, and to restore the integrity of the contours of the anterior compartment so that there is no restraint to the ability of the semi-liquid fat pad to fill the space and attenuate force. Avoid resection of the fat pad, a structure of many functions, in the absence of properly controlled studies to support this. The Discussion section introduces new aspects of knee physiology that relate to the structure and function of the contents of the anterior compartment of the knee. The operation interrupts this physiology and in so doing provides pain relief in most. Table 2 outlines the steps involved in performing the procedure as is further outlined in detail in this section. Table 3 discusses what might go wrong, and how to avoid this.

Figure 2 shows the operative setup and approaches. Figure 1 is a composite of screenshots from the first case in Video 1 and correlates with further images from kinematic studies (Figs 3 and 4). Figure 5-8 are screenshots from the second case described in Video 1 and correlate with the steps described in the following sections, outlining how to perform this operation.

**Table 2.** Steps in Surgical Management for Untethering of Fat Pad

| |
|---|
| The contents of the anterior compartment show wide variation, normally containing the IPP[34-36] and fat pad.[37] Releasing or resecting the IPP untethers the fat pad, modifying the physiology of this normal tissue complex that can become a pain generator. The following steps are recommended: first untether the fat pad and then address observed abnormalities. |
| To untether the fat pad, release and resect the following structures: |
| If the IPP is either separate or split, do as follows: |
| Release its FA, a curved arc of fibrous tissue, using an arthroscopic punch. |
| Use a shaver cautiously to remove the fibrous elements of the IPP, avoiding resection of fat pad elements as much as possible. |
| If the IPP is a vertical septum, with or without a fenestra, do as follows: |
| Release the FA (as above). |
| Use the shaver (hood reversed) to protect the ACL, starting from the FA, carefully removing the attached fibrous and fatty elements down to the intermeniscal ligament. |
| If an anomalous band is present, completely remove it, usually with a punch and shaver. |
| At this point, the fat pad should be sitting free, distracted by filling pressure. You should have an unobstructed view of the normal structures: trochlea above, bony notch, ACL, PCL, superior tibia, anterior horns of menisci, intermeniscal ligament, and fat pad. Usually, the operation is complete at this point. |
| Pathologic structures are relatively uncommon and are approached as follows: |
| The cyclops lesion at the base of the ACL may have fibrous, cartilaginous, and bony elements; a combination of a punch, shaver, and burr allows complete removal. |
| A cyst may appear as a soft-tissue prominence which can be unroofed, using a punch, and debrided with a shaver. |
| Masses are approached according to their nature. |
| Adherent or protuberant arthrofibrotic scar is removed or resected back to the approximate margin of the adjacent tissues. |
| Local tissues that appear normal, such as a lipoma, local PVNS, and fibrous or osteocartilaginous masses, are excised. |
| Heterotopic ossification is excised; abnormal bone (post-traumatic, osteophytic) can be resected back to the normal bone contour using a burr. |

ACL, anterior cruciate ligament; FA, femoral attachment; IPP, infrapatellar plica; PCL, posterior cruciate ligament; PVNS, pigmented villonodular synovitis.

**Table 3.** Risks of Release or Resection of IPP

| Risks and Pitfalls | How to Avoid Risks and Pitfalls |
|---|---|
| Hemarthrosis, leading to scarring or contracture | Careful dissection and meticulous hemostasis |
| Stiffness and/or loss of knee motion postoperatively | Early mobilization emphasizing active and passive range of motion to full range with an experienced physical therapist |
| Failure to fully achieve optimal strength and range of motion | Understanding that the progressive decrease in function of the limb accompanying chronic AKP may require 12 to 18 mo of rehabilitation; perseverance is required |
| Deep venous thrombosis | Use of postoperative chemical and mechanical prophylaxis as determined by patient risk factors; early mobilization |

AKP, anterior knee pain; IPP, infrapatellar plica.

## Step 1: Preoperative Setup and Diagnostic Arthroscopy

The patient is positioned supine with a small bolster under the hip to bring the leg into a neutral position, with the anterior surface of the patella parallel to the floor. A tourniquet is applied but rarely inflated. Standard diagnostic arthroscopy is performed using the anterolateral portal (ALP) and anteromedial portal (AMP), with occasional use of the superolateral portal (SLP) (Fig 2).

## Step 2: Viewing of Apex of Notch, Classification of IPP, and Observation of Abnormalities

The ALP is established with the knee flexed 90°; at the level of the lower pole of the patella, a longitudinal incision is placed just lateral to the palpable edge of the patellar tendon (Fig 2). After completing the joint survey, the surgeon should approach the anterior compartment from above, noting the integrity of the trochlear articular surface as the apex of the notch comes into view. The trochlear surface may be normal or may show surface changes from linear grooves, beginning at the apex (Fig 8C), to frank osteoarthritis, a presumed effect of increasing compression and shear, arising only in terminal knee extension, induced by tension forces in the adjacent IPP and FP as they distort remarkably (Figs 3 C and D and 9). Figure 5 presents sample screenshots from the second clinical case in Video 1, with views of the apex of the notch and the contents of the anterior compartment of a right knee viewing from the ALP, which show that the IPP type is a fenestrated vertical septum (Fig 5A). Obtaining a clear view of the apex of the notch can be difficult if there is abundant fat. The IPP tethers the FP and, because it is non-isometric, holds the FP tightly against the distal femur, increasingly approaching end extension. To obviate this, the knee should be flexed 30° to 45°, relaxing the IPP. A probe (blunt trocar or hook) can be inserted through a portal established medially (AMP). The surgeon should use an 18-gauge

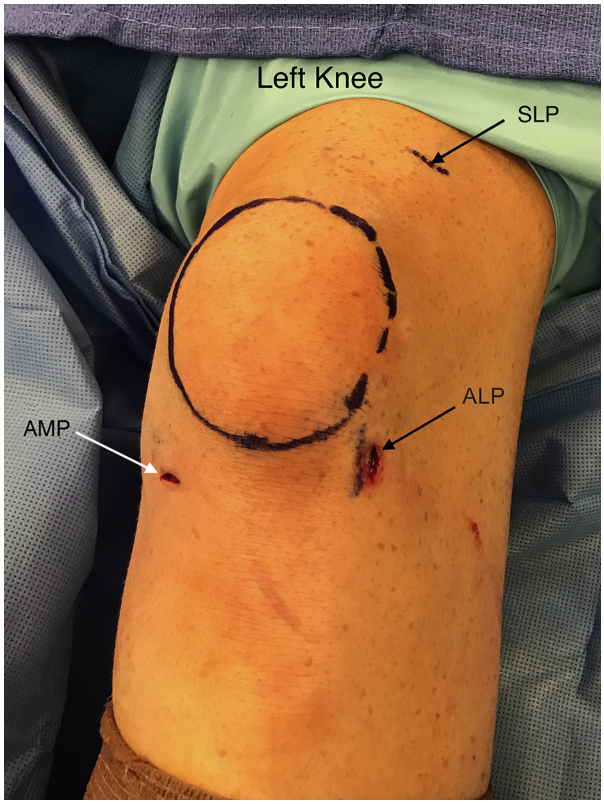


**Fig 2.** Photograph of the left knee of a supine patient who has undergone release and resection of the infrapatellar plica for anterior knee pain. Usually the anterolateral portal (ALP) and anteromedial portals (AMP) are used. Local anesthetic (2 mL of 0.25% bupivacaine) is instilled at the site immediately before placement of any portal. The ALP is established first as the primary working portal. With the knee flexed 90°, the incision is made at the level of the lower pole of the patella, just lateral to the palpable lateral border of the patellar tendon. The AMP is selected using percutaneous placement of an 18-gauge spinal needle, entering just superior to the medial meniscus, avoiding the medial border of the fat pad. The superolateral portal (SLP) is established for viewing from above, as well as for more direct instrument access. It was not used in this case, but its location is marked, 2.5 to 3 cm above the superior pole of the patella, in line with its lateral border.

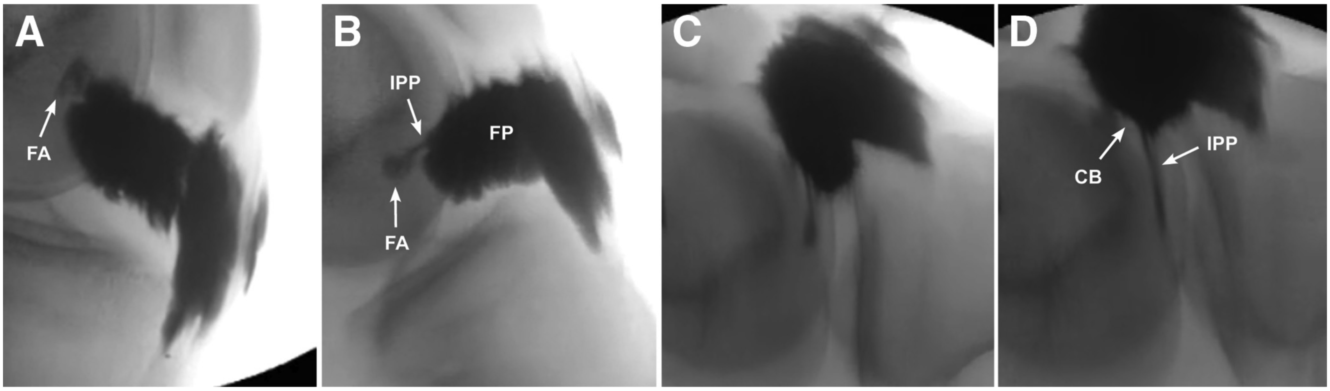


**Fig 3.** Kinematics of contents of anterior compartment, including infrapatellar plica (IPP)—fat pad (FP) complex (screenshots from Video 1). Radiographic contrast was placed into the IPP and FP of a volunteer undergoing arthroscopy for anterior knee pain. All views show the right knee from the anterolateral portal. (A) With approximately 90° of knee flexion, the IPP femoral attachment (FA) has a broad base and then narrows and disappears; it is hidden in the overlap of contrast of the FP. The overall shape of the FP is tubular. (B) With approximately 45° of knee flexion, the IPP is lax as shown by the ripple in its mid portion; more of the IPP is visible. The FP (tubular, broader, appearing foreshortened) seems to "point" to the IPP; there is a gap between the lower pole of the patella and the FP. (C) With approximately 5° of knee flexion, the IPP is linear and stretched. The former broad base is less visible; the contrast has been squeezed out of the FA. The FP is now irregular in shape, with a small gap between the FP and patella. (D) Maximal extension, with maximal effort at quadriceps contraction (quadriceps-set maneuver), combined with the relative changes in the position between the femur and tibia with the screw-home mechanism, produces remarkable stretch of the IPP and further distortion of the FP. The central body—transition zone IPP-FP (CB) is now seen, previously hidden by overlap of the medial and lateral extensions of the FP. In summary, best observed in B, the FP is pulled away from the lower pole of the patella by the IPP tether. Highly innervated, the IPP-FP complex stretches and distorts as the knee moves, tethered centrally by the IPP.

spinal needle, placed superior to the meniscus, avoiding the FP (Fig 2). The tip of the needle should be advanced to verify that the instruments placed along this line can fully access the IPP. The surgeon should use distraction with the probe to visualize the IPP, which is normally floppy and easily stretched, noting any variance from the categories described by Kim et al.,[34] as well as any other abnormalities (anomalies,

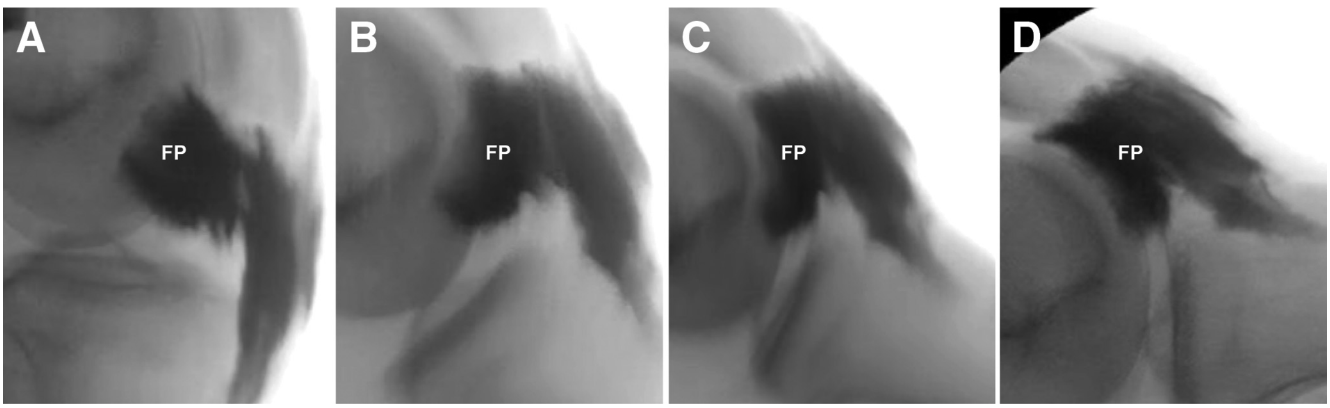


**Fig 4.** Kinematics of infrapatellar plica (IPP)—fat pad (FP) complex after release of IPP (screenshots from Video 1). All views show the right knee from the anterolateral portal. The central body and IPP are not seen; the FP has been untethered. (A) With approximately 90° of knee flexion, the FP appears quadrilateral, occupying the notch with medial and lateral extensions apposing the condyles. (B) With approximately 45° of knee flexion, the FP sits matching the curve of the articular surface of the femoral notch, with the superior border immediately adjacent to the patella above, not distracted by the central tether of the IPP. This image should be compared with Figure 3B. (C) With 5° of flexion, there is a similar appearance to B with the FP matching the curves of the distal femur. (D) At maximal extension, the FP again matches the contour of the trochlea and condyles, with the superior border apposing the patella tightly. In summary, the compliant, semiliquid, now-untethered FP simply fills the available space of the anterior compartment, with far less distortion. The mechanical perturbations of the enthesis organ have been abolished by untethering the FP.

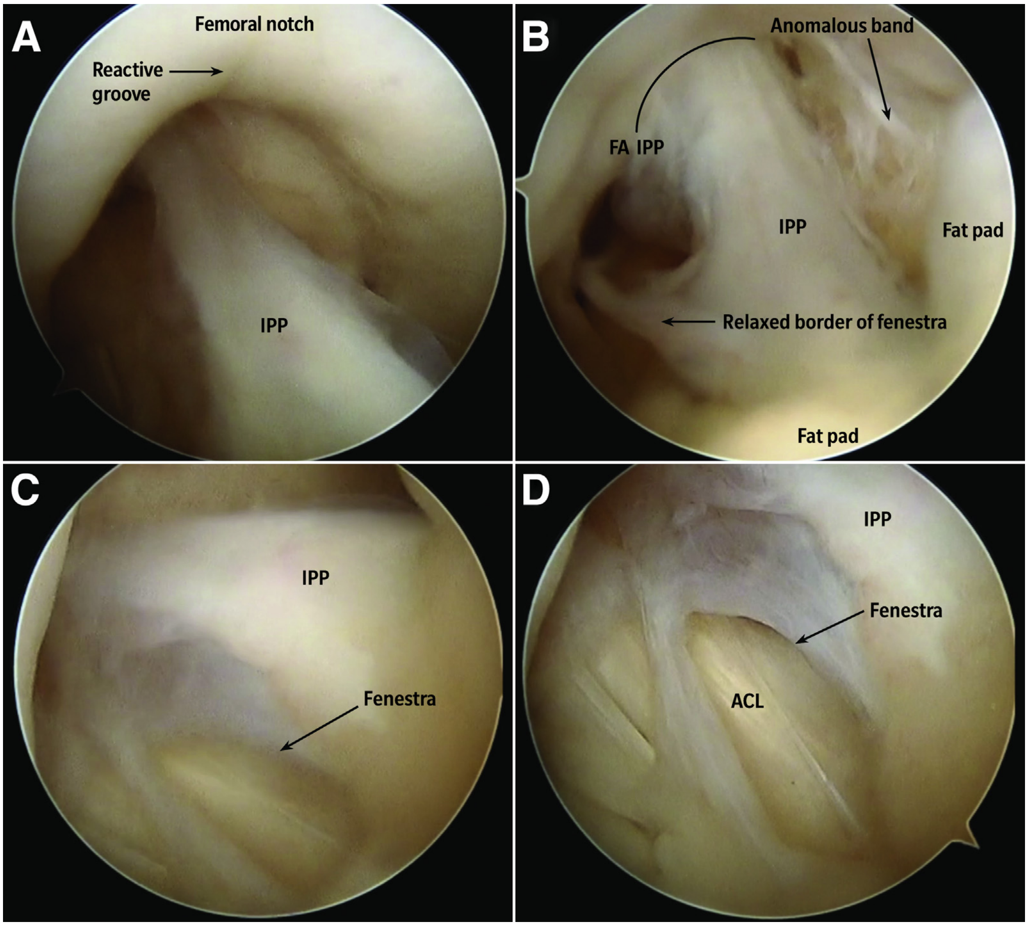


**Fig 5.** In step 2, we view the apex of the notch, classify the infrapatellar plica (IPP), and note abnormalities. A right knee is shown, viewed through the anterolateral portal, in a 32-year-old male patient with anterior knee pain for 6 years after a direct blow to the front of the knee (second case presented in Video 1). (A) In this gestalt view in mid flexion, an attempt is made to visualize the complete functional unit of the IPP. There is a shallow groove at the apex of the notch and below, the IPP appears "separate". (B) However, adjusting flexion to 30° gives the complete picture. The IPP is a wall of connective tissue, a vertical septum, in which there is an opening, or fenestra. Above, the femoral attachment of the IPP (FA)—an enthesis—is seen as a curved arc of connective tissue attached to bone. Below and behind is the now relaxed border of the fenestra, connective tissue that merges with the anterior border of the ACL. Adjacent to the IPP is a separate connective tissue band, an anomaly. The IPP is thus a fenestrated vertical septum. (C) At about 60° the more dense superior border of the IPP is apparent, with diaphenous loose connective tissue at the margin of the window. (D) Close-up of the fenestra, with the ACL behind, the rest of the IPP above, and fat pad to the right. (ACL, anterior cruciate ligament.)

cyclops lesions, bony prominences, inflammation, cysts, osteophytes, or other soft-tissue and bony masses). The surgical principles of untethering the FP are outlined in Table 1. The sequence involved is further discussed in Table 2.

## Step 3: Evaluation of Mechanical Behavior of IPP

As every human being is unique, anatomic variation is expected and normal. We use Kim's classification of the IPP (five subtypes), noting that Derganc[35] in 1969 described ten, and Wachtler[36] in 1979 described five. Brooker in 2009[37] focused on the FP, rightly describing wide variation in the gross anatomy, and an absence of data on what is normal and what is pathologic. This paper focuses on the combined structure and function of the tissue complex of the IPP and FP. It notes that that no two knees are the same, and that abnormal tissues are present in a minority of patients with AKP treated with success by this procedure. Behavior can be observed directly through the arthroscope (representative screenshots are shown in Figs 1 and 5-8) and indirectly by kinematic studies (Figs 3 and 4) performed in volunteers undergoing arthroscopy.[28]

The 2 clinical cases can be reviewed in Video 1 and the screenshots that follow; in both cases, viewing is performed from the ALP in right knees. The first case, with a split IPP, shows characteristic non-isometric behavior in the composite image in Figure 1. The IPP

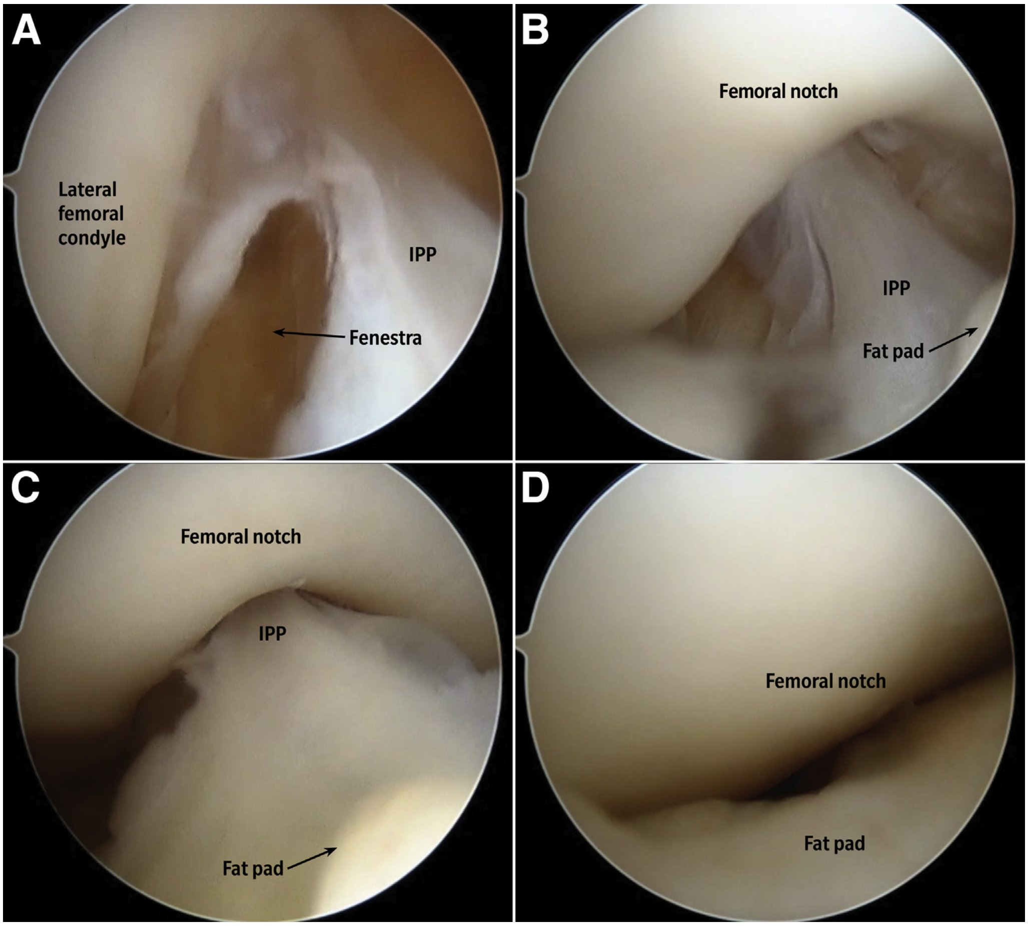


**Fig 6.** In step 3, we evaluate the mechanical behavior of the infrapatellar plica (IPP). A fenestrated vertical septum is present. A right knee is shown, viewed through the anterolateral portal. (A) With the knee at approximately 90°, the IPP is vertical and the fenestra is distorted. (B) With the knee at approximately 45°, the leading edge of the IPP is straight; attachment to the underlying anterior cruciate ligament attenuates the mechanical behavior—laxity is not seen. (C) With the knee at approximately 15°, the IPP, under increasing stretch (non-isometric plus screw-home mechanism), contacts the articular border at the apex of the notch, which becomes a pulley. Tension in the fat pad is arising as well from the proximal pull of the extensor apparatus; tension in the IPP is arising from non-isometricity plus posterior rotation of the femoral attachment. (D) With the knee at approximately 15°, the IPP is no longer seen; the fat pad is apposed to the trochlear articular surface. Under increasing tension as shown in Figure 9, the complex tissues arrayed in the IPP, including dense and loose connective tissue, elastin, and fat, merge with direct dense connective tissue bundles connecting to the lower pole of the patella (Fig 10B). This connective tissue network mechanically acts as an increasingly loaded cable, a construct of remarkable strength, a principle used in architecture, wherein a floppy cable, of the right material, when anchored from a firm base becomes increasingly more rigid, capable of supporting bridges, roofs, and walls.

is increasingly linear and taut approaching full flexion (Fig 1A), is lax in mid-arc (Fig 1B), and then appears to tighten, with its leading edge straightening and approaching the apex of the notch (Fig 1C) and contacting it (Fig 1D) at about 10° to 20° of flexion. The IPP then disappears and rotates out of view (Fig 1E), ending the opportunity for direct viewing.

The vertical septum variant (with or without an opening, or fenestra; Figs 5-8) is physically attached to the ACL, a robust ligament that is nearly isometric[38]; its mechanical behavior is damped and is not so apparent. The screenshots from the second case in Video 1 are representative of this: In Figure 6A, at 90°, the IPP is vertical but not so clearly stretched; in Figure 6B, at 45°, no laxity is apparent as the leading edge is straight; in Figure 6C, the IPP contacts the articular surface at the apex of the notch at 10° to 15° of knee flexion; and finally, in Figure 6D, the IPP is no longer seen as the central body transition zone and FP are drawn tightly against the trochlea.

The kinematic studies involve the introduction of radiographic contrast medium into the FP and IPP in patients undergoing arthroscopy (Video 1; Figs 3 and 4, showing representative screenshots).[27,28,30] Lateral fluoroscopy allows indirect observation of the mechanical behavior of the IPP-FP complex, especially

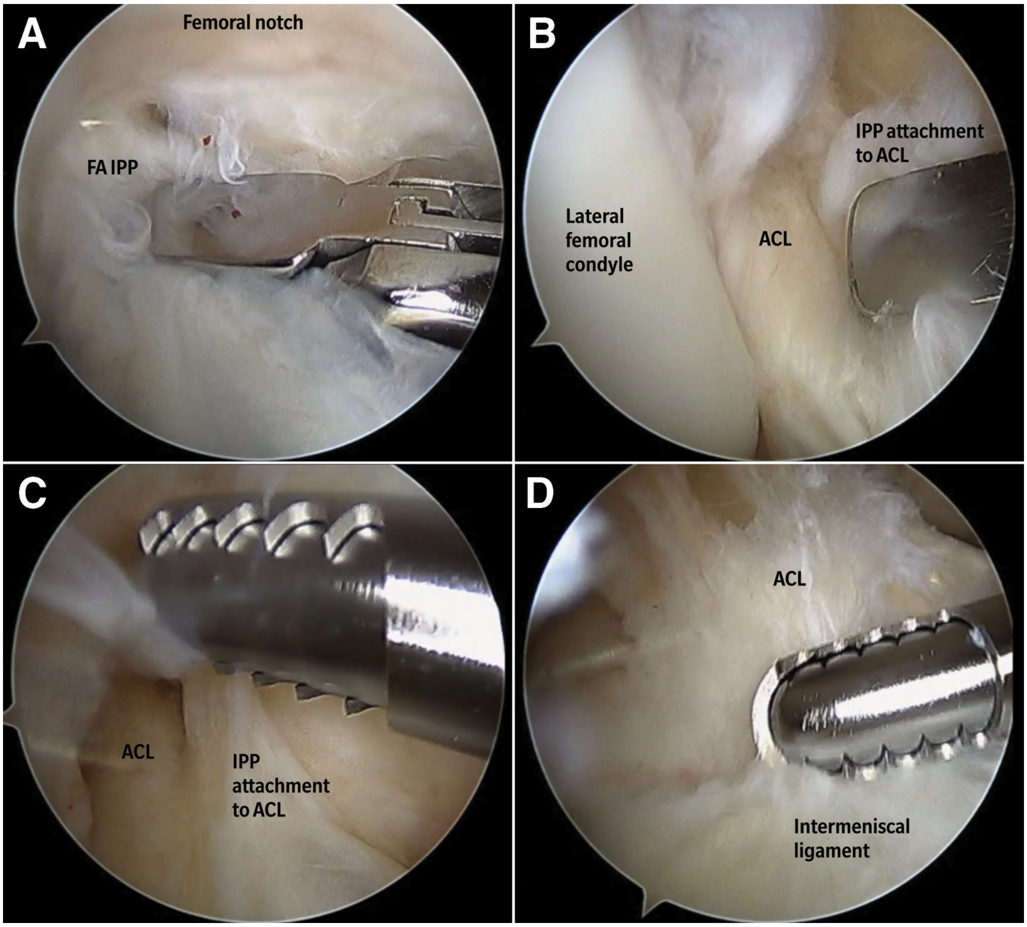


**Fig 7.** In step 4, untethering of the fat pad is performed by release and resection of the infrapatellar plica (IPP) and restoration of the anatomy of the anterior compartment. (A) A carefully positioned punch is used to release the femoral attachment (FA). (B) The punch is used to detach the connective tissue elements adherent to the underlying anterior cruciate ligament (ACL). (C) The shaver is introduced, with the hood reversed, to tease the connective tissue from the ACL, working from proximal to distal. (D) The surgeon should stop at the intermeniscal ligament. The abnormality—an anomalous fibrous band—is removed using the shaver. This completes the untethering of the fat pad. Other abnormalities are not often present, but if encountered, the combination of a punch, soft-tissue shaver, burr, and radiofrequency device is used to remove and restore the anatomy.

in terminal extension, when the tight apposition of the IPP, central body, and FP against the distal femur blocks the possibility of a direct view. These studies, with awake, mildly sedated volunteers, support direct arthroscopic observations of non-isometric behavior (Fig 1) during knee motion, including stretch in flexion (Fig 1A) and contact of the IPP with the apex of the notch (Fig 1 C and D, Video 1) during extension. In Figure 3B, the ripple seen in the IPP suggests laxity in mid-flexion. What happens in terminal extension cannot be seen directly because the arthroscope is pushed out of the way by the semiliquid FP as it attempts to fill the changing external geometry of the space. What is observed in Figure 3 C and D is remarkable stretch of the IPP and distortion of the FP, with contrast being squeezed out of the base.

With identification completed and mechanical behavior confirmed, the anterior compartment is inspected for abnormalities, which occur rarely. These include bony and soft-tissue anomalies, cysts, heterotopic bone, osteophytes, fibrotic scarring including cyclops lesions and fibrous connective tissue bands, tumors, and contracture of the anterior interval.[39]

### Step 4: Untethering of FP by Release or Resection of IPP and Restoration of Anatomy of Anterior Compartment

If the IPP is separate or split, a simple release of the IPP at the FA point is carried out with a Stryker punch (Conquest, 3.4 mm straight or 15° up-angled) and small shaver (Stryker Formula Tomcat Cutter, 4.0 mm) or similar device to sever or remove the connective tissue at the bony attachment, which is not a single point but rather an arc of connective tissue that is inferior to the articular margin at the apex of the notch (Figs 1 B and F, 5B, 7A, and 8B; Video 1). A radiofrequency

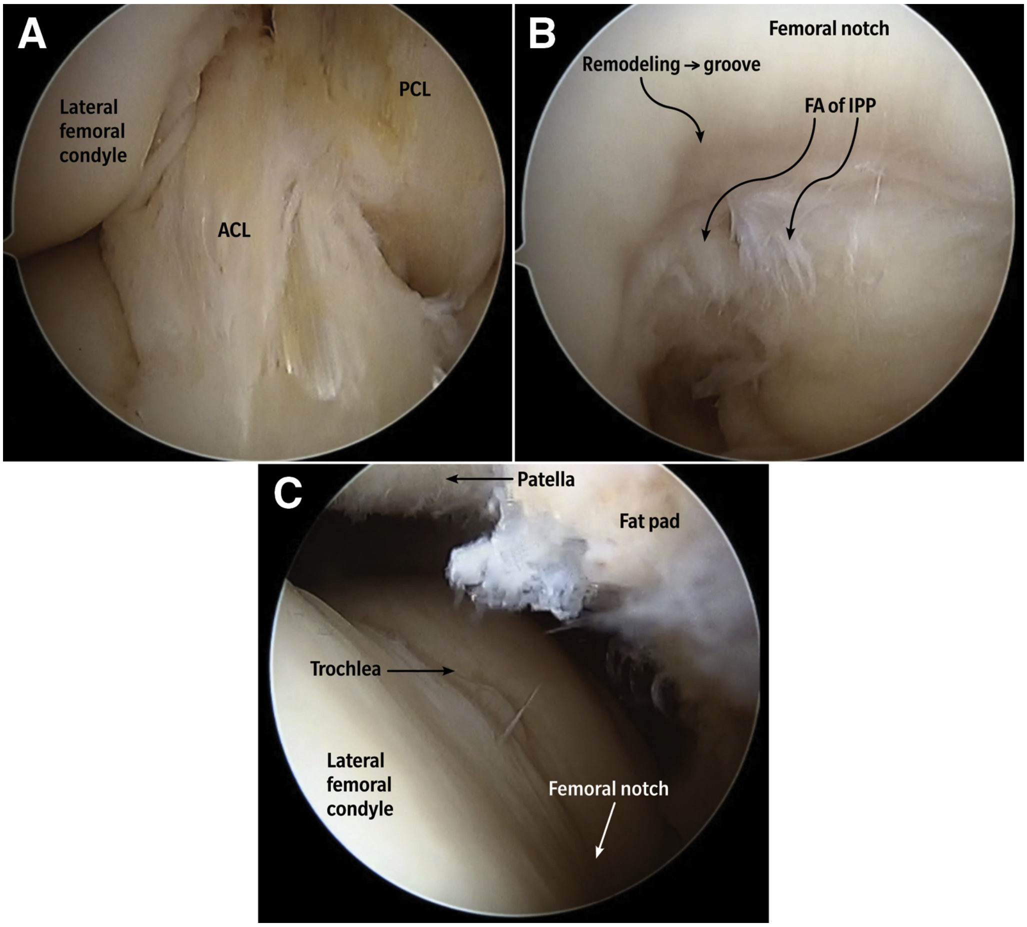


**Fig 8.** The surgeon should review and verify that the fat pad has been untethered and the borders of the anterior compartment restored. A right knee is shown, viewed through the anterolateral portal. (A) In the gestalt view, the anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) are intact; the anomalous band and the infrapatellar plica (IPP) have been removed. The fat pad, now with no connection to the distal femur or structures in the notch and displaced by fluid pressure, is out of view. (B) Close-up of the apex of the notch. Again, the fat pad is displaced. The cartilage and underlying bone at the apex of the notch have regressively remodeled, creating a groove in response to the mechanical forces applied by the leading edge of the IPP, with contact beginning in terminal extension (15°-20°). Remaining strands of connective tissue mark the location of the femoral attachment (FA)—the entheseal attachment of the IPP (histology in Fig 11 C and D). (C) In the gestalt view with the anterior compartment below, the trochlear articular surface shows linear erosion along its length, the fat pad is again untethered and displaced, and the patella above shows grade 2 chondral surface changes.

device (Werewolf Flow 50 Wand; Smith & Nephew) can be used to shrink the connective tissue and to establish hemostasis.

If the IPP is a vertical septum or is fenestrated, further resection of the substance of the IPP attached to the ACL is necessary after release at the FA. Any other connective tissues attached to the FP, including anomalous bands (Fig 5B) and post-traumatic fibrous bands, are removed in their entirety. Any mass lesion (cyclops lesion, cyst, or other tissue) is removed to allow the FP unobstructed freedom to fill the space. Meticulous dissection should be performed, with the use of a punch and small shaver to sever or remove the connective tissue at the FA and attached to the ACL. The radiofrequency device can be used for further removal or shrinkage of soft tissues and for hemostasis, which should be complete. A burr is used for bony resection. The final step is a joint survey to verify that the anterior compartment has been restored and that nothing is left tethering the FP, which is observed to sit at a distance from the notch, distracted by the fluid pressure of the pump system (Figs 1F and 8; Video 1). At this point, the procedure is terminated.

Concomitant pathology is addressed as follows: If a medial plica is present, it is not removed unless there is evidence of mechanical interference with the articular surface of the medial femoral condyle or the medial aspect of the patella, or if it appears thickened and inflamed. If a medial shelf is present, it is removed. Any other plica or fibrous adhesion should be assessed; if it is

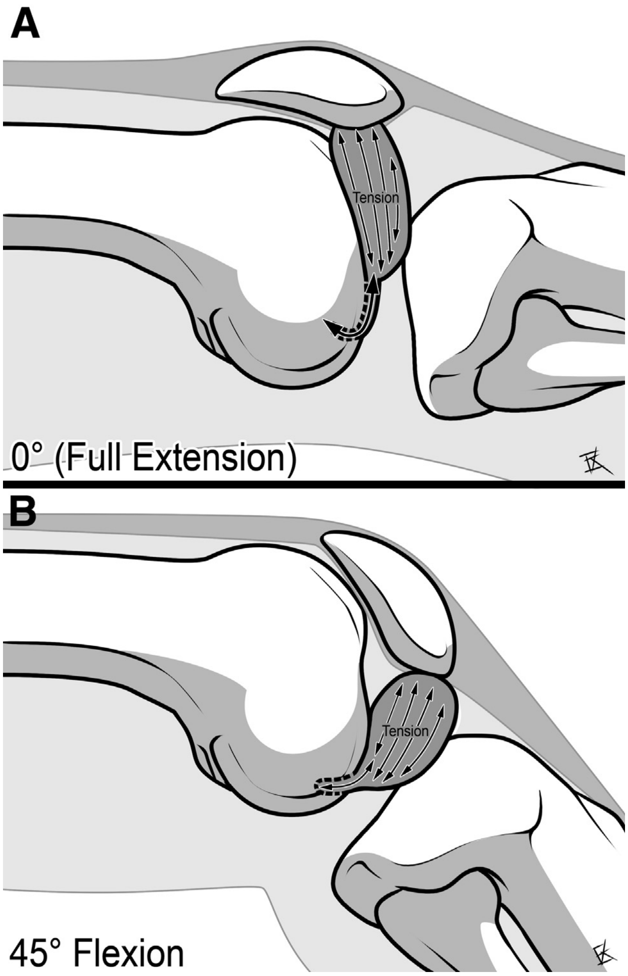


**Fig 9.** Artist's sketches showing the biomechanical effect of the infrapatellar plica (IPP)—fat pad (FP) complex. (A) The combined effect of the screw-home mechanism (in which the femoral attachment moves relatively posteriorly and the tibia moves anteriorly and rotates externally, approaching full extension), and isometricity, induce increasing stretch of the IPP and distortion of the FP, perturbing the contained neural network. As the knee approaches terminal extension, tension increases within the IPP-FP complex, as they are, as a functional unit, compressed increasingly against the trochlear articular surface. Shear and compression forces on the articular cartilage may lead to morphologic change, in the form of regressive remodeling (linear grooves are often seen in the trochlea attesting to this) (Fig 8C). Frank osteoarthritic change clearly could follow if the forces are excessive or of long duration. The extensor apparatus is linked to the IPP-FP complex through the dense connective tissue connections of the synovial layer, in essence a force-transmitting and attenuating array (Fig 11B). The kinematic studies show even more stretch and deformity with the quadriceps-set maneuver. (B) At 45°, the studies show that the separate plica is lax (Fig 3B) such that the IPP can be easily stretched with a probe and has minimal tension within it.

a solid fibrous structure spanning portions of the synovial layer of the joint, it should be meticulously removed. Any other connective tissue element spanning the compartment—and clearly not part of the IPP—is an anomaly that should be removed because it will be non-isometric and likely symptomatic. An attempt is made to restore the bony contours of the compartment by resecting osteophytes, heterotopic bone, and prominent callus if there has been a previous fracture. If chondromalacia is present, it is debrided sufficiently to produce a stable articular surface using the radiofrequency device in the Coblation setting (Smith & Nephew). Inflamed synovium is debrided.

### Postoperative Recovery and Rehabilitation

The postoperative course involves rest and self-directed exercises for the first week, allowing the physiology of the knee to return toward normal. A small effusion may remain for a week or, if there has been substantial dissection, for a longer period. The duration and intensity of the rehabilitation program are individualized. In general, physical therapy is directed toward achieving a full range of motion. Core and global strengthening of the lower extremities is undertaken. In many patients, within 4 weeks, the extremity is near normal and a return to training for sport can begin. The rehabilitation process can be prolonged if the problem has been present for years, but with persistence, full pain-free function can be expected.

## Discussion

The operation involves release or resection of the IPP, an intra-articular ligament, which tethers the FP. Knowledge of the structure, function, and physiology of these tissues is important in understanding how this relieves pain. Structure—gross anatomy and histology (Figs 10 and 11)[29]—is linked to function (filling space and force attenuation), observable as mechanical behavior, directly through the arthroscope (Figs 1 and 5-8) and indirectly by kinematic studies performed by the senior author (T.V.S.) (Figs 3 and 4).[27-29] In these studies, radiographic contrast was placed arthroscopically into the IPP and FP of cadavers and volunteers. The gross and microscopic analyses show that the ligamentous IPP and the FP function together as an enthesis organ.[29] This is a concept defined by Benjamin et al.[40] in which the entire collection of tissues associated with an enthesis participates in the task of "force attenuation." In the knee, the enthesis (Fig 11 C and D) is the FA of the IPP (Figs 1B, 3 A and B, 5B, 7A, 8B, 10 A and C, and 11 A and B). The enthesis organ concept strongly suggests a different understanding of knee physiology, that is, that the highly innervated IPP and FP[29,41,42] collectively act as a unit—a deformable, semiliquid, hydraulic shock absorber filling the anterior compartment. Direct observation arthroscopically (Figs 1 and 5-8, Video 1) and kinematic studies (Fig 3, Video 1) show non-isometric behavior, with the

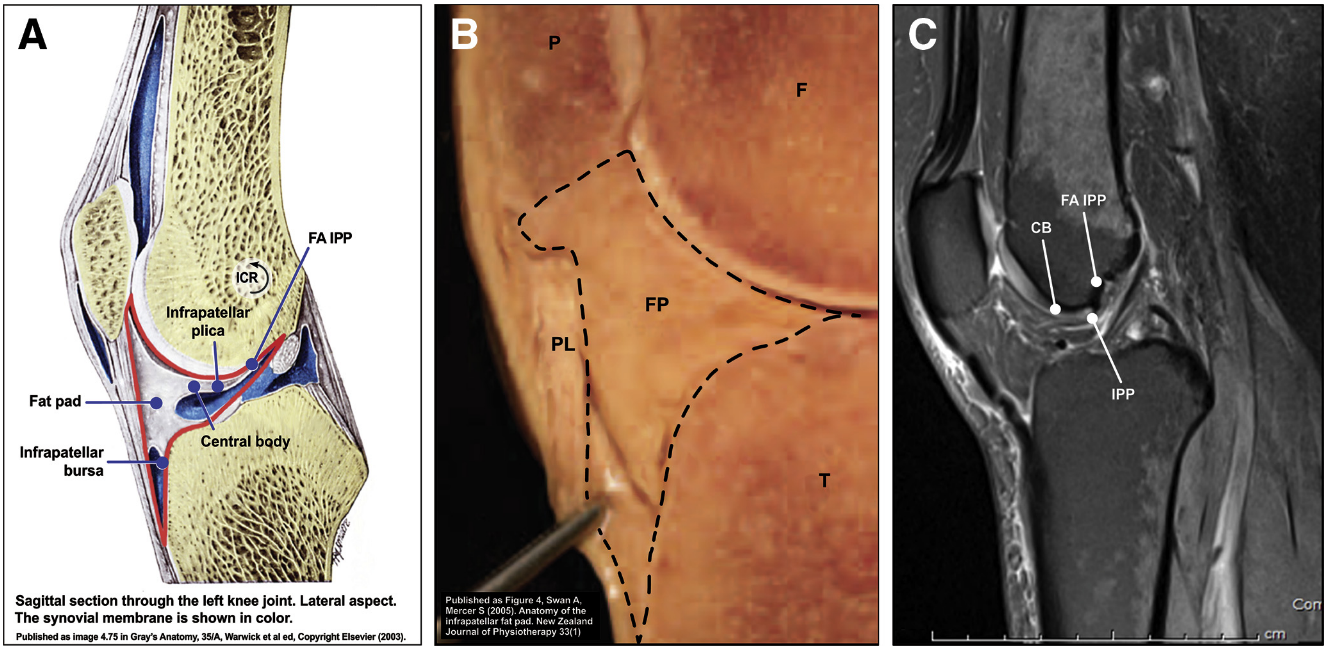


**Fig 10.** Anatomic relations of the anterior compartment (AC), a space whose borders change with motion. (A) A midline sagittal section shows the contents of the AC (bordered in red). Structured to be semiliquid and deformable, the fat pad (FP) fills the space, tethered to the femur at the femoral attachment (FA) by the infrapatellar plica (IPP), a ligament, which is present in most patients (86% depending on population). The composite structure—FP, IPP, and contained deep infrapatellar bursa—is defined as a functional unit, the IPP-FP complex, an enthesis organ, whose task is filling space and attenuating force. The key biomechanical concept is that the FA (an enthesis) is located inferior to the instant center of rotation of the knee (ICR), making the IPP-FP complex non-isometric. With motion, contained within the borders of the AC, the IPP-FP complex, tethered at the FA, rotates around it and not the ICR (Fig 3, Video 1), leading to stretch and deformity. (B) Sagittal section of an anatomic specimen showing how the AC (bordered by the dashed line) is filled by the IPP-FP complex. The probe is in the infrapatellar bursa. (C) Magnetic resonance imaging correlate, with the knee in full extension. The IPP-FP complex fills the AC and is in tight apposition to the articular surface of the trochlea. (CB, central body [which links FA and FP].)

IPP and FP rotating about the FA, that is, the enthesis.[29] The kinematic behavior of the IPP-FP complex when the IPP is separate or split shows stretch and deformity at the extremes of knee motion (Figs 1A and 3 C and D), with laxity in between (Figs 1B and 3B), because the central attachment point of the IPP is at the FA. This is well below the instant center of rotation of the knee, making the so-tethered IPP and FP non-isometric (Fig 10A and C, Video 1). The relative changes in the position of the femur (the FA moves posteriorly) and tibia (which rotates externally and moves anteriorly) arising from the screw-home mechanism likely also add to non-isometricity in terminal extension (Fig 3D). The dynamic changes in the shape of the IPP-FP complex are eliminated when the plica is released at its FA, untethering the FP and allowing it to fill the changing geometry of the anterior compartment without central constraint (Fig 4, Video 1).

This physiology is present in all knees with an IPP (86.5%[34]). When pain is present, the physical distortion and stretch of the IPP-FP complex perturb the nociceptive neural network, and the symptom complex of AKP results.[27,30] Pain perception is from activated nociceptive nerves. Ascribing pain causation is problematic because morphologic change, such as inflammation, fibrosis, or contracture of these structures, is present in only a minority of cases. AKP is not well correlated with location around the knee because it is physically linked to the widespread innervation of these central, pain-sensitive structures.[41] Indeed, the neural network involved arises from all the nerves supplying the knee (femoral, tibial, common peroneal, recurrent peroneal, and obturator).[42] Pain generated from the IPP-FP complex can thus be felt anywhere in and about the knee, explaining the varied perceived localization of AKP and why it mimics other pathology. The current general consensus lumps together all the highly innervated soft tissues, including the retinacula, synovium, and FP, and the medial patellofemoral ligament as the sources of pain.[4,5,7,14,43,44] This article focuses on a much more specific concept, that is, that the common link in AKP, when it is associated with the presence of an IPP, is the physiology and function of the highly innervated and sensate IPP-FP complex. This operation, which untethers the FP, alters this physiology, and reliably helps most such patients.

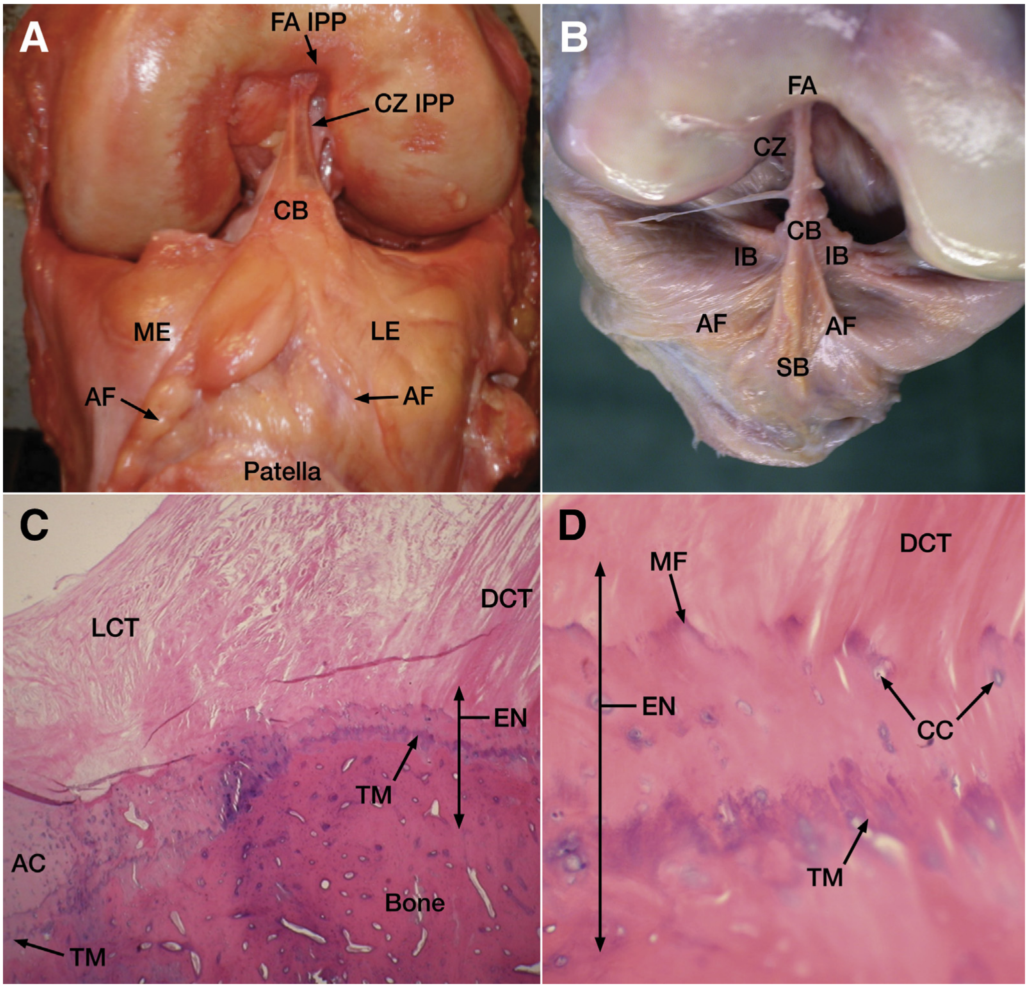


**Fig 11.** Gross anatomic relationships of fat pad (FP) and infrapatellar plica (IPP) in 2 specimens (A, B) and histology of enthesis (EN) (C, D). The extensor apparatus has been released from the femur and flipped 180°, with the femur above and the patella below. (A) The FP elements are the conical central body (CB), the FP transition zone to the IPP; the extensions, comprising the medial extension (ME) and lateral extension (LE) of the FP, which appose the condyles; and the alar folds (AFs), which are connective tissue links to the synovial layer elements above. The IPP elements include the femoral attachment (FA), an EN, the transition zone attachment to bone, ligamentous central zone (CZ), and CB transition zone to the FP. (B) Specimen from a cachectic donor, showing little remaining fat, thus allowing the underlying dense connective tissue (DCT) array to be seen. The DCT from all quadrants coalesces at the CB to merge with the DCT of the CZ; inferiorly, the inferior bands (IB) attach to the tibia, intermeniscal ligament, and anterior horns of the menisci; superiorly, on either side, the AFs merge with the parapatellar folds, and centrally, thick superior bands (SB) attach to the lower pole of the patella (mechanical role in full extension). The DCT network transmits and attenuates force; the compressible fat, in septate lobules, attenuates force. (C, D) Photomicrographs of FA, both stained with Hematoxylin and Eosin, confirming that it is an EN, a transition zone attenuating force. (C) 20 × original magnification. Overview of the FA at the apex of the notch. Articular cartilage (AC) merges with bone at the lower left with the loose connective tissue (LCT) above, bordering the DCT, at upper right. Force attenuation (function) correlates with tissue structure at the EN, in which each layer is less rigid, with bone as the anchor. (D) 100 x original magnification of EN. The zones are (1) cortical bone below; (2) The tidemark (TM), a densely calcified, irregular anchoring structure; (3) a second irregular calcified line beginning at MF, which marks the adjacent region of mineralized and unmineralized fibrocartilage, containing chondrocytes (CC) in lacunae; and (4) the DCT of the ligamentous IPP above.

Success is not always achieved, again indicating the complexity of the problem. Complete rehabilitation must be ensured, requiring patience in the very chronic case. The approach, when pain returns or is not relieved, is to re-evaluate clinically. The possibility of neuromatous formation at the portals is eliminated and patellar stability rechecked, given the overlap of AKP with patellar instability. If indicated, further surgery is offered. Psychosocial and secondary gain issues associated with Workers' Compensation must also be carefully considered.

Many surgeons, faced with chronic recalcitrant AKP, consider this a nonsurgical problem best treated by further conservative management or by pain management specialists.[6,45,46] We have observed that adolescents, whose quality of life has been profoundly disrupted for years, returned to a pain-free state after this simple procedure. A subset of successfully treated adults had experienced adolescent AKP, requiring lifestyle modifications to minimize pain. Many with this symptom complex, despite normal radiographs, had been advised that they had "arthritis." Even after many years, such patients can be restored to full function, including active sports, with minimal symptoms. Accordingly, our approach is to carefully explain the complex nature of the problem and the risks, benefits, and alternatives, and to suggest the option of arthroscopic treatment. We offer a confirmatory clinical test in which the patient exercises to induce the pain. A dilute local anesthetic mixture containing bupivacaine (8 mL, 0.125%) is injected into the symptomatic knee immediately after exercise. Complete pain relief indicates that the problem is intra-articular, in which case we offer arthroscopy to address any observed pathology. We consider every case individually: The more chronic the pain, the longer that the neural pathways and secondary, compensatory lifestyle modifications have been established. In such cases, we proceed even if the patient had some remaining pain after injection of the local anesthetic. We have shown success in most patients with the described procedure, with complete pain relief immediately after the operation in most cases, even after many years. The only complication has been transient portal pain, which can be neuroma-like, treated, if persistent, by local injection. The mixture is bupivacaine (3 mL, 0.25%) and 10 mg of methylprednisolone acetate, injected slowly with a 1.5-inch No. 25 needle, starting 1 inch proximal to the painful portal; this is followed by weeks of use of a neoprene sleeve, applying slight pressure to the soft tissues of the knee. Other risks of the procedure are shown in Table 3.

The finding that recalcitrant AKP is relieved in many patients by release or resection of the IPP strongly suggests consideration of this as a first surgical approach in the patient in whom conservative management has failed. AKP is complicated and multifactorial,[1] but treatment in this way, as a symptom complex with a specific anatomic link to the FP and IPP, allows pain relief for many patients.

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