Intra-operative Visualization of Deformation of the Infrapatellar Plica and Fat Pad -- The Link to Anterior Knee Pain

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OBJECTIVE

1. To provide historical, clinical, anatomic, histologic, biomechanical, and experimental data to support the following hypothesis:

The infrapatellar plica (IPP), attached to its bony central anchor, acts as a **non-isometric intra-articular ligament**, tethering the fat pad (FP) at its central body (CB). The effect of knee motion is to impart inexorable stretch and relaxation to the IPP, and CB, transmitting force to its attachments at the femur, and the FP. The FP is thus tethered and deforms as a result of the mechanical behavior of the IPP.

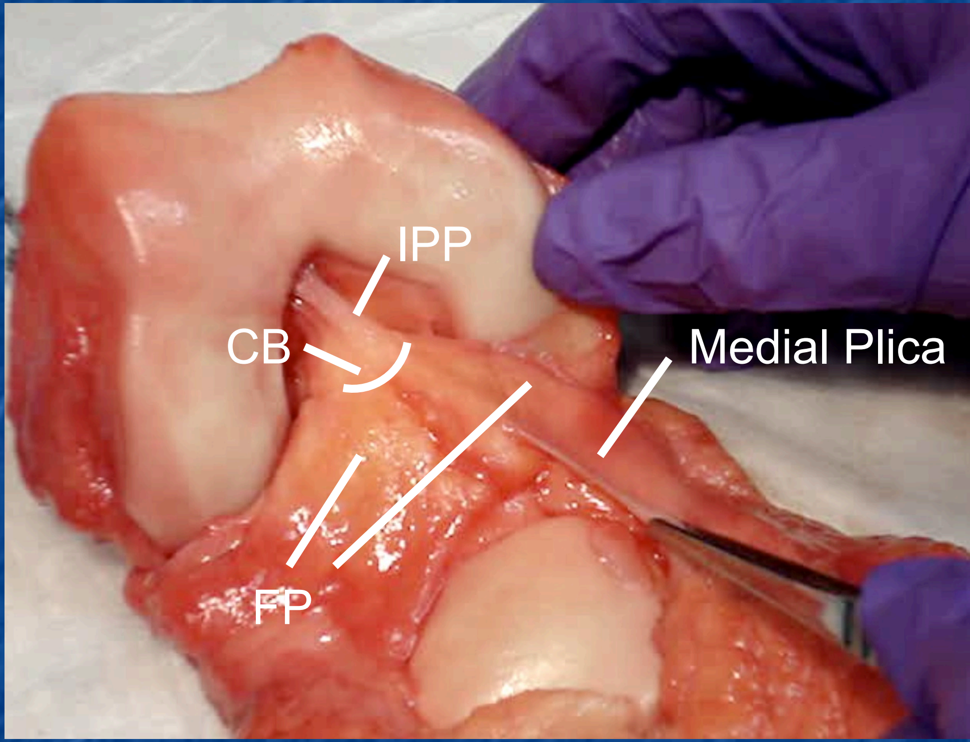


Figure 1. Synovial connective tissue continuum; flip of extensor apparatus 180^0 shows relationships not apparent otherwise.

2 To suggest, given the above hypothesis, how releasing the IPP may eliminate AKP.

BACKGROUND DATA -- HISTORICAL

CLINICAL IMPORTANCE OF THE IPP

In a German article in 1979 *Die Plica synovialis infrapatellaris beim Menschen*[1], Wachtler described the IPP. In the English abstract, he concluded: "…from a mechanical and teleological point of view, the IPP may have little relevance…"

The IPP has been described in the English literature as an embryonic remnant, a synovial fold of no clinical significance [2]:

"…most recent literature on the pathology of plica claims that the infrapatellar plica has little clinical relevance and does not cause symptoms…" [3]

*"…*It is generally agreed that the infrapatellar plica does not cause symptoms…**"** [4,5]

However, five clinical reports suggest that releasing the femoral insertion of the IPP improves idiopathic anterior knee pain (AKP) in most.[3,6,7,8,9]

THIS IS A PARADOX

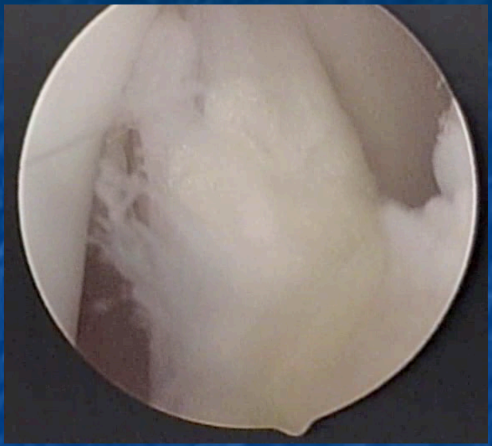
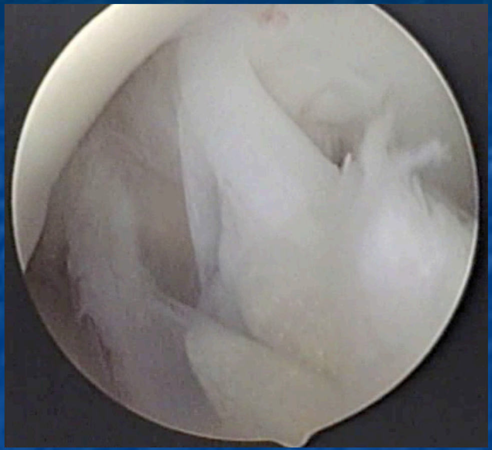
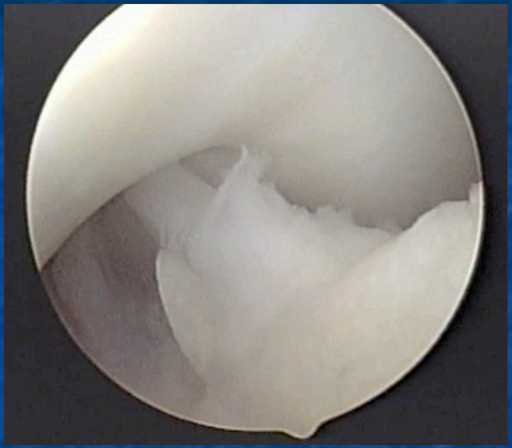
On one hand: Releasing the IPP helps AKP.

On the other: IPP is an embryonic remnant, a synovial fold of no clinical significance.

BACKGROUND DATA – CLINICAL

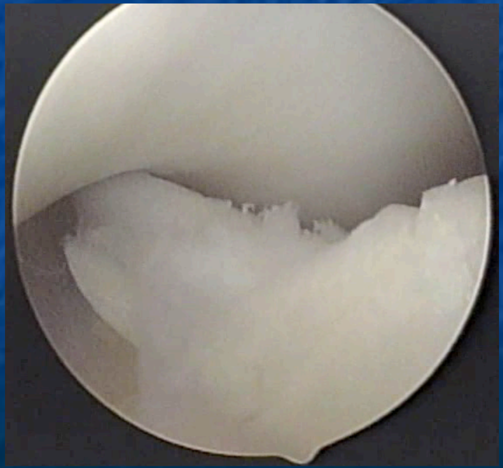
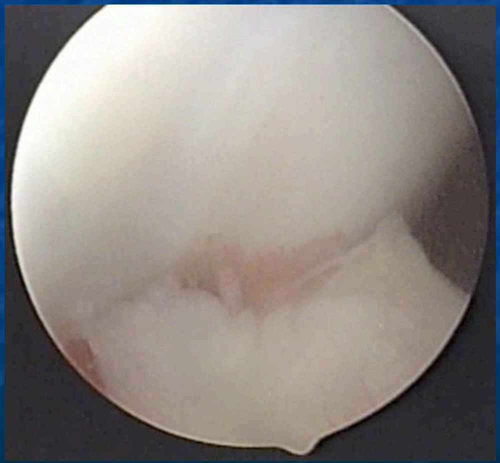
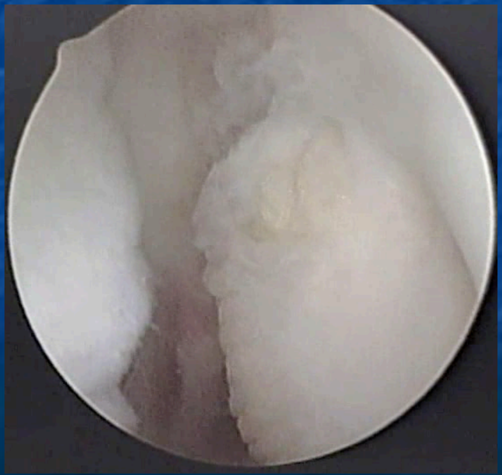
Sentinel Patient: ***the idea of linking anterior knee pain to the IPP*** originated with a fit soldier with this problem, whose knee at arthroscopy was pristine. Erythema at IPP origin focused attention on mechanical behavior as shown. Given no other abnormalities, the IPP was released. The soldier's pain disappeared.

These screen shots from similar, later case.

Knee Flexion: 90 ^{0} Mid Flexion ~ 50^0 ~ 25 ^{0}

IPP: taut, straight lead edge (LE) lax, gentle arc LE LE straight, no notch contact

Knee Flexion: ~ 20 ^{0} Full extension, IPP not Post release of IPP at femur

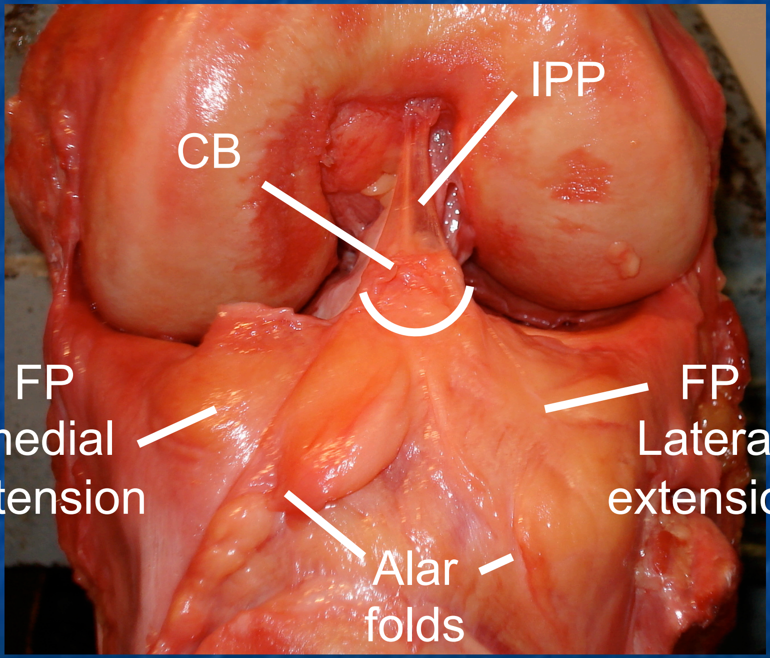
IPP: LE contacts notch seen;CB/FP contacts notch FP now free, sits apart

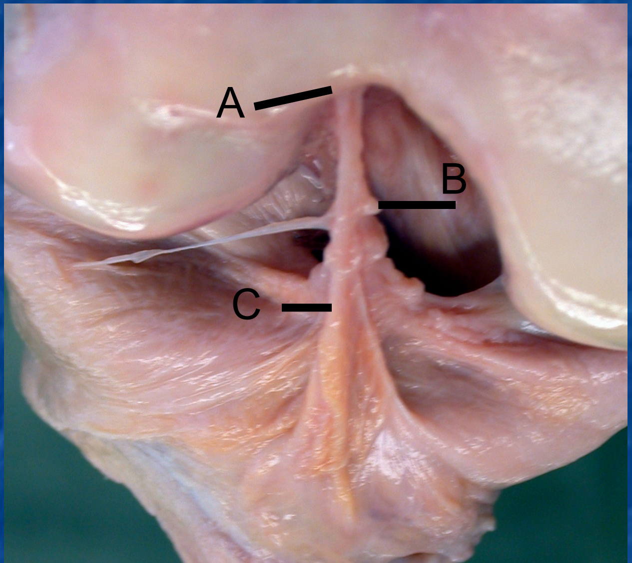
BACKGROUND DATA – ANATOMICAL
Knees with an IPP seen from a different perspective

Fundamental concept: Synovial layer is a continuum, a linked array of connective tissue (CT) part of whose function is force transmission.

- From Gray's Anatomy, the IPP connects with surrounding connective tissue (CT) elements. [10]
- CT from medial and lateral alar folds, and from below the patella merge with IPP.
- The connective tissue elements, as shown below, are thus linked.

Knee motion perturbs this linked CT array; the deformable fat, in lobules, is along for the ride.





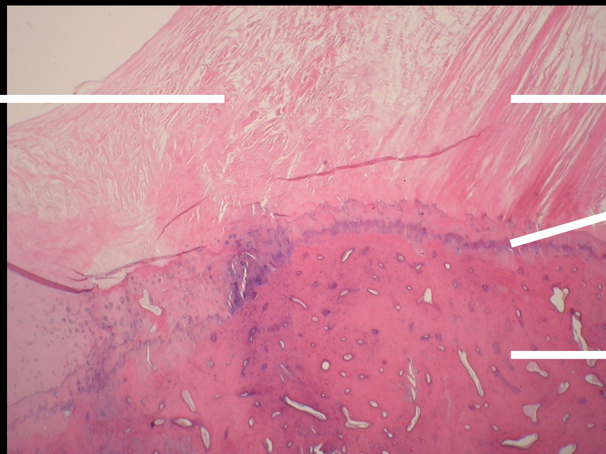
A, B, C: levels of histologic section, next slide.

This specimen was from an emaciated elderly person. Fat in FP has been consumed, allowing the CT connections to be apparent.

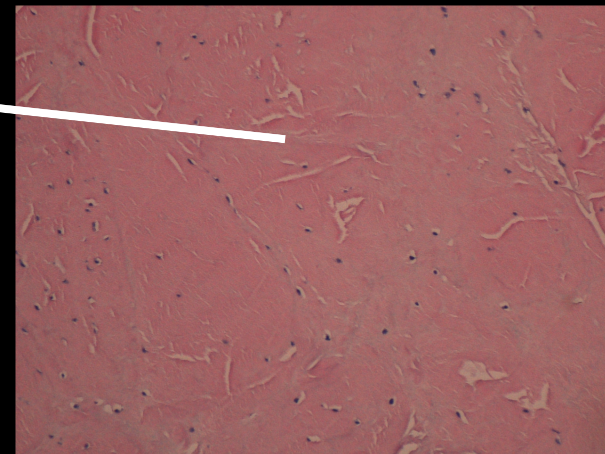
180^0 Flipped view : detaching and flipping extensor apparatus shows relationships. Left: CT in alar folds merges with elements from below the patella to blend with and become the CB and IPP. Right: the CT connections are more clear as there is little remaining fat in the specimen.

BACKGROUND DATA -- HISTOLOGIC

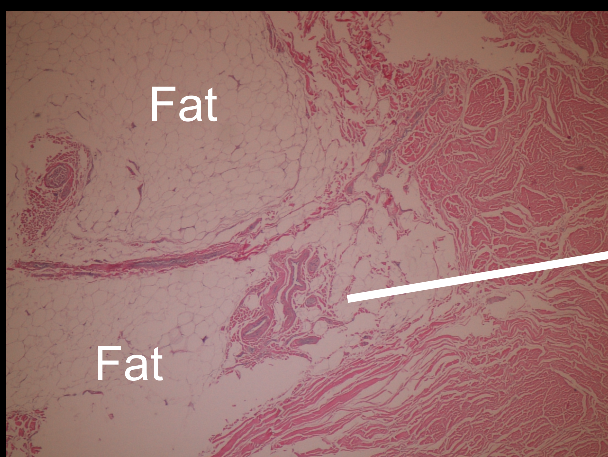
The IPP has a broad attachment (A), narrows to a rope-like zone (B), then grasps the FP with finger-like CT septae that merge with the CT of the FP (C). This CB region is unique, with redundant, tortuous neurovascular bundles that must stretch and relax with each cycle of knee motion as you will see. Wachtler described but did not demonstrate this histology.[1] These are representative sections of a separate IPP. Sections A and B are typical of any ligament..[11]



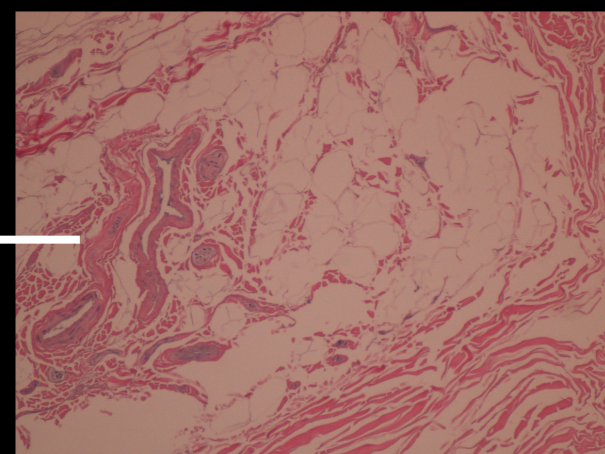
A. Femoral Attachment: Connective tissue (CT) above, fibrocartilagenous transition zone (FCTZ) to cortical bone (CB) below.



B. Cross-section: rope-like IPP in mid portion shows dense connective tissue.



C. Central Body IPP Attachment: finger-like CT projections from IPP merge with septae of FP.



C. Central Body IPP Attachment --HIGHER POWER: Neurovascular bundle (NVB) lodged in fat between CT septae; wavy, tortuous look suggests capability to stretch.

SUMMARY OF HISTOLOGIC DATA

A fundamental concept of nature is that structure and function are linked at all levels.

The microscopic structure of the IPP:

- Femoral attachment: Fibro-cartilagenous transition CT to bone;
- Rope-like central portion: dense CT;
- FP attachment at the CB: CT links from the IPP merge with the septa of CB; neurovascular bundles lodged in fat between septa, are tortuous, adapted to stretch.

The IPP is an intra-articular ligament.[11] The CB[11] and the FP are highly innervated.[12] By virtue of location, this is a structure that must stretch and relax with every cycle of knee motion.

Clinical implications of this innervation:

- Dye has described the fact the FP and adjacent synovium are highly pain sensitive.[13]
- Once AKP is initiated, knee motion perpetuates the problem.

BACKGROUND DATA -- BIOMECHANICAL

Instant center of rotation of the knee:

Constant and directed from antero-superior on the medial side to postero-inferior on the lateral side, passing through the origins of the medial and lateral collateral ligaments and superior to the crossing point of the cruciates.

Instant center of rotation of the FP → femoral attachment of the IPP:

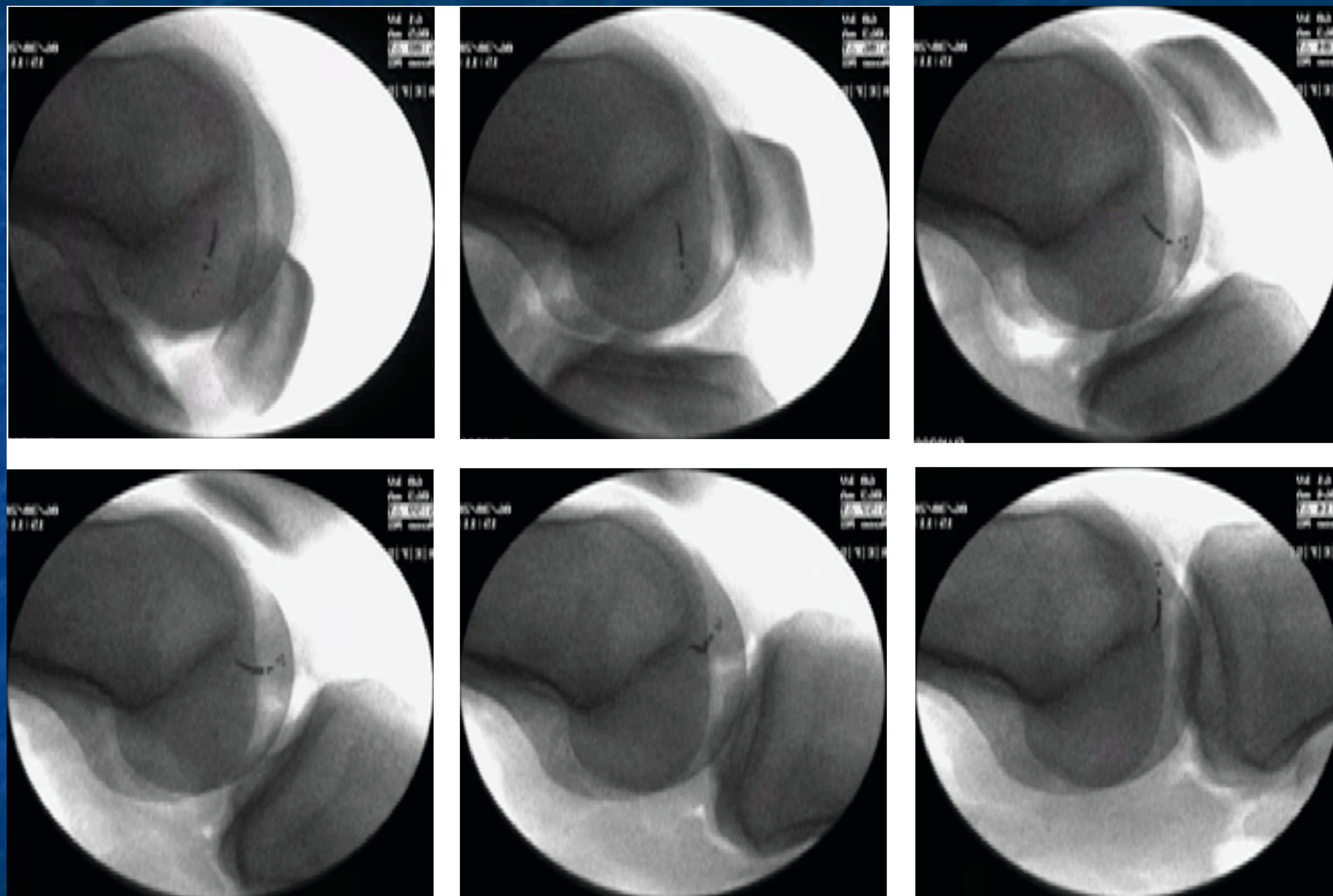
As the knee moves through its arc of motion, the FP, through its central body and the IPP, rotates around this fixed bony attachment.

The disconnect:

As the femoral attachment of the IPP sits anterior and inferior to the flexion/extension axis of the knee, the IPP must act non-isometrically, changing in length and tension as the knee moves through the arc of motion. As the FP attachment of the IPP is the soft tissue central body, it must distort as well. This is the key concept in linking AKP to the IPP/FP complex, as the central body as well as the FP, is highly innervated.

MATERIALS AND METHODS – IN VITRO -- 2 CADAVER KNEES

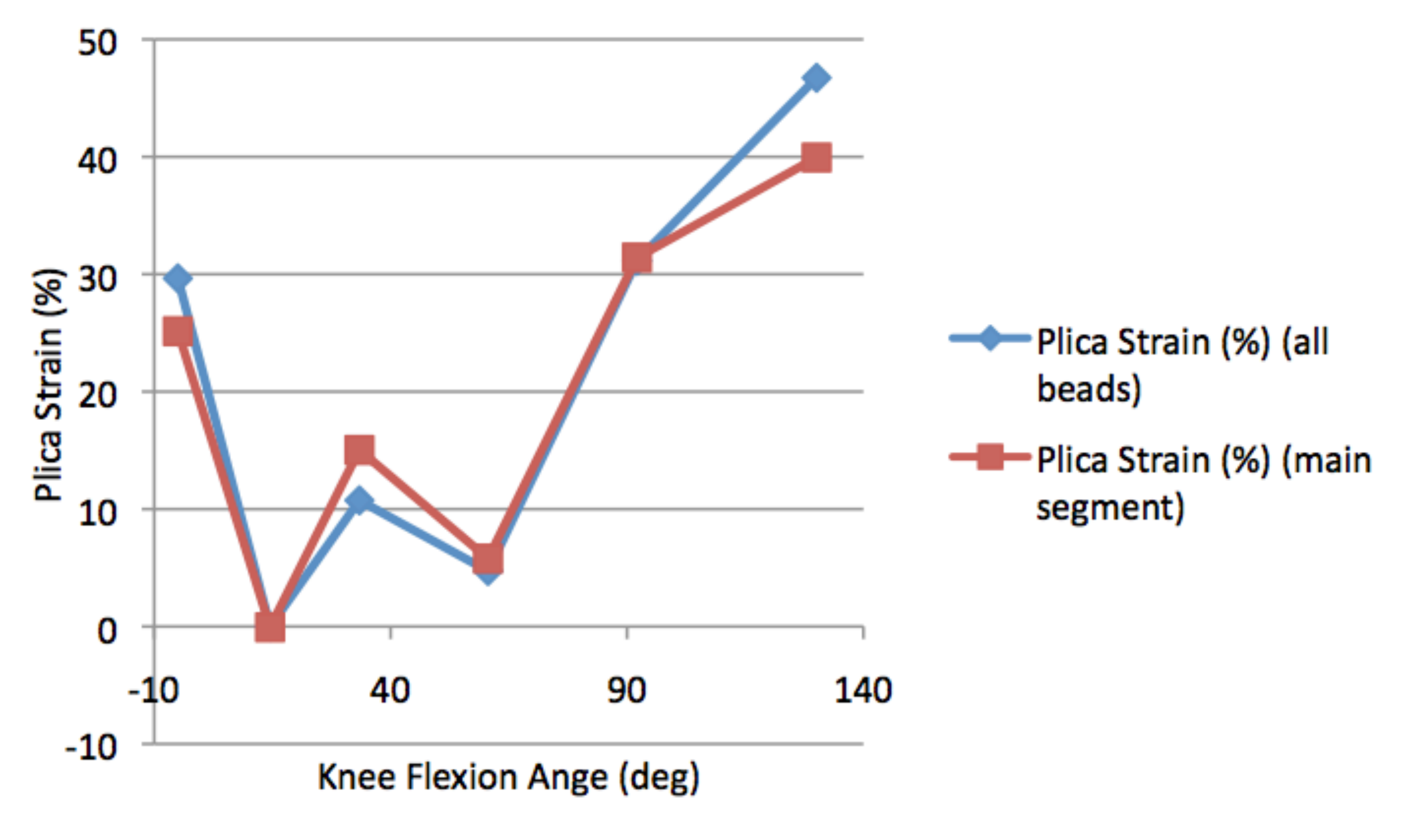
Cadaver experiment 1: using tantalum beads implanted in IPP:



Bead "movie" showing selected frames from flexion to extension: observe changing length of the bead column as the knee moves; this correlates with observed arthroscopic changes in the IPP with stretch and vertical orientation in flexion, an arc in mid-flexion (i.e. lax IPP), and stretch and vertical orientation in extension.

MATERIALS AND METHODS – IN VITRO

Cadaver knee experiment 1: The bead column changes length with knee motion. Plica strain (%); assume no strain in shortest segment and compare at each position.

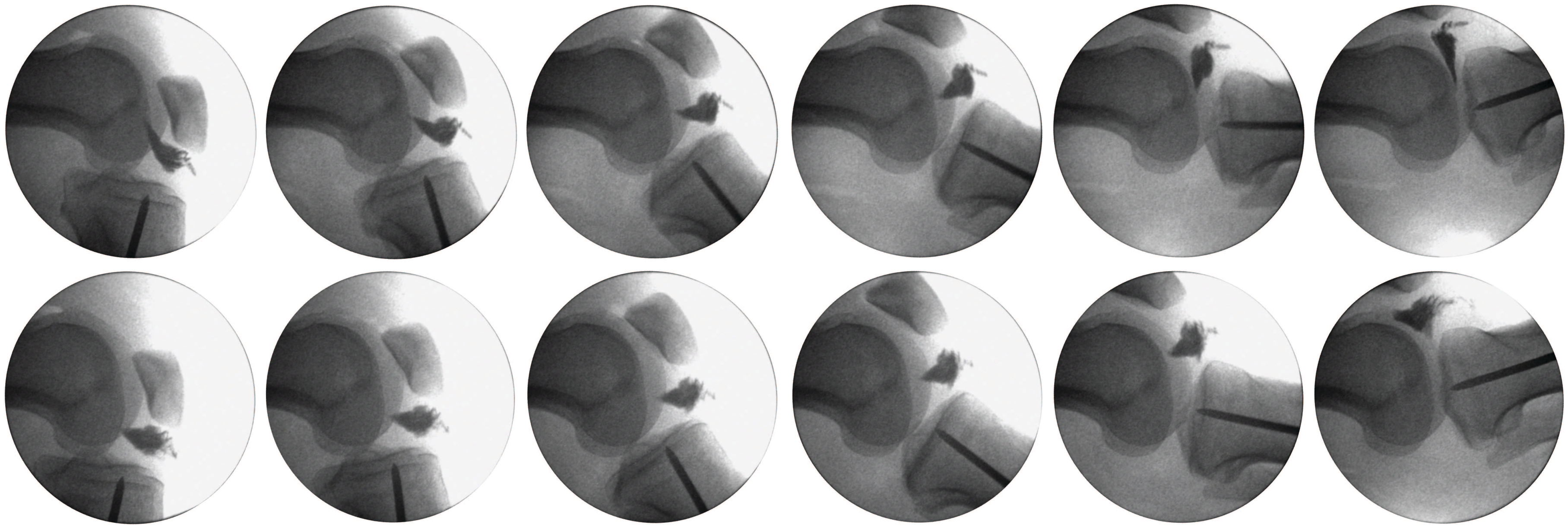


Plica strain is increased in high in extension and maximal in full flexion. This in vitro observation gives a very rough approximation of what may be happening in vivo.

MATERIALS AND METHODS – IN VITRO

Cadaver knee experiment 2: using radiographic contrast implanted in IPP, pre and post resection of femoral attachment of IPP.

IPP Intact



IPP Released

The IPP and CB only have filled; this shows their behavior in isolation from the overlying FP, the central portion of which has filled.

TOP ROW: Sequence from flexion to extension shows –

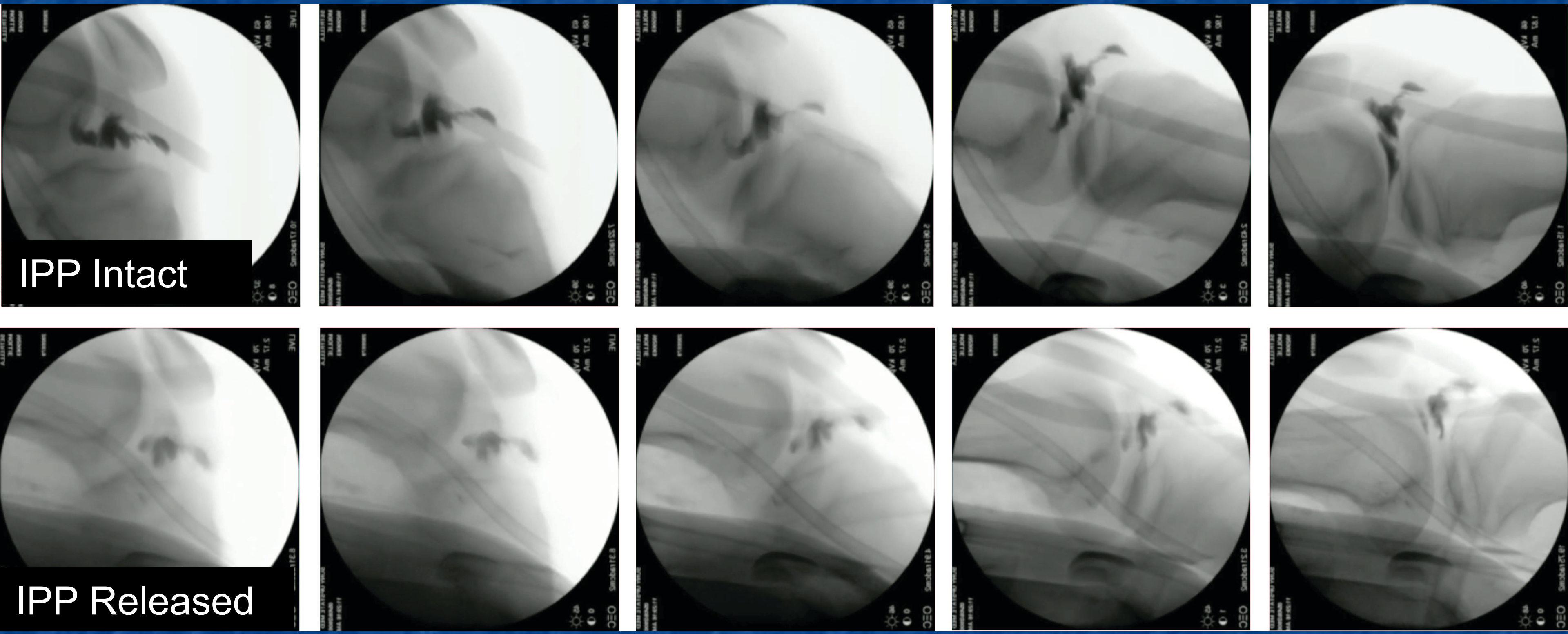
- slight stretch of the IPP/CB complex in maximal flexion; then a mid-flexion zone where there is little change other than in direction, then remarkable distortion and stretch in terminal extension (5^0 flexion to 5^0 hyperextension).

BOTTOM FRAMES: After release of femoral attachment –

- the IPP/CB complex floats freely with little distortion other than in terminal extension.

MATERIALS AND METHODS – IN VIVO – 9 VOLUNTEERS

An IRB approved study of patients undergoing arthroscopy, the cadaver experiment was reproduced. If an IPP was present, contrast was placed in the FP, CB, and IPP, motion observed and recorded using fluoroscopy. The IPP was released and observations recorded. This was the first patent, 18 Y/O MS, who suffered from anterior knee pain.



OBSERVATIONS: case mimics, and reproduces the finding in the cadaver experiment.

TOP ROW: The contrast filled the worm-like IPP/CB complex, and a small central region of the FP; this mimics the cadaver experiment; one can see behavior of the IPP/CB complex without FP overlap.

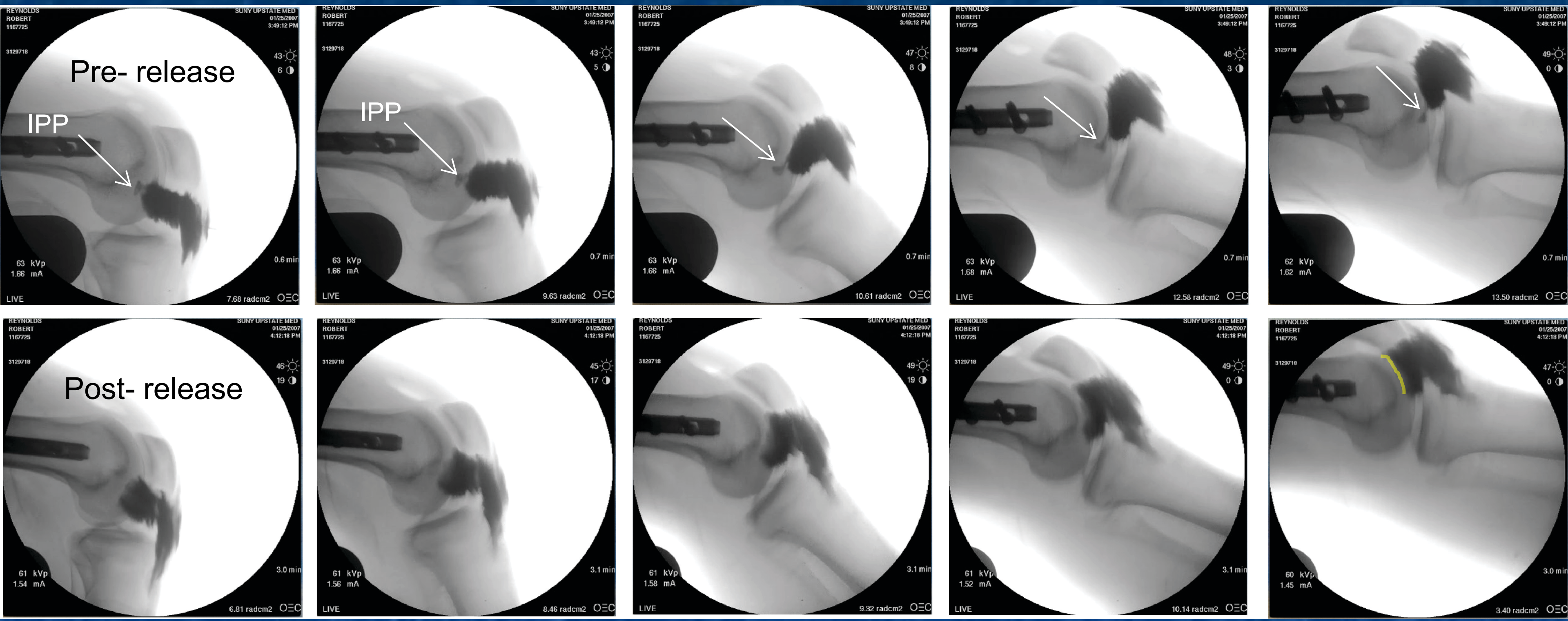
- In flexion IPP is vertical; mid flexion zone shows curved leading edge suggesting little tension; stretch and distortion begins at about 5^0 and continues to max at terminal extension.

BOTTOM ROW: Post release of the IPP

- No link to notch; little distortion of visualized FP elements until terminal extension.

MATERIALS AND METHODS – IN VIVO

Case 2, 18 Y/O RR, complaining of anterior knee pain post MVA and IM rodding of femur. Release of the IPP markedly improved AKP in this knee, and in both knees in Case 1.



OBSERVATIONS: Top row pre-IPP release

- Some of the detail of IPP/CB behavior is obscured by overlying FP; however, the origin of the IPP fills and changes shape with knee motion.
- IPP detail is obscured in max flexion; in mid flexion the IPP changes little; at 15^0 stretch and distortion of the IPP/CB complex begins, and is maximal at terminal extension of -5^0 (patient had flexion contracture);
- the IPP prevents natural translation of the FP; FP is distorted, and prevented from conforming with the distal femur.

OBSERVATIONS: Bottom row post-IPP release

- IPP/CB complex no longer seen; FP changes shape, leading edge conforming with the condyles.

RESULTS

Cadaver studies: IPP/CB demonstrates non-isometric mechanical behavior

- Experiment 1(tantalum beads): For the IPP
  - From flexion to extension there is stretch initially, then a zone of minimal tension, then approaching terminal extension, increasing stretch.

- Experiment 2(radiographic contrast): For the IPP/CB complex
  - IPP, CB, and a portion of the FP fill.
  - From flexion to extension there is initial stretch, then a zone of minimal tension, then with terminal extension, increasing stretch and distortion.
  - Release of the femoral attachment of the IPP virtually eliminates stretch and distortion.

RESULTS

In-Vivo Volunteer Study: Technically difficult -- successful intra-operative visualization of deformation of the IPP, and FP was achieved in 3/9 cases

- Case 1, MS:
  - Visualization poor in max flexion; leading edge is an arc in mid-flexion, suggesting little tension; IPP elongated with CB and FP distortion as the knee approached full extension.
  - Release of the IPP at the femur eliminated almost all of the distortion through the full arc of motion.
- Case 2, RR:
  - FP and IPP fill; the normal broad femoral attachment is very well seen; some overlap of FP obscures detail in IPP/CB complex.
  - Distortion of IPP origin is seen in full flexion; mid-flexion, IPP shows little change; at 15^0 stretch and distortion of IPP/CB begins and is maximal at terminal extension.
  - Release of the IPP obscures the IPP/CB from view
  - Pre release, FP distorts because of IPP tether; post, leading edge matches condyles.

CONCLUSIONS

- Preliminary data suggests that the IPP is a non-isometric, intra-articular ligament whose effect is to capture the fat pad. The fat pad, and its central body are highly innervated, pain sensitive structures.[11]
- Experimental evidence in vitro (2 cadaver knees) and in vivo (2 examples shown in volunteer patients), using lateral fluoroscopy demonstrates that the fat pad rotates about the femoral attachment of the IPP. Because this axis of rotation is not that of the knee, motion imparts inexorable stretch and relaxation to the IPP, and central body, transmitting force to its attachments at the femur, and the fat pad.
- The fat pad, thus tethered to the IPP through its central body, must deform as a result of this non-isometric mechanical behavior of the IPP.
- In vivo experiments involving volunteers provided intra-operative replication of the observations in cadavers, and added data on deformation of the fat pad. When tethered by the IPP, the fat pad deforms in response to its link to the notch.
- Release of the IPP at the femoral attachment virtually eliminates the perturbations arising from fat pad capture of the IPP/CB, and fat pad. After release, the fat pad simply conforms to the contours of the femoral condyles.

SIGNIFICANCE OF THE FINDINGS

- This report outlines a previously unknown phenomenon in the human knee. Previously considered not relevant, clinically or mechanically, the infrapatellar plica shows unexpected mechanical behaviour in that it is:
  - Non-isometric, and
  - It tethers the fat pad at its femoral attachment.

- With respect to idiopathic anterior knee pain, while the mechanism initiating the pain is not known, the clinical observation is that chronic pain of this nature, not responsive to conservative management, is relieved in 80 to 90% of knees by release of the femoral attachment of the IPP. [5,8,9,10,14]

SIGNIFICANCE OF THE FINDINGS

- There is thus an anatomic link between the fat pad/IPP complex and anterior knee pain. These unexpected mechanical effects may warrant reconsideration of the source of pain in other knee disorders.

- Pain relief in AAKP may be a result of the demonstrated elimination of the observed mechanical perturbations, or of interruption of neurogenic pathways (denervation).

- Linking AAKP to the IPP and fat pad, which are centrally located and innervated soft tissue structures, bypasses considerations related to malalignment, tilt, and articular surface damage in considering unilateral pain when both knees have such findings.

- Idiopathic anterior knee pain could be termed the fat pad capture syndrome, reflecting this described link.

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