Mamoru Niitsu

Magnetic Resonance Imaging of the Knee

English Translation Supervised by
Ali Guermazi

Translated by
Daichi Hayashi

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Preface

I just ‘love the knee’. Just like my ultimate mentor, Dr. Yuji Itai (specialist of abdominal imaging, now deceased) being so excited to see the images of the liver during conferences, my heart starts beating faster as soon as I encounter images showing the anterior cruciate ligament or menisci of the knee joint.

It was during the year 2010 when I received an offer from Dr. Daichi Hayashi, a Research Scholar at Boston University School of Medicine, to publish an English edition of my book entitled ‘Hiza MRI (= Knee MRI in Japanese)’. I accepted it without hesitation, since I thought this was a golden opportunity for me to publish a book in English and to share my knowledge and experience with radiologists around the world. I am wholeheartedly grateful to Dr. Hayashi’s supervisor, Prof. Ali Guermazi, who highly appreciated the value of my publication at a glance. I gave my full trust to Dr. Hayashi who was educated in the United Kingdom (and therefore is bilingual) to translate the entire book all by himself. It must have taken him lots of time and effort to complete the translation, and I am genuinely thankful for his dedication to this project. Moreover, I would like to thank Prof. Kunihiko Fukuda, Dr. Hayashi’s mentor in Japan and the Chairman of Radiology Department at the Jikei University Hospital, Tokyo, Japan, who introduced Dr. Hayashi to me.

The first edition of the original book in Japanese ‘Hiza MRI’ was published almost 10 years ago. During the last decade, technological advances enabled improvement of the quality of images, thanks to development and clinical application of 3.0T MRI systems, multichannel coils and other new imaging apparatus. At the same time, my collection of images expanded steadily. The second edition of the Japanese edition was published in 2009. Both these publications could not have materialized without the unreserved support from Dr. Kotaro Ikeda, an orthopaedic surgeon and the Director of Ichihara Hospital, Tsukuba, Japan. Most of the arthroscopic images were kindly provided by Dr. Ikeda. I also received support from other orthopaedic surgeons in Tsukuba and Tokyo, and I would like to express my sincere gratitude to all those who helped me. Last but not least, I am extremely thankful to Dr. Toru Fukubayashi of Waseda University, Dr. Yukihisa Saida of St Luke’s International Hospital, Tokyo, Japan, and editorial staff of Igakushoin (the Japanese publisher of the original book) for their generous support.

Finally, I would like to finish by emphasizing the importance of slight flexion of the knee during acquisition of knee MRI (mainly for the purpose of better delineation of the anterior cruciate ligament). Details are found in Chapter 3. This simple maneuver is not routinely done in the clinical practice (at least in Japan). This is an unfortunate and regretful situation since I have been emphasizing this point for over a decade. I sincerely wish that the readers of this book appreciate the value of such practice and it will become widespread knowledge and eventually ‘common sense’ all over the world

December 2011

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Preface by the Translator Supervisor

It was during a busy clinical day that I went to my research lab to see my (then) research fellow, Dr. Daichi Hayashi, during a lunch break. When I entered his office, he was reading knee MRI for our research project, and beside him was a green textbook written in Japanese. "What are you reading?" I asked. Daichi replied, "It is a Japanese 'bible' of knee MRI." I had a look at the book myself, but of course, I could not fully understand the full value of the book then because it was written in Japanese. However, what I did realize was that this book has an excellent and well-organized collection of cases regarding MRI of knee pathologies. I understood this book was more like an MRI atlas of knee pathology, rather than a reference material. I then suggested to Daichi that perhaps we could translate this book into English so that non-Japanese radiologists can also benefit from this "Japanese bible" of knee MRI. I then contacted my dear friend, Ute Heilmann at Springer who immediately gave me full support with enthusiasm, as usual. I had to rely on Daichi to communicate with the Japanese author of the original book, Professor Mamoru Niitsu, and the publisher Igakushoin to make this project come true, and Daichi did an excellent job for me. Fortunately for me, I had a chance to visit Japan because I was invited as a guest speaker at the Japanese Congress of Radiology in Yokohama in September 2010. There, I met with Prof. Niitsu and had further discussion about this project in person. Initially, I suggested that we add some new images to replace some figures that looked a little bit outdated or of suboptimal quality in today's publication standard. However, during our negotiation, Prof. Niitsu made it clear that he wished that the translated book is an exact "English" copy of the original book. Unfortunately, he could not provide images with better quality, so in the end, we all agreed that we would fully honor Prof. Niitsu's wish. Therefore, no additional figures or illustration were introduced into this English version. Personally, some references seem outdated, but since this book only concerns clinical diagnosis and not up-to-date clinical research studies, I believe it does not matter too much. MRI appearance of ACL tear should not have changed within the last couple of decades! Once the project began, Daichi showed his dedication to it and worked day and night. He is a Japanese-born British-educated radiologist-in-training and is a true bilingual man. Without his passion and commitment, this translation project could not have materialized. Some contents were specifically referring to Japanese terminology used in clinical practice in Japan, and these were omitted from this translation because it was impossible to translate. Otherwise, the end product is an almost exact "English copy" of the original book. I sincerely hope that this MRI atlas of knee pathology becomes a good companion to general radiologists and residents all over the world in their clinical work on a daily basis. I will certainly recommend this book to residents who are doing MSK rotation in my hospital! As always, I would like to thank Ute and the editorial team at Springer for their unreserved support toward this project. Also, I am thankful to Prof. Niitsu and the editorial staff at Igakushoin who provided all images for this book. Having read through the English version, I strongly believe my decision to take up this project was a right one!

December 2011

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Biography

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Translator's Note

The original Japanese publication of this book is considered a "bible" of musculoskeletal radiologists and radiology residents in Japan. The author, Prof. Mamoru Niitsu, is a well-known expert of knee MRI, and it is a great honor for me to be able to translate this book into English so that Prof. Niitsu's expertise can be shared among non-Japanese readers worldwide. This project's intention was to produce English translation of the book without altering scientific contents of the original Japanese version, and I did my best to achieve this. When I was working as a radiology resident in Tokyo, Japan, I always had this book with me during MSK (musculoskeletal imaging) reporting sessions. In fact, all my MSK colleagues were using this book! The book is small enough to carry with me while having sufficient information and abundance of MR images to help me in my daily clinical practice in diagnostic radiology. This book should be used as an MRI atlas of knee pathologies during reporting sessions, not as a reference material which one would read in a library in their spare time. Fortunately for me, I now have an English version of the "bible," which will undoubtedly help me in my clinical practice in the United States. I would like to thank Prof. Niitsu and my supervisor at Boston University, Prof. Ali Guermazi, who enabled this project to materialize. Without their support and supervision, I could not have completed it. To be honest, I was really surprised when Ali wanted to produce an English translation of this book, but I am glad I did! To be able to translate the contents of this book, I had to fully understand its contents first so that I can produce accurate English translation. By doing this project, I learned a great deal about knee MRI and gained confidence in interpreting MRI of knee pathology. I would also like to thank Ute Heilmann, Daniel Brandt, and Corinna Schaefer of Springer and Minoru Sakamoto and Norihisa Amano of Igakushoin (Japanese publisher of the original book) for their support and encouragement toward this project. Finally, I would like dedicate this work to my wife Sakiko and daughters Sue and Lily, who gave me their full support and understanding throughout my struggle to accomplish this project (needless to say, I spent many hours late at night and on weekends at home working on this) and also working at the Department of Radiology, Boston University School of Medicine. I can now rest and have a peaceful New Year celebration with my family and friends in Brookline, Massachusetts!

December 2011

Daichi Hayashi, M.D., Ph.D.
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How to Use this Book

This book is aimed to be a practical MRI atlas which busy diagnostic radiologists can glance at during reporting sessions.

- To achieve this aim, all texts are written using bullet points and references are given within each topic or subtopic.
- A large number of images are used to illustrate the key messages.
- Key points regarding MRI examination and reporting are provided.
- Although various types of soft tissue and osseous tumors can arise in the knee, those lesions are outside the scope of this book.
- Description of the principles of MRI physics is limited to knowledge that is deemed essential for clinicians.
- For details of MRI acquisition protocols, please refer to page 23.
- Sagittal plane is the most commonly used imaging plane in this book. All MR images are acquired in the sagittal plane unless otherwise stated in the figure legend.

Contents

Abbreviations

ACL	Anterior cruciate ligament
AMB	Anteromedial bundle
BPTB autograft	Bone-patellar tendon-bone autograft
CHESS	Chemical shift selective
ET	Echo train length
FSE	Fast spin echo
FS	Fat-suppressed
GCTTS	Giant cell tumor of tendon sheath
GRE	Gradient-recalled echo
LCL	Lateral collateral ligament
MCL	Medial collateral ligament
MTC	Magnetization transfer contrast
MT effect	Magnetization transfer effect
OA	Osteoarthritis
OCD	Osteochondritis dissecans
PCL	Posterior cruciate ligament
PDWI	Proton density-weighted image
PLB	Posterolateral bundle
PVS	Pigmented villonodular synovitis
SAR	Specific absorption rate
SE	Spin echo
SLJ disease	Sinding-Larsen-Johansson disease
STIR	Short TI (tau) inversion recovery
TI	Time of inversion
T1WI	T1-weighted image
T2WI	T2-weighted image
T2*WI	T2*-weighted image

1 Anatomy of the Knee

1.1 Sagittal Views

3.0 mm slice thickness/0.3 mm interslice gap, 150 mm FOV, 512×256 matrix
(a) Intermediate-weighted (close to proton density-weighted) FSE, TR/TE=1,321/17 ms, ET=5
(b) T2*-weighted GRE, TR/TE=522/14, flip angle 30°

- Sagittal view is the basis for knee MRI including ACL evaluation. To improve delineation of ACL, the knee is slightly flexed (see Chap. 3 for more details). If the slice thickness is 3 mm or so, it is not possible to visualize ACL and PCL in their entire lengths in one plane. Menisci are depicted as bow-tie-shaped structure with homogeneous hypointensity.

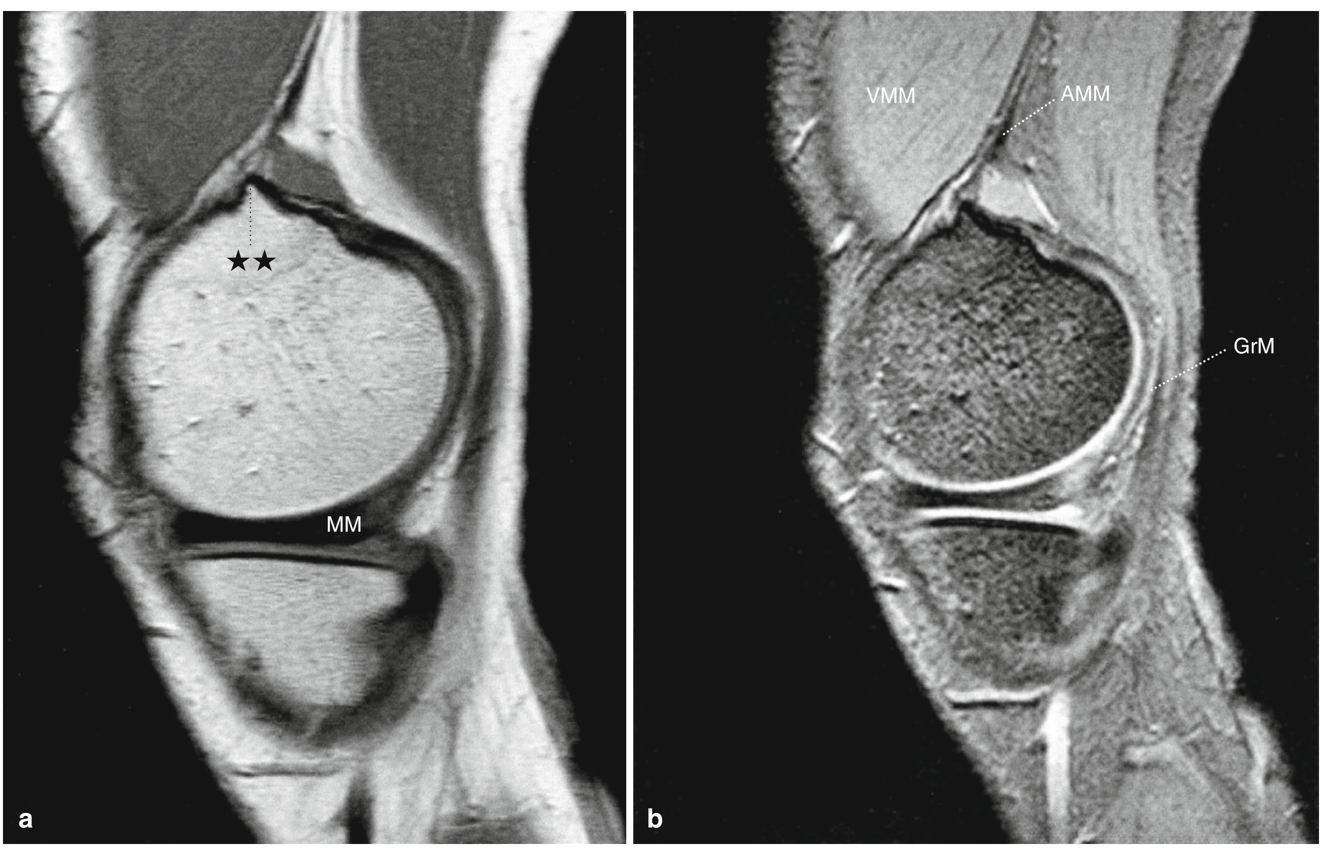

Fig. 1.1 (**a**) *MM* medial meniscus, ☆☆ adductor magnus muscle insertion, where distal femoral cortical irregularity may arise. (**b**) *VMM* vastus medialis muscle, *GrM* gracilis muscle, *AMM* adductor magnus muscle

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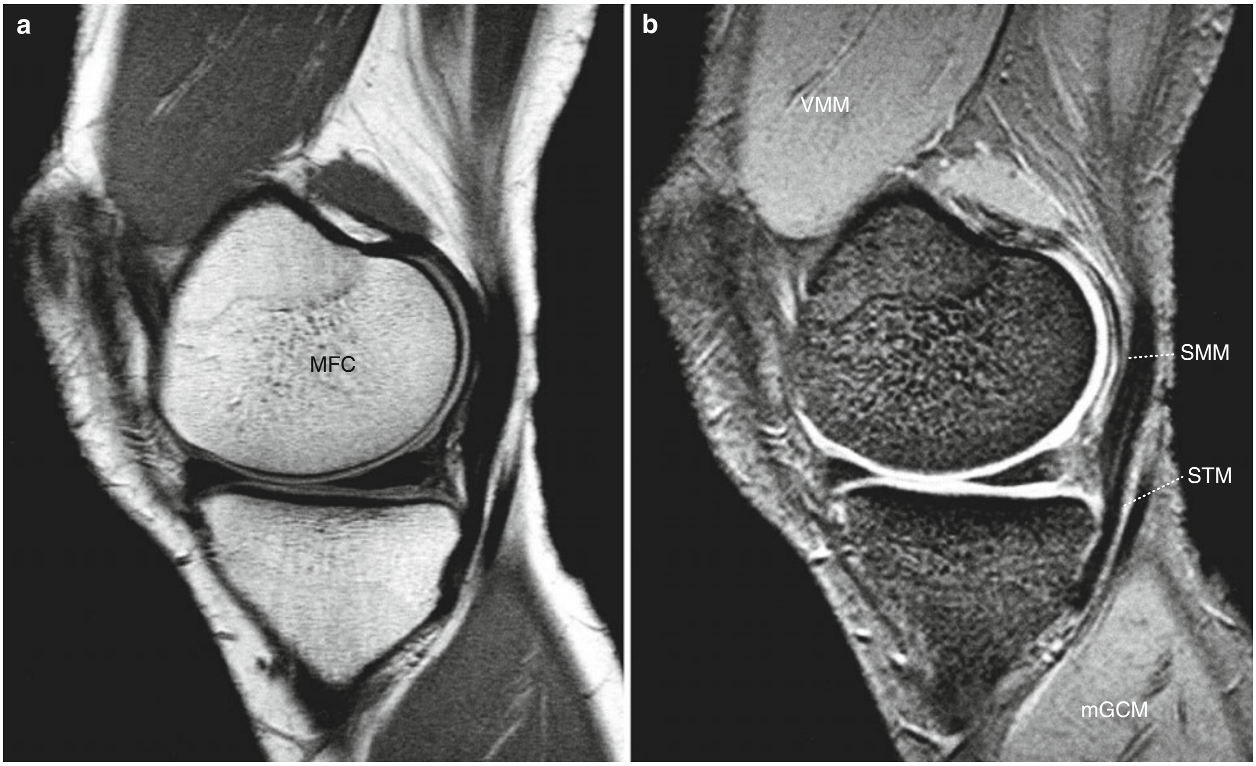


Fig. 1.2 (**a**) *MFC* medial femoral condyle. (**b**) *VMM* vastus medialis muscle, *SMM* semimembranosus muscle, *STM* semitendinosus muscle, *mGCM* medial head of gastrocnemius muscle

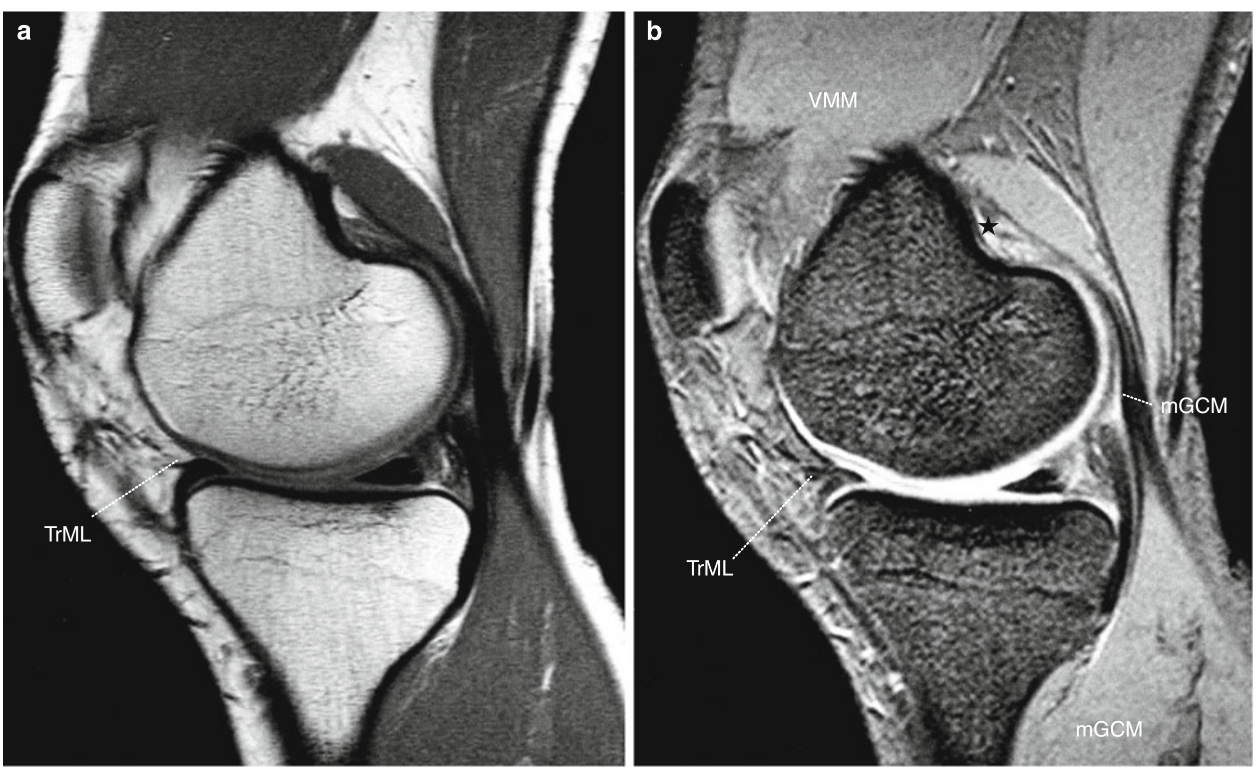


Fig. 1.3 (**a**) *TrML* transverse meniscal ligament. (**b**) *mGCM* medial head of gastrocnemius muscle, *VMM* vastus medialis muscle, *TrML* transverse meniscal ligament, ☆ distal femoral cortical irregularity at the insertion of mGCM

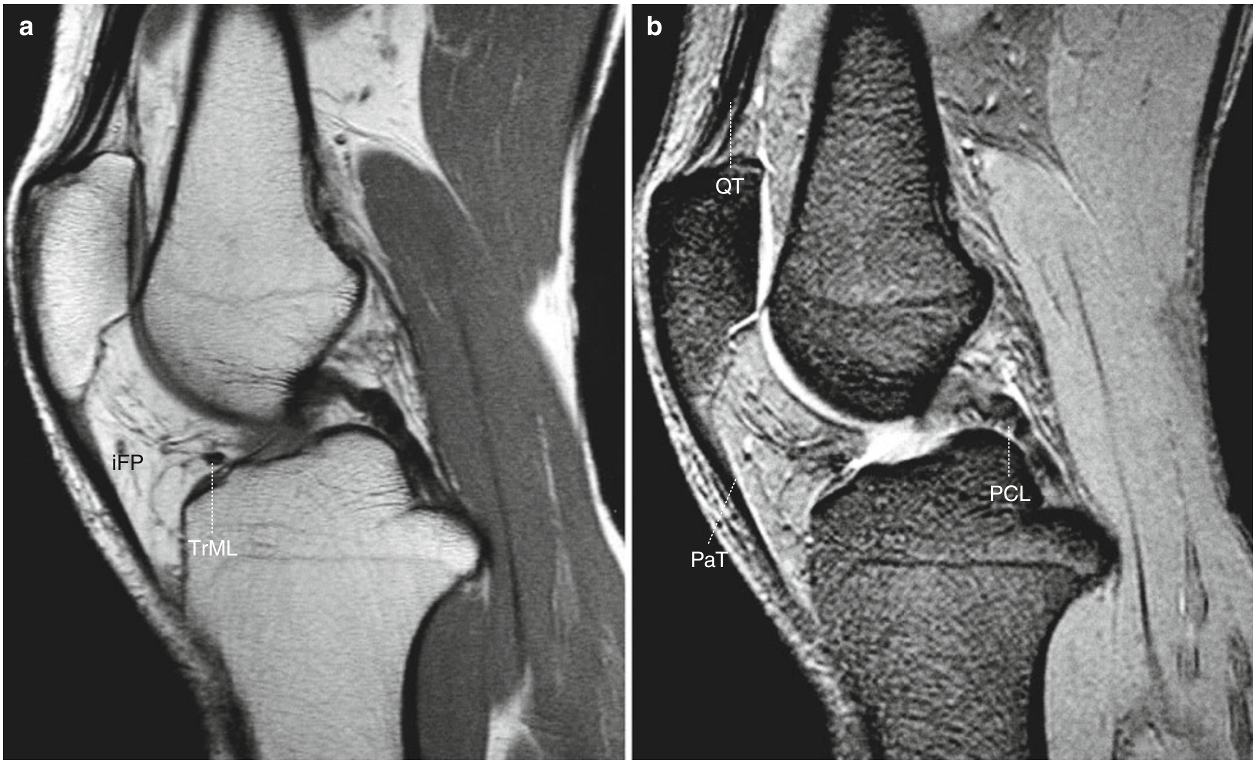


Fig. 1.4 (**a**) *iFP* infrapatellar (Hoffa's) fat pad, *TrML* transverse meniscal ligament. (**b**) *QT* quadriceps femoris tendon, *PCL* posterior cruciate ligament, *PaT* patellar tendon

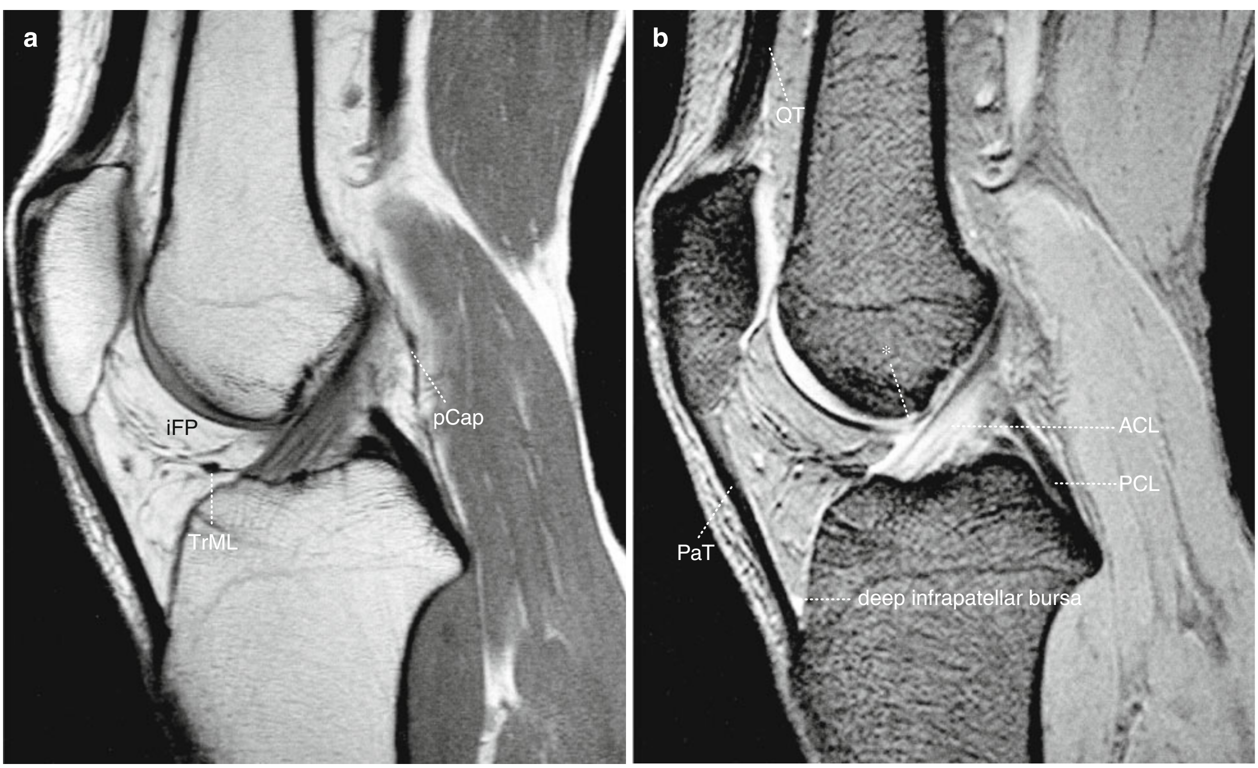


Fig. 1.5 (**a**) *iFP* infrapatellar (Hoffa's) fat pad, *pCap* posterior capsule, *TrML* transverse meniscal ligament. (**b**) *QT* quadriceps femoris tendon, *ACL* anterior cruciate ligament, *PCL* posterior cruciate ligament, *PaT* patellar tendon, deep infrapatellar bursa, * location where infrapatellar plica and infrapatellar (Hoffa's) fat pad curves in toward the femur

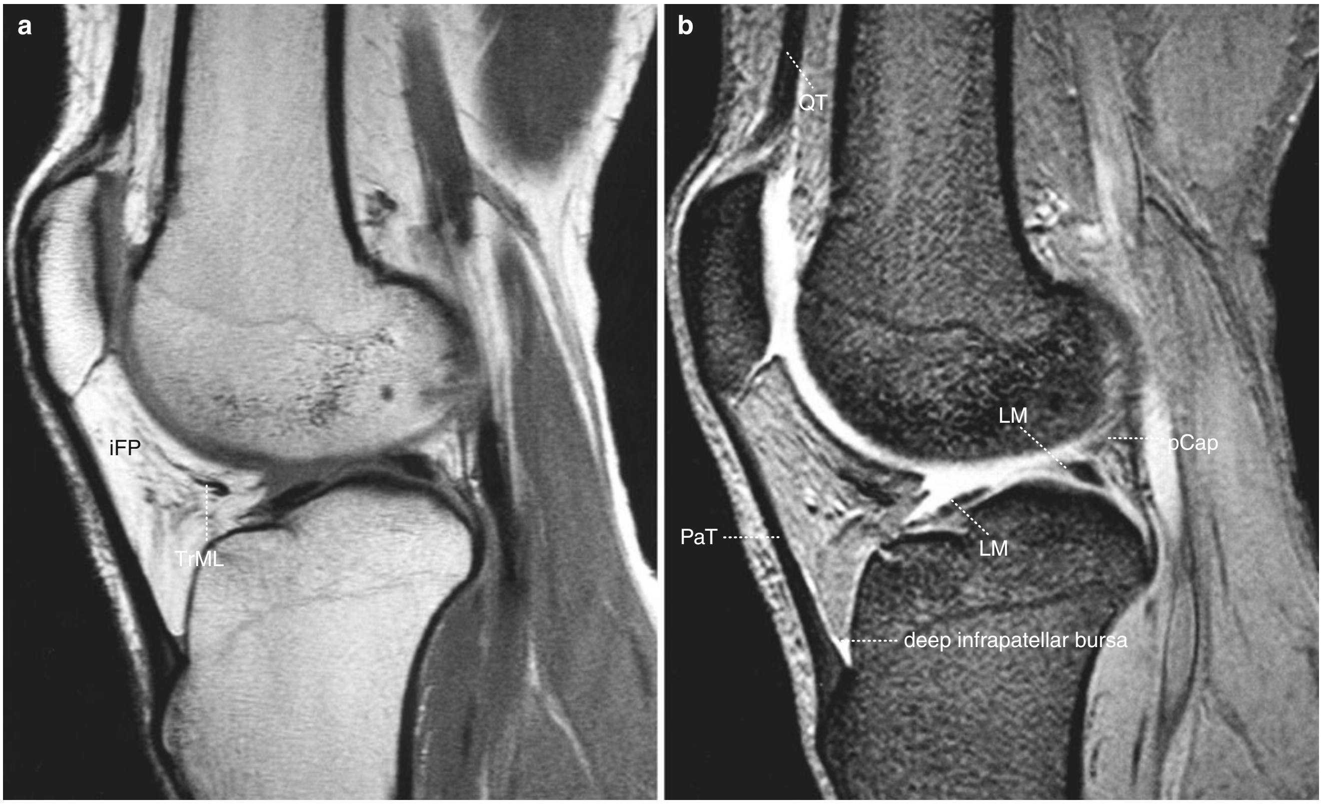


Fig. 1.6 (**a**) *iFP* infrapatellar (Hoffa's) fat pad, *TrML* transverse meniscal ligament. (**b**) *QT* quadriceps femoris tendon, *pCap* posterior capsule, *LM* lateral meniscus, *PaT* patellar tendon, deep infrapatellar bursa

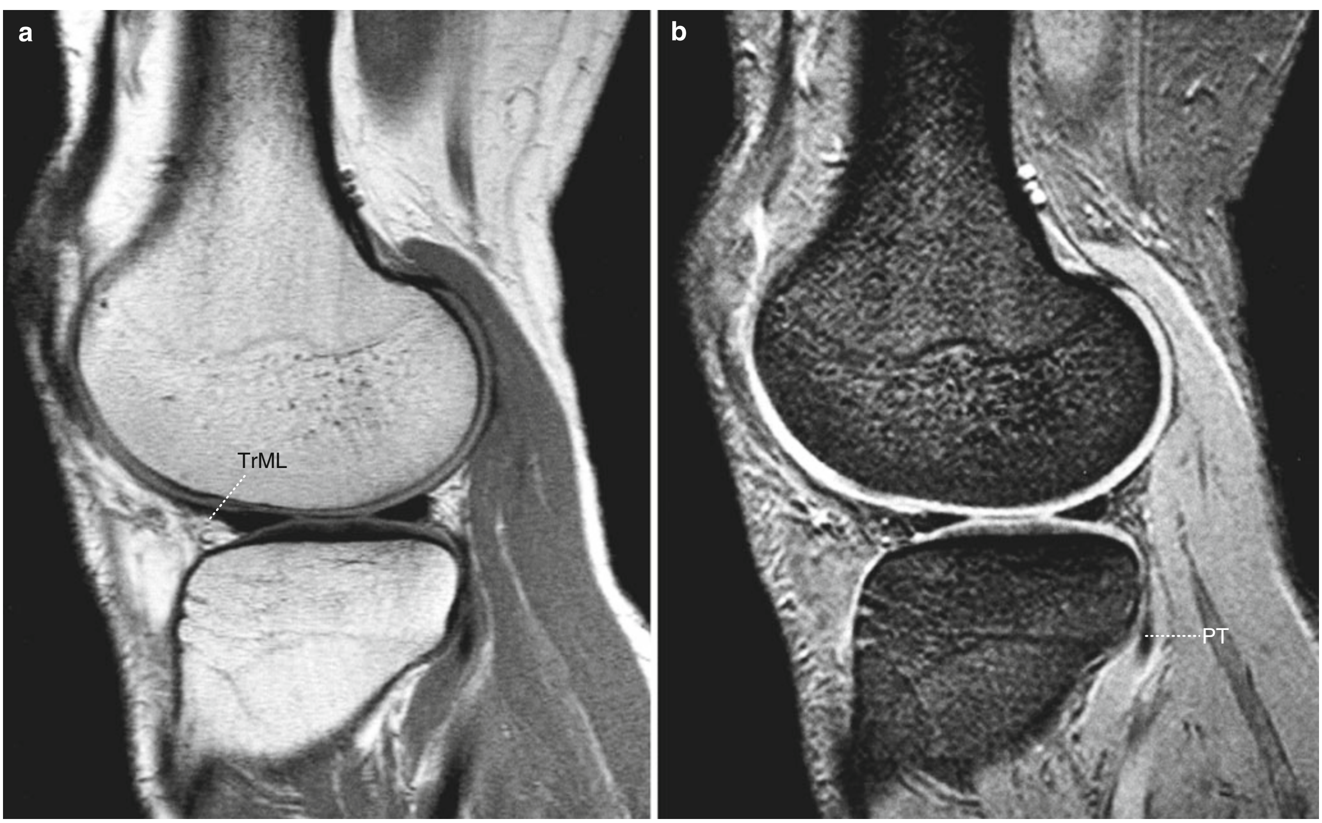


Fig. 1.7 (**a**) *TrML* transverse meniscal ligament. (**b**) *PT* popliteus tendon

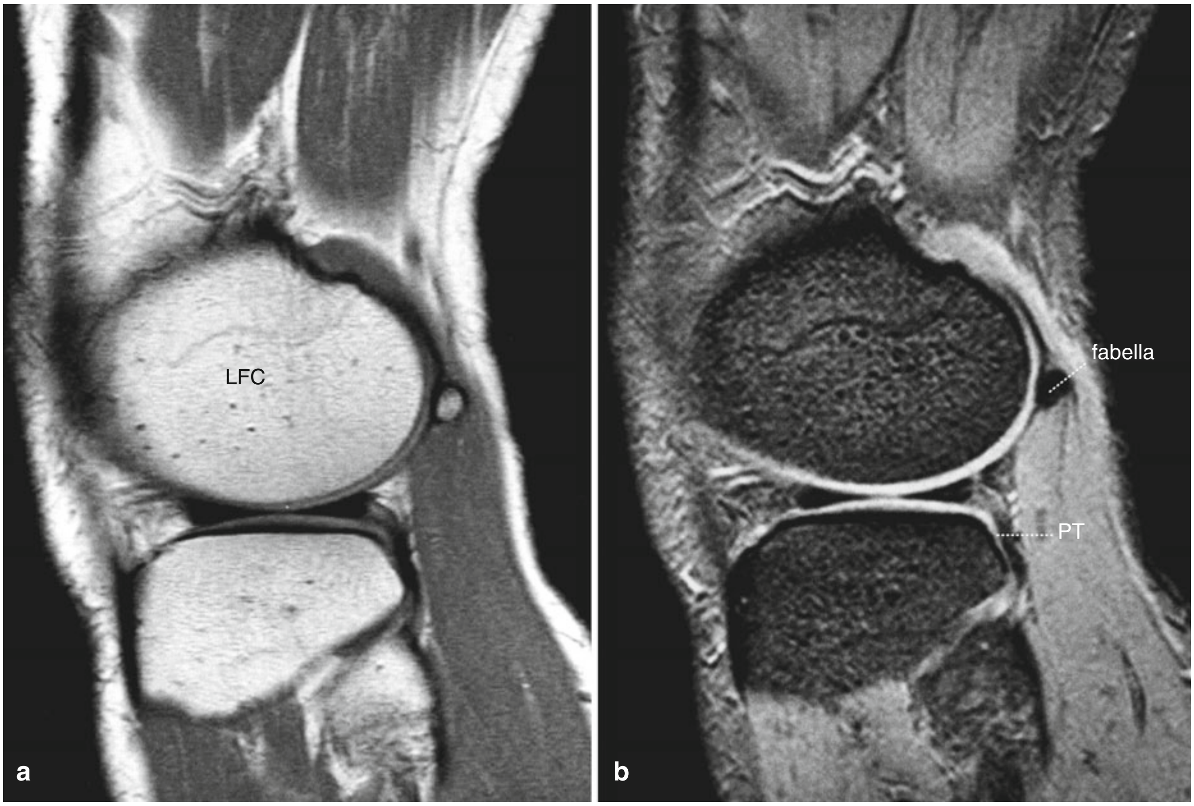


Fig. 1.8 (**a**) *LFC* lateral femoral condyle. (**b**) fabella, *PT* popliteus tendon

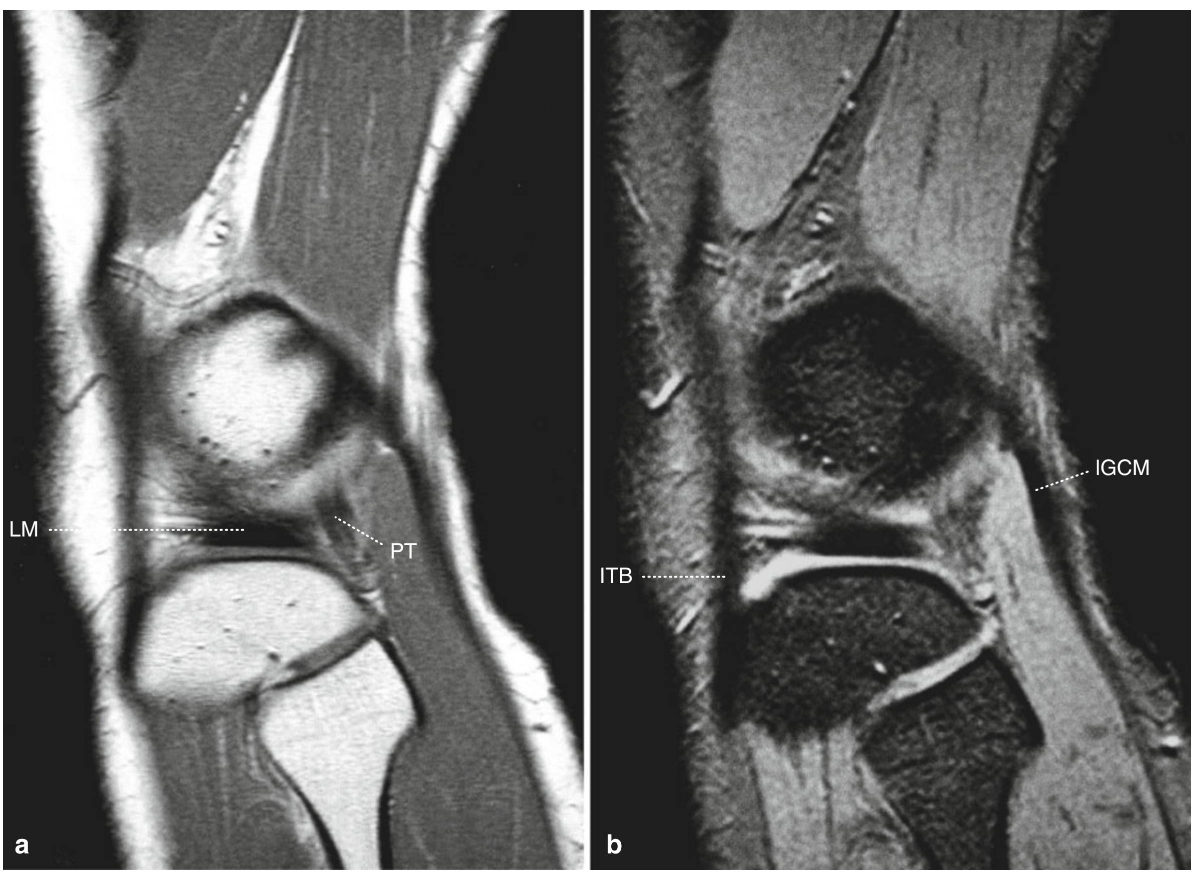


Fig. 1.9 (**a**) *PT* popliteus tendon, *LM* lateral meniscus. (**b**) *lGCM* lateral head of gastrocnemius muscle, *ITB* iliotibial band

1.2 Coronal Views

3.0 mm slice thickness/0.3 mm interslice gap,
150 mm FOV, 512 × 256 matrix
T2*-weighted GRE, TR/TE = 414/14, flip angle 35°

- Coronal view is primarily used for evaluation of menisci and medial and lateral collateral ligaments. Attention should be paid to minute irregularity of meniscal surface due to small tears, especially discontinuity of the free border.

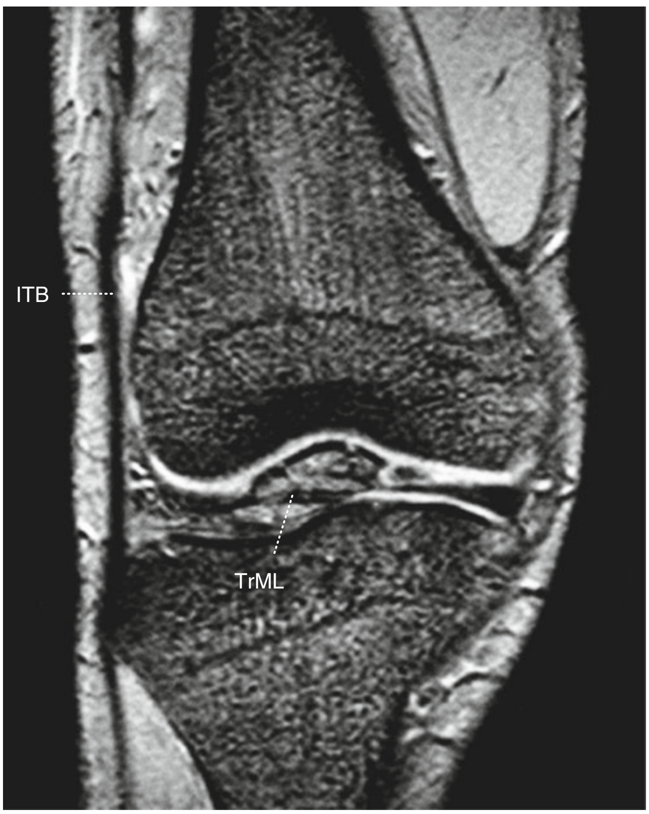


Fig. 1.10 *ITB* iliotibial band, *TrML* transverse meniscal ligament

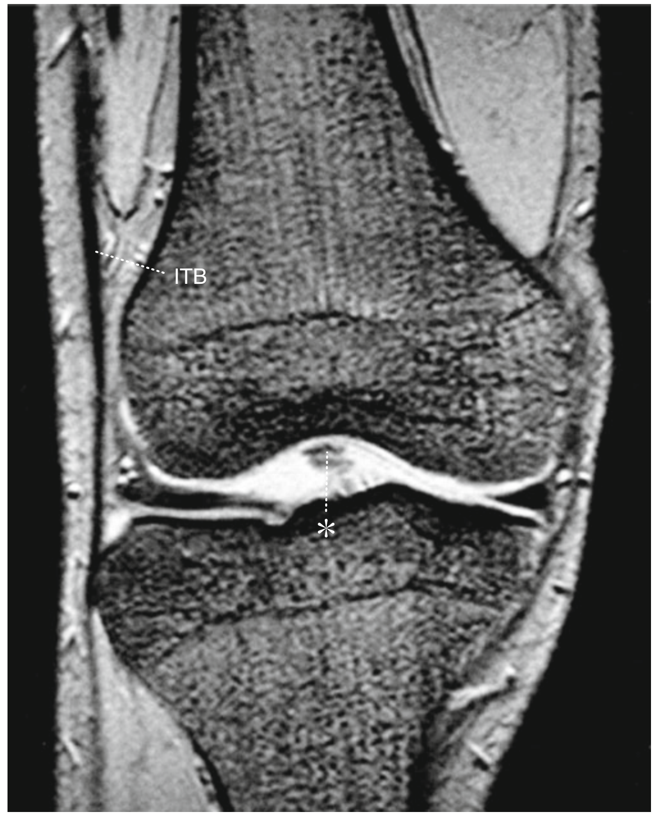


Fig. 1.11 *ITB* iliotibial band, * location where infrapatellar plica and infrapatellar (Hoffa's) fat pad curves in toward the femur

Fig. 1.12 *ITB* iliotibial band, *ACL* anterior cruciate ligament, *MCL* medial collateral ligament

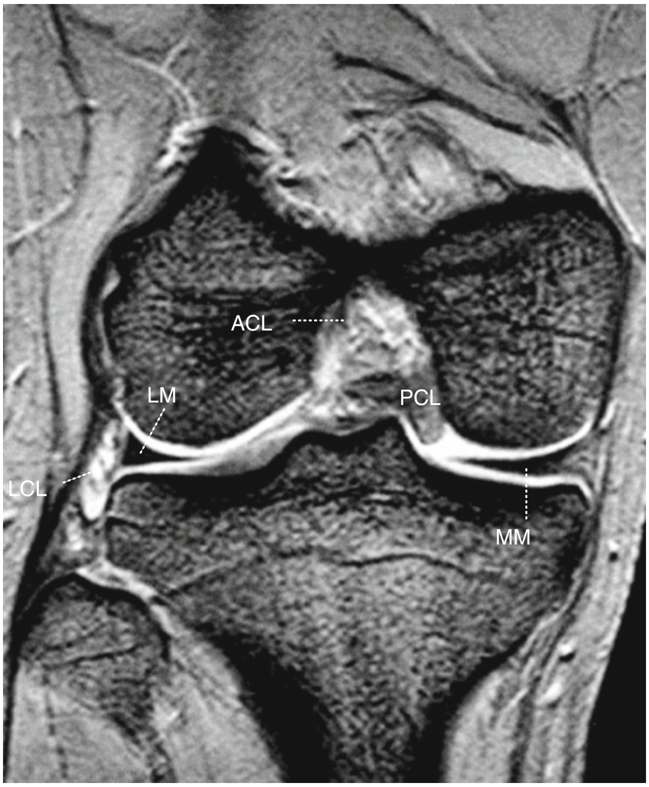


Fig. 1.13 *ACL* anterior cruciate ligament, *PCL* posterior cruciate ligament, *LM* lateral meniscus, *MM* medial meniscus, *LCL* lateral collateral ligament

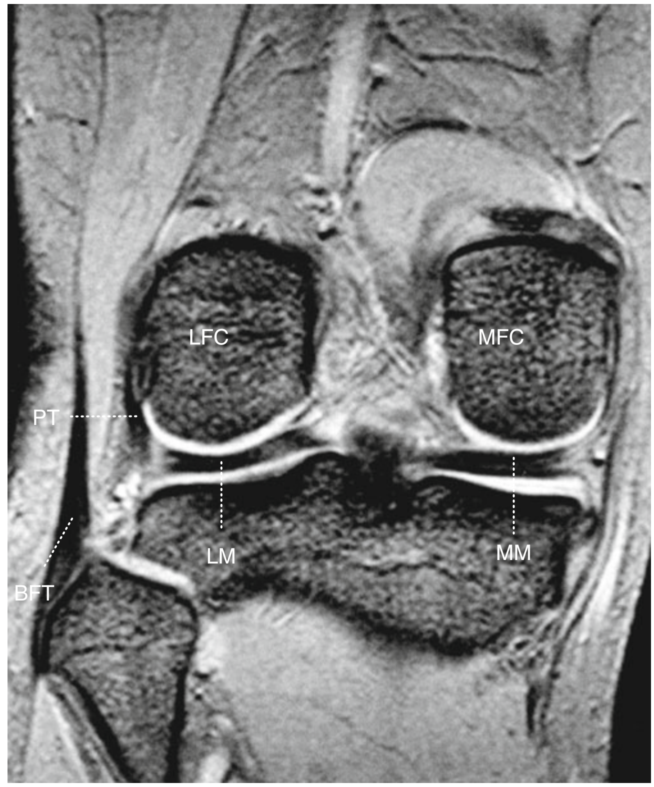


Fig. 1.14 *LFC* lateral femoral condyle, *MFC* medial femoral condyle, *PT* popliteus tendon, *LM* lateral meniscus, *MM* medial meniscus, *BFT* biceps femoris tendon

Fig. 1.15 *LFC* lateral femoral condyle, *MFC* medial femoral condyle, *PT* popliteus tendon

1.3 Axial Views

> 3.0 mm slice thickness/0.3 mm interslice gap,
> 150 mm FOV, 512×256 matrix
> T2-weighted FSE, TR/TE=3,403/90, ET=11

- Axial view is suitable for delineation of the cruciate ligaments at the site of femoral insertion. Partial tear of anterior cruciate ligament, which may be difficult to assess in sagittal views, can be visualized. Also, evaluation of periarticular fluid collection, plicae, and patellofemoral joint can be performed.

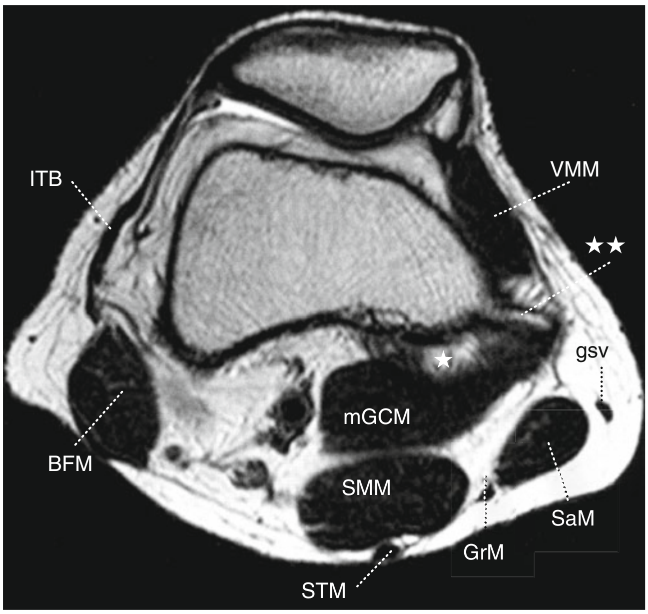


Fig. 1.16 *ITB* iliotibial band, *VMM* vastus medialis muscle, *BFM* biceps femoris muscle, *gsv* greater saphenous vein, *mGCM* medial head of gastrocnemius muscle, *SMM* semimembranosus muscle, *STM* semitendinosus muscle, *SaM* sartorius muscle, *GrM* gracilis muscle, ☆ distal femoral cortical irregularity at the site of mGCM attachment, ☆☆ site of adductor magnus muscle attachment

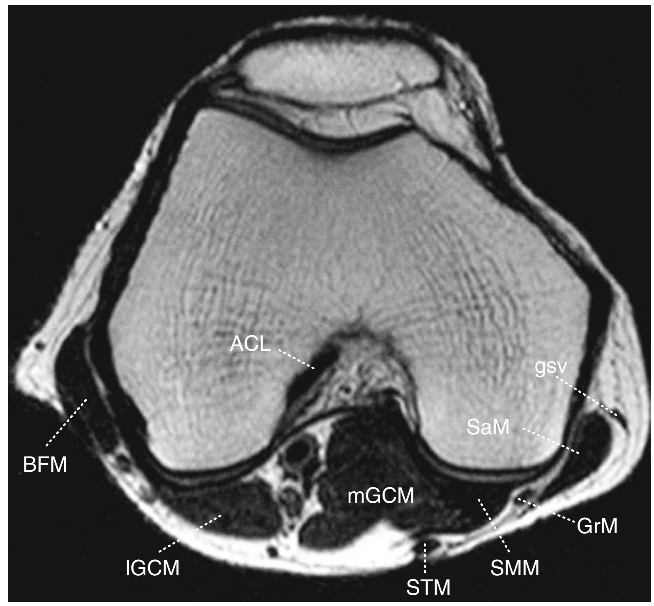


Fig. 1.17 *ACL* anterior cruciate ligament, *BFM* biceps femoris muscle, *lGCM* lateral head of gastrocnemius muscle, *mGCM* medial head of gastrocnemius muscle, *SMM* semimembranosus muscle, *STM* semitendinosus muscle, *gsv* greater saphenous vein, *SaM* sartorius muscle, *GrM* gracilis muscle

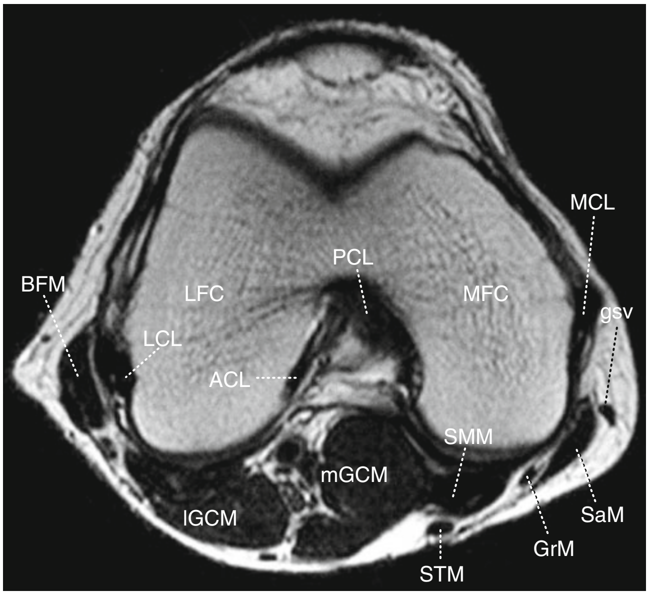
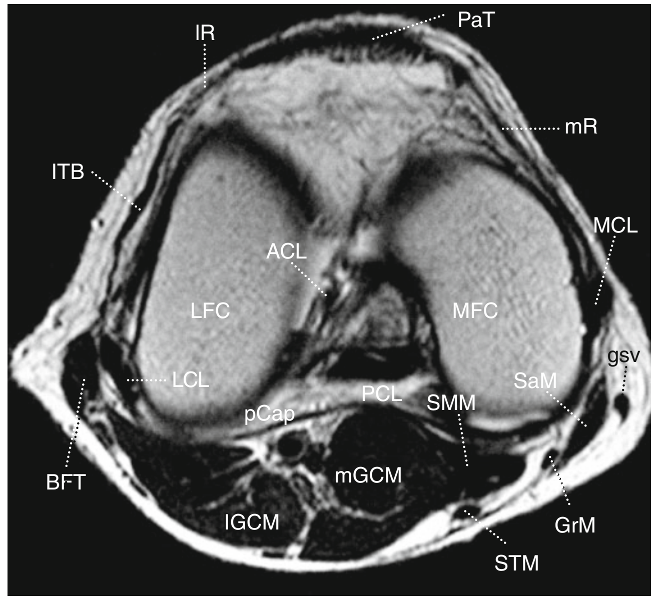


Fig. 1.18



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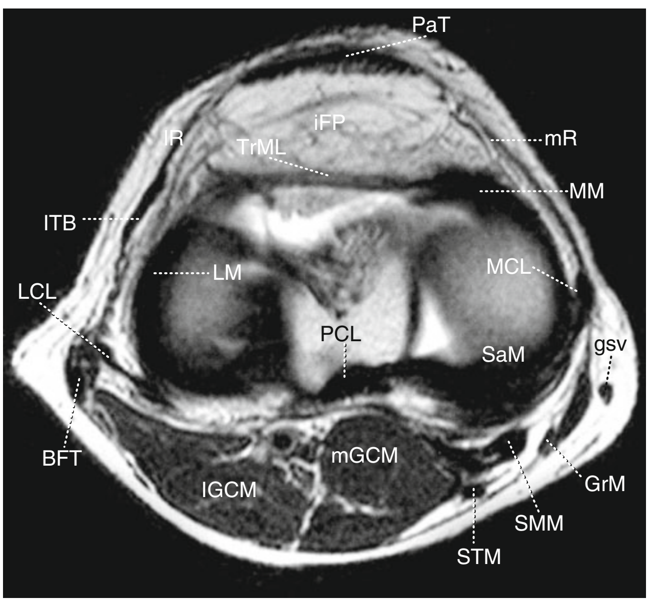

Fig. 1.20

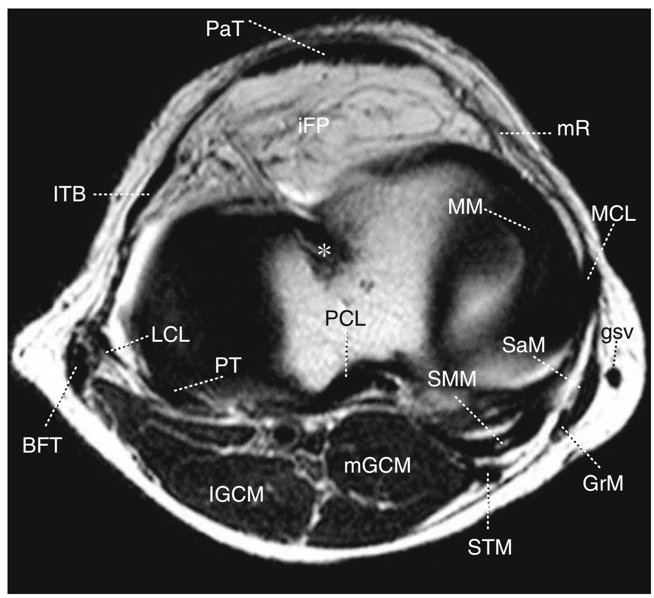

Fig. 1.21

ACL anterior cruciate ligament
PCL posterior cruciate ligament
MM medial meniscus
LM lateral meniscus
v*PaT* patellar tendon
mR medial retinaculum
lR lateral retinaculum
MCL medial collateral ligament
LCL lateral collateral ligament
pCap posterior capsule
iFP infrapatellar (Hoffa's) fat pad
MFC medial femoral condyle
LFC lateral femoral condyle

SaM sartorius muscle
SMM semimembranosus muscle
STM semitendinosus muscle
GrM gracilis muscle
mGCM medial head of gastrocnemius muscle
lGCM lateral head of gastrocnemius muscle
PT popliteus tendon
TrML transverse meniscal ligament
ITB iliotibial band
BFM/T biceps femoris muscle/tendon
gsv greater saphenous vein
* root of the anterior horn of the lateral meniscus

2 MRI Technical Considerations

2.1 Positioning and Fixation of the Knee

- It is not possible to diagnose ACL pathology using sagittal MR images acquired with fully or overextended knees.
- It is therefore important that the knee is slightly flexed within the coil (see Chap. 3 for more details).

2.2 Acquisition of Images in the Sagittal Plane

- It is essential that the range of image acquisition covers the entire femoral condyles and the tibial plateau from the medial to the lateral edge in the axial image (Fig. 2.1).
- In a typical adult male patient, more than 25 slices will be required at the slice thickness of 3 mm.
- In old days, acquisition of MR images in diagonal slices was severely limited by foldover artifacts. In those circumstances, it was necessary to externally rotate the distal lower limb by 15–20° to visualize ACL, which runs diagonally across the intercondyloid fossa, in sagittal images.
- Thanks to improvement in both hardware and software in MR imaging, this limitation has become less significant. However, one should be careful not to unnecessarily internally or externally rotate the knee to prevent distortion of ligamentous structures including cruciate and collateral ligaments (Fig. 2.2).

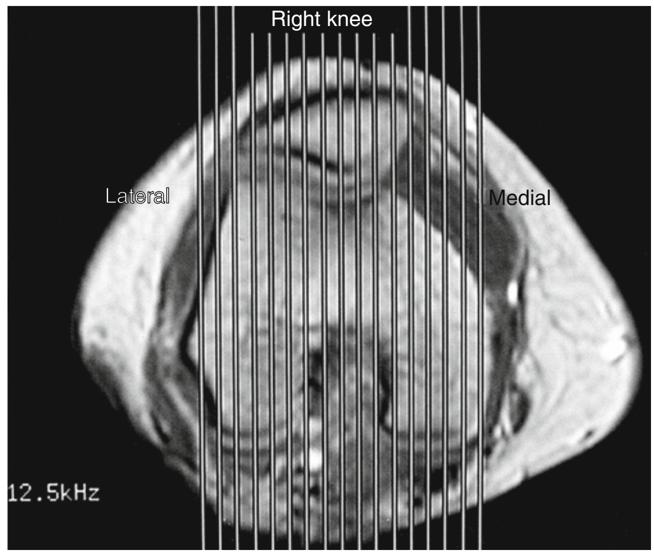

Fig. 2.1 **Setup of sagittal slices (right knee)**. In this example, there are only 17 slices, but ideally, there should be more than 25 slices at slice thickness of 3 mm to visualize fine changes in cartilage and menisci

- In sagittal acquisition, direction of phase encoding is usually anterior to posterior. In this case, however, images will be hindered by artifacts arising from blood flow in the popliteal artery and vein (Fig. 2.3). This can be prevented by setting the phase encoding direction to superior to inferior, but one should attempt to minimize foldover artifacts.

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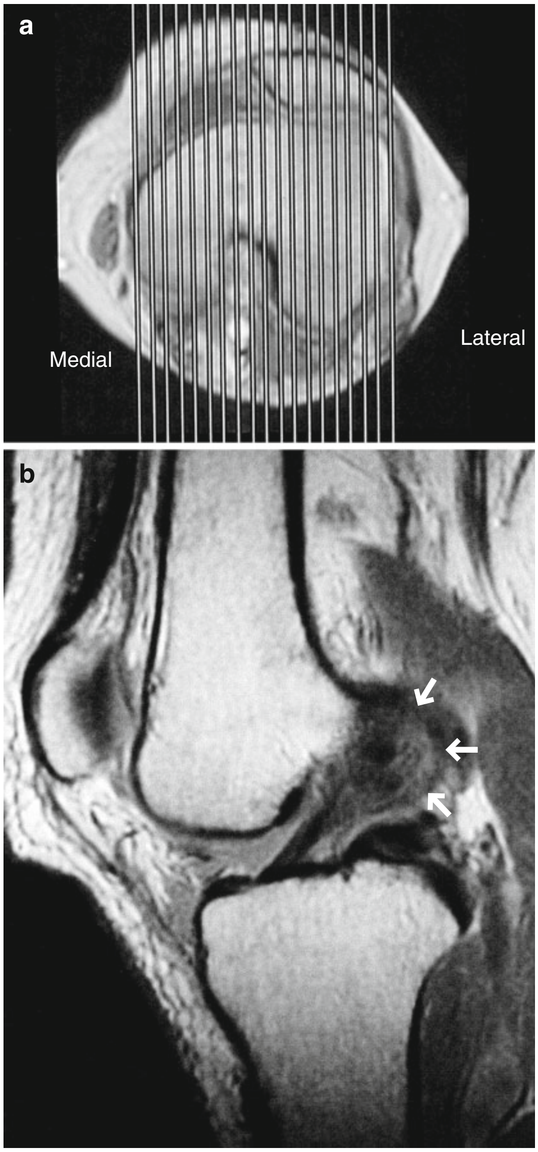

Fig. 2.2 Example of unsuccessful image acquisition due to excessive external rotation of the distal lower limb (right knee). Excessive external rotation of the distal lower limb leads to the direction of sagittal slice paralleling the lateral wall of intercondyloid fossa (**a**). In sagittal images, there will be partial volume effect from the bone cortex, which also hinders the delineation of ACL (**b**, *arrows*)

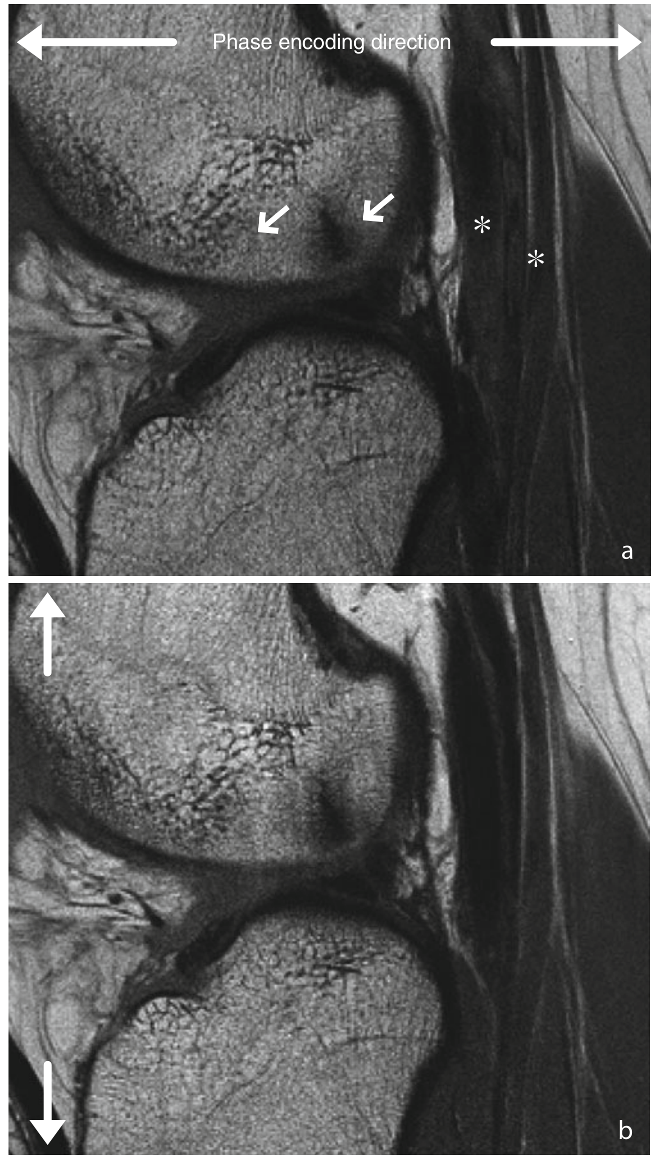

Fig. 2.3 Blood flow artifacts arising from inappropriate phase encoding direction. In sagittal acquisition, direction of phase encoding is usually anterior to posterior. In this case, however, images will be hindered by artifacts (**a**, *arrows*) arising from blood flow in the popliteal artery and vein (*). This can be prevented by setting the phase encoding direction to superior-to-inferior (**b**)

2.3 T1-Weighted and Proton Density-Weighted Fast Spin-Echo Sequences

- Although both T1- and T2-weighted images are automatically acquired at many institutions without much consideration, T1-weighted images do not have much value in delineating ligamentous and meniscal lesions.
- Normal ligaments and menisci show low intensity signals, and thus proton density- or intermediate-weighted images will allow better contrast with the surrounding cartilage and joint fluid (Fig. 2.4).
- Fast spin-echo (FSE) sequence requires much shorter acquisition time compare to conventional spin-echo (SE) sequence and enables acquisition of images with higher anatomical resolution. Thus, FSE is often utilized in knee MRI.

– However, one needs to be cautious regarding the following issues:
  1. Echo train length (ETL) should be kept to the minimum to prevent occurrence of blurring of image.

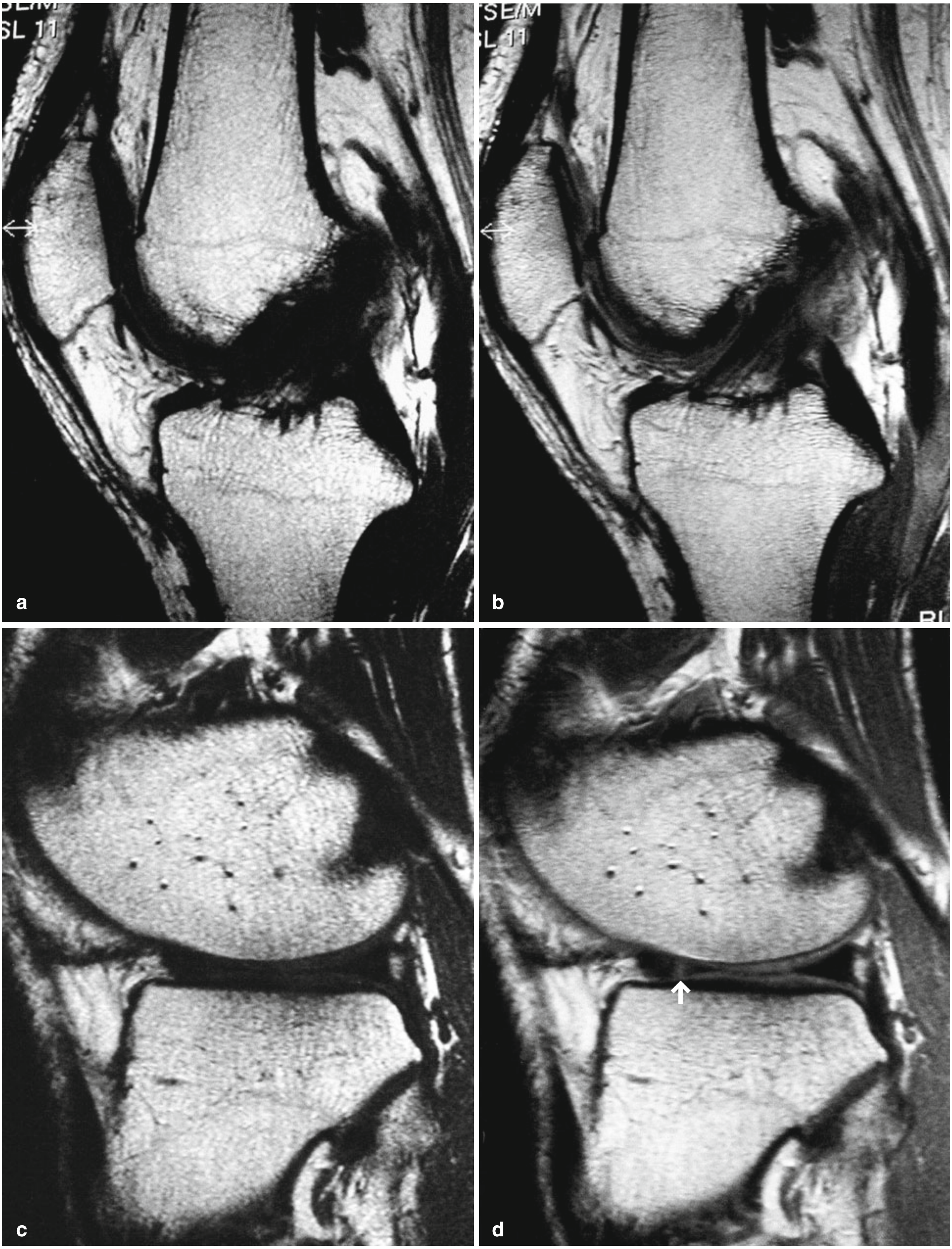

Fig. 2.4 Comparison of T1WI and intermediate-weighted (close to PDW) images. (**a**) and (**c**) T1WI (SE 350/14). (**b**) and (**d**) intermediate-weighted (close to PDW) images (FSE 1.324/17, ET 5). The latter demonstrates the margins of ACL and cartilage better than the T1WI, also with a better contrast of meniscal tear (**d**, *arrow*)

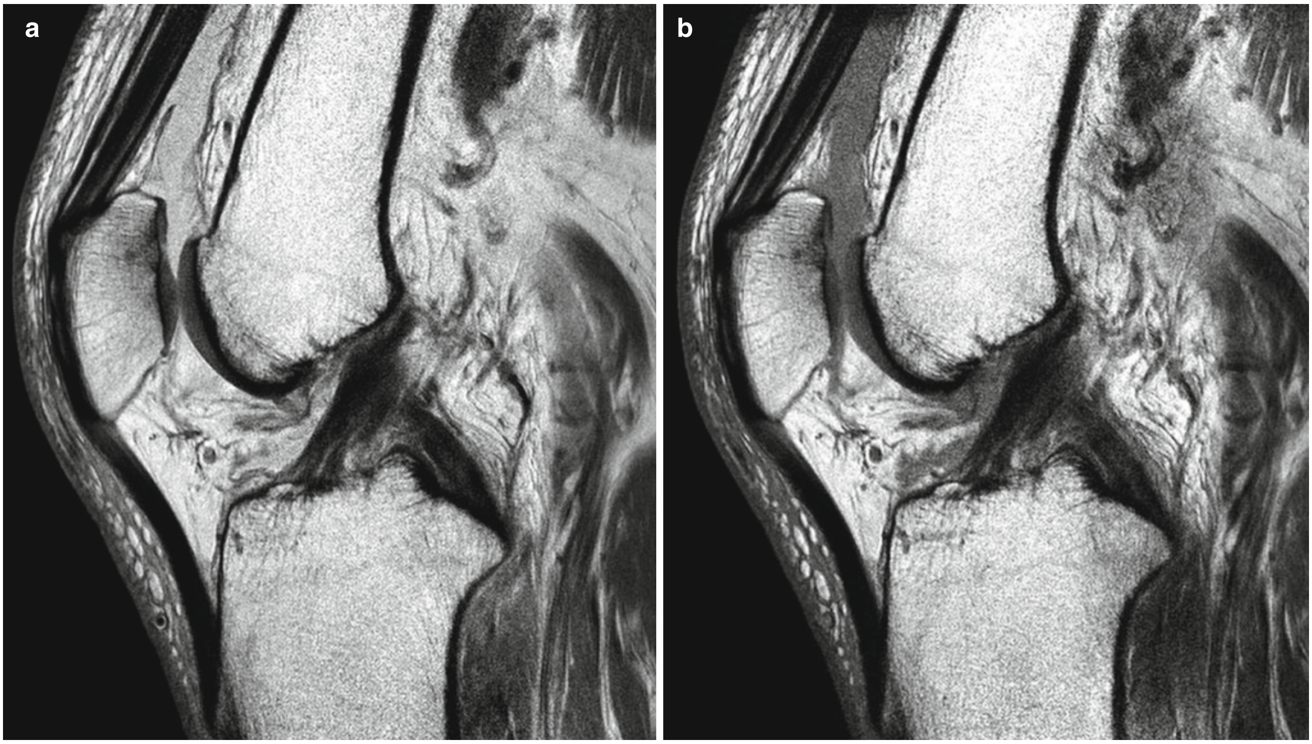

Fig. 2.5 PDWI with DRIVE (a), in which joint fluid is depicted as hyperintensity, and conventional PDWI (b). In (**a**), joint fluid is depicted as hyperintensity which creates better contrast with cartilage and ACL, allowing these structures to be more clearly delineated (FOV 150 mm, slice thickness 3 mm, slice gap 0.3 mm, 23 slices, 512 scan matrix, 864 ZIP, scan time 6 m)

2. Fat may be depicted as hyperintensity and may lower the contrast against meniscal lesions. This can be prevented by application of fat suppression.

- To acquire proton density-weighted FSE images, ETL should be kept to the minimum (max 5 or 6).
- Using proton density-weighted FSE sequences with water-highlighted technique (adding –90° pulse at the end of the echo train to forcefully recover vertical magnetization, such as DRIVE (Philips), FRFSE (GE), RESTORE (Siemens) and T2 Plus (Toshiba)), one can emphasize the T2-weighted contrast even with a relative short TR. Joint fluid will be depicted as hyperintensity and with better delineation of cartilage, ligaments, and menisci (Fig. 2.5).

2.4 Magic Angle Effect

- The magic angle effect is a phenomenon that results in artifactual hyperintensity in structures with ordered collagen, such as tendons and ligaments. This is because when collagen is oriented at 55° to the main magnetic field, dipole-dipole interactions becomes zero, resulting in a prolongation of T2 relaxation time.
- Care must be taken not to mistake this as a pathological finding such as a ligamentous tear.
- Magic angle effect is particularly notable with short TE sequences such as T1-weighted, proton density-weighted, or T2*-weighted (which is based on a gradient-recalled echo sequence using a low flip angle) sequences (Fig. 2.6).
- Magic angle effect can also affect the posterior horn of the lateral meniscus (Fig. 2.7).
- Magic angle effect can be avoided by using a long TE. Therefore, if magic angle effect is seen in T2*-weighted images, it can be eliminated by using SE sequences with a long TE or T2-weighted FSE sequences (Fig. 2.8).

References

Erickson SJ, et al. The “magic angle effect”: background and clinical relevance. Radiology. 1993;188:23–5.

Peterfy CT, et al. Magic-angle phenomenon: a case of increased signal in the normal lateral meniscus on short-TE MR images of the knee. AJR. 1994;163:149–54.

Fig. 2.6 **Magic angle effect affecting the patellar tendon**. T2*WI (GRE 560/14, flip angle 30°). Superior aspect of the patellar tendon exhibits localized hyperintensity (*arrows*). This phenomenon can be seen when the tendon is oriented at 55° to the main magnetic field (Bo, superior-inferior direction)

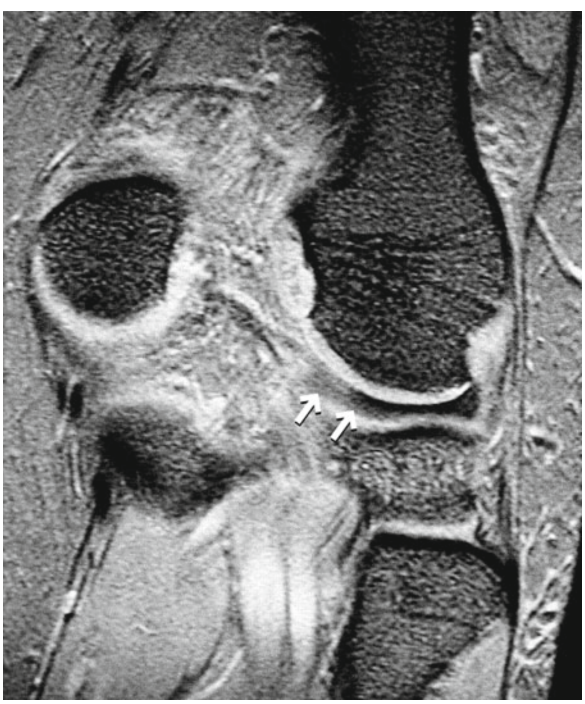

Fig. 2.7 **Magic angle effect affecting the posterior horn of the lateral meniscus**. Coronal T2*WI. Normal posterior horn of the lateral meniscus exhibits localized hyperintensity (*arrows*)

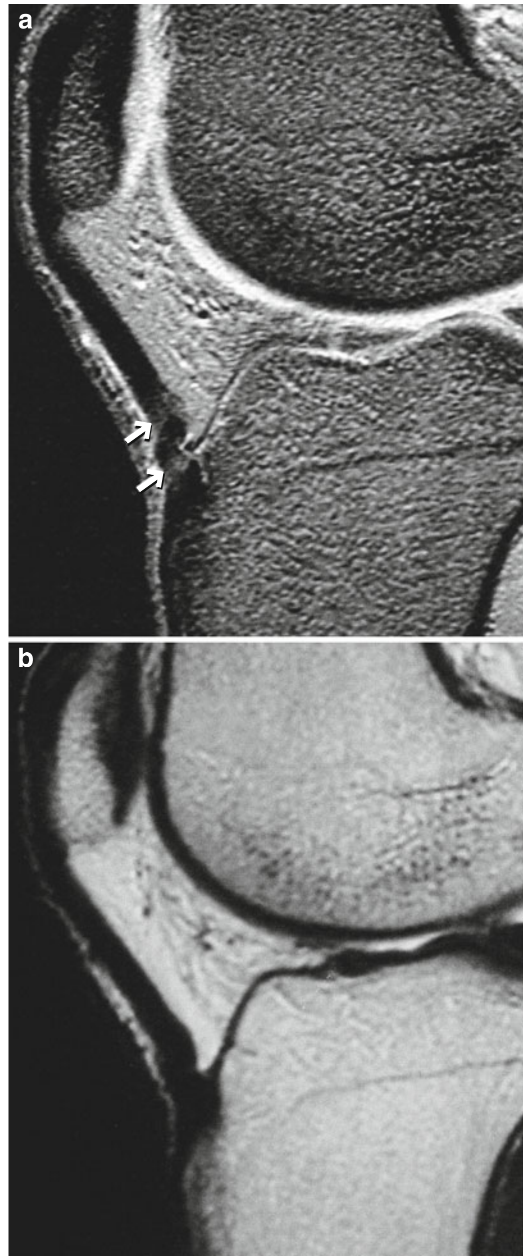

Fig. 2.8 **TE-dependent nature of the magic angle effect**. T2*WI (GRE 560/14, flip angle 30°) (**a**) and T2WI (FSE 3,000/90) (**b**). Localized hyperintensity at the inferior aspect of the patellar tendon seen in (**a**, *arrows*) disappears if TE is made longer (**b**)

T2-Weighted and T2*-Weighted Images

T2- and T2*-weighted images are useful sequences for knee imaging because it creates a good contrast between joint fluid (hyperintensity) and the lesions of ligaments and menisci. A gradient-recalled echo (T2*-weighted) sequence is particularly useful for delineating fine lesions. However, bearing in mind that the magic angle effect can cause an unwanted artifact, a long TE, SE, or FSE sequence should be added (either sagittal or coronal).

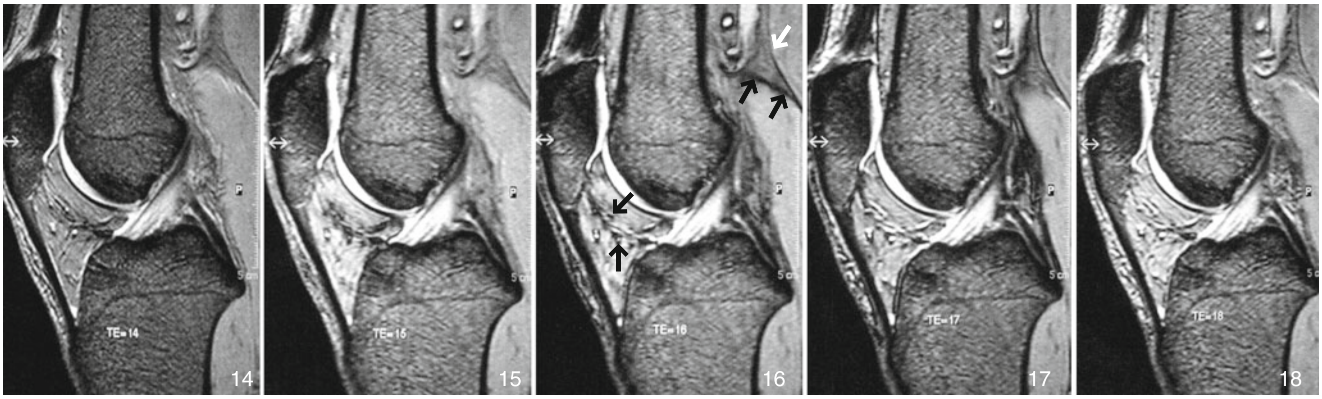

Fig. 2.9 TE-dependent variability of signal strengths in gradient-recalled echo sequence (From left, TE = 14, 15, 16, 17, and 18 ms). TE = 14 and 18 ms results in in-phase, while out-of-phase images will be created at TE = approx. 16 ms. When out-of-phase, signals from water and fat within the same pixel cancel out and the signals are lost. For example, the boundaries between subcutaneous fat and muscle or blood vessels will appear *black* ("boundary effect" (*black* and *white arrows*))

Table 2.1 TE (ms) representing in-phase and out-of-phase at 1.5 T

In-phase		4.5		9.0		13.5		18.0		22.5		27.0
Out-of-phase	2.3		6.8		11.3		15.8		20.3		24.8	

Table 2.2 TE (ms) representing in-phase at 1.0 and 1.5 T

In-phase at 1.0 T	6.8	13.5	20.3	27.0
In-phase at 0.5 T		13.5		27.0

2.5 In-Phase and Out-of-Phase Imaging

- In gradient-recalled echo sequences, signals from fat and water vary depending on TE.
- Resonance frequency of water is higher than that of fat by 3.5 ppm. This equates to about 220 Hz (63.9 MHz × 3.5 ppm) in a 1.5-T system.
- Thus, resonance frequencies of water and fat synchronize every 4.5 ms of TE (in-phase 220 Hz = 4.5 ms).
- When out-of-phase, signals from water and fat within the same pixel cancel out and the signals are lost. For example, the boundaries between subcutaneous fat and muscle or blood vessels will appear black ("boundary effect") (Fig. 2.9, Table 2.1).
- Multiply these values by 0.5 at 3.0 T, by 1.5 at 1.0 T, and by 3 at 0.5 T (Table 2.2)
- Note: TE = approx. 14 ms results in in-phase in any case

2.6 Usefulness of Axial Images

- Axial images add useful information to sagittal and coronal images, which are mainly used for assessment of ligaments running in the superior-inferior direction and menisci.
- Axial images are particularly suitable for delineation of the femoral attachment site of the cruciate ligaments, for example, partial tear of ACL which can be difficult to detect in sagittal images
- Cross-sectional areas of the hamstrings and patellar tendon, which is used for ACL reconstruction, can be measured
- Medial synovial plica and patellofemoral cartilage (the thickest cartilage of the knee joint) are clearly visualized in axial images and evaluation of patellar subluxation
- Fluid collection around menisci, including meniscal cysts, can also be clearly visualized

Reference

Roychowdhury S, et al. Using MR imaging to diagnose partial tears of the anterior cruciate ligament: value of axial images. AJR. 1997;168:1487–91.

2.7 Techniques for Fat Suppression

- Lesions that are present within the bone marrow, which comprises mostly fatty marrow, and subcutaneous fat should be assessed using fat suppression techniques.
- Chemical shift selective (CHESS) method, Chem Sat method = a method which utilizes the difference in resonance frequency between fat and water (224 Hz at 1.5 T) to add a suppress pulse only to fat signals.

Table 2.3 Comparison of fat suppression techniques

Technique	Pros	Cons
CHESS	Prolongation of scan time is little, and there is little limitation in the image acquisition techniques	Magnetic field inhomogeneity may lead to failure of fat suppression in an uneven fashion, particularly at the periphery of a large FOV
STIR	Homogeneous and almost perfect fat suppression can be expected	Need for addition of an IR pulse cause a number of restrictions in the image acquisition technique (especially the need for increased interslice gap and prolonged scan time)
Selective water excitation	Prolongation of scan time is minimal	Very sensitive to magnetic field inhomogeneity

- Short TI (tau) inversion recovery (STIR) = a method based on IR technique which sets the TI (tau) to be the null point for the fat signal.
- There is a new method called water selective excitation. This is an addition of an excitation pulse to the water, rather than adding a suppression pulse to the fat. Excitation pulses, which are called binomial pulse (e.g., 1-1, 1-2-1, 1-3-3-1), are split, and the phase difference between the resonance frequencies of water and fat is utilized (Fig. 2.14). Each technique has pros and cons (Table 2.3).

2.8 Metallic Artifacts

- Inevitably, a metallic artifact will arise if there is a ferromagnetic component within the human body.
- Staples used in the ACL reconstruction surgery will distort the image due to localized magnetic field inhomogeneity. In this case, characteristic "signal dropout" in the direction of frequency encoding and overlapping of the artifact in a wider range in the phase encoding direction (Fig. 2.10).
- Metallic artifacts are particularly notable with the gradient-recalled echo technique, which is sensitive to magnetic field inhomogeneity.
- Very small metallic particles may be incidentally discovered at MR imaging (Fig. 2.11). Metallic artifacts arising from such small objects are localized to a small area, but one needs to be careful because it can cause a burn injury.

Fig. 2.10 Metallic artifact. Status post-ACL reconstruction. (**a**) Surgical stables are observed in the femur and tibia in this lateral knee radiograph. (**b**) On sagittal PDWI, image distortion due to localized magnetic field inhomogeneity (*arrows*) and signal dropout are seen. The phase encoding direction is superior-inferior, while the frequency encoding direction is anterior-posterior. (**c**) Metallic artifacts are particularly notable with the gradient-recalled echo technique, which is sensitive to magnetic field inhomogeneity (coronal T2*WI)

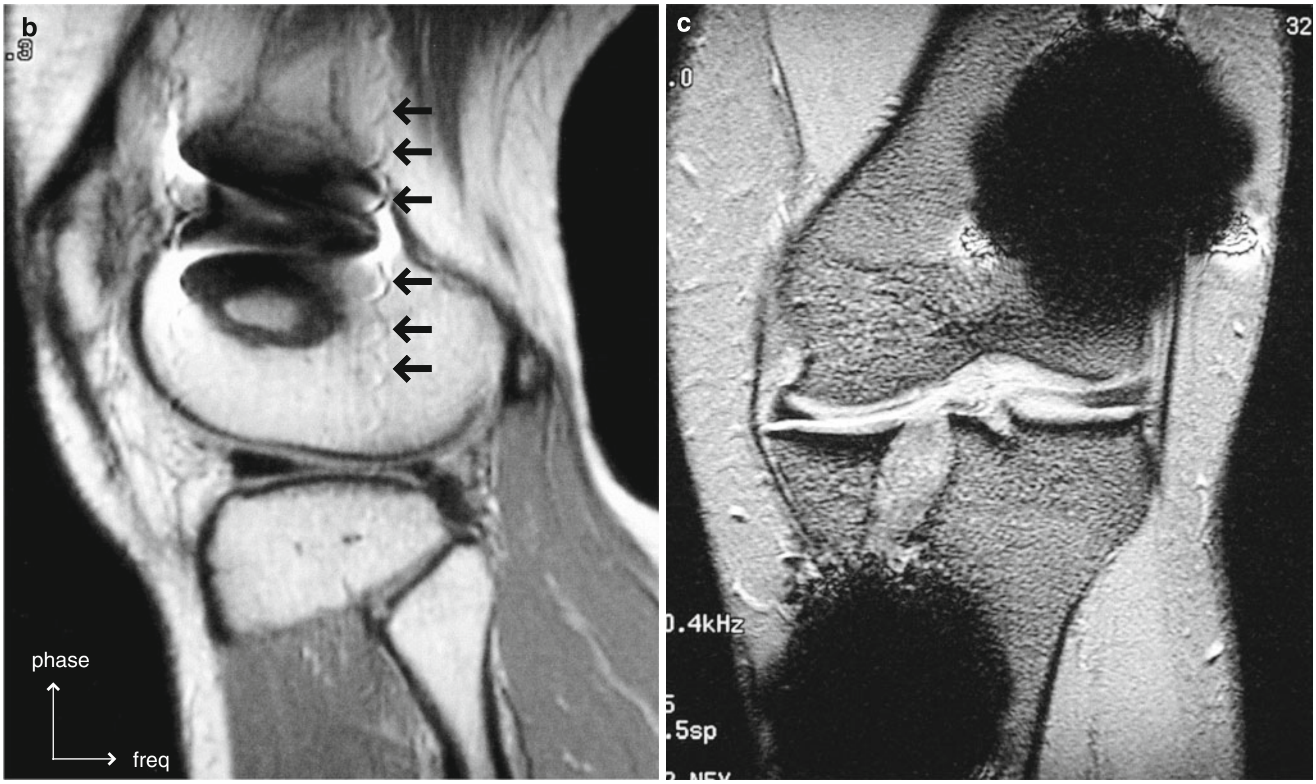

Fig. 2.10 (continued)

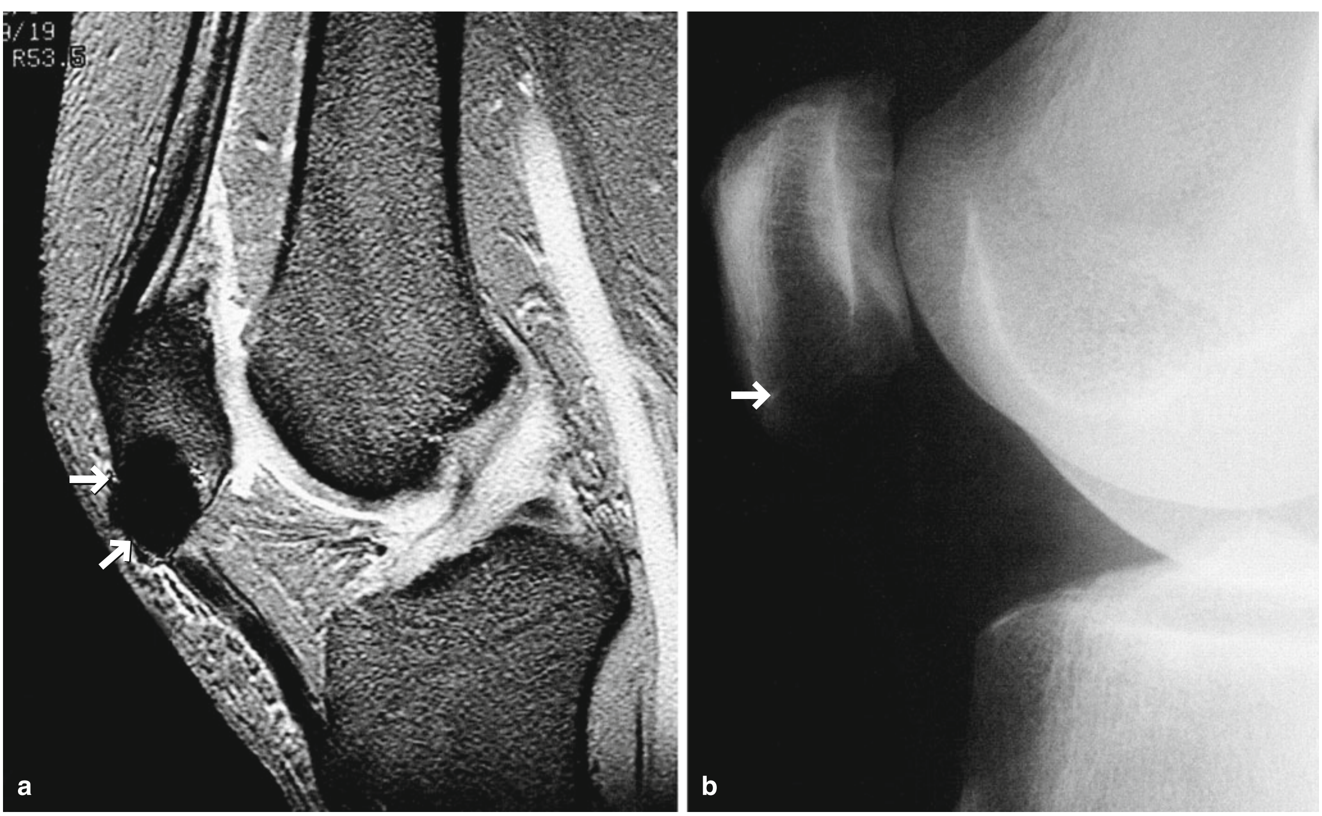

Fig. 2.11 Metallic artifact due to a very small metal particle. (**a**) In this T2*WI, there is a localized signal dropout and image distortion at the inferior aspect of the patella (*arrows*). (**b**) This was due to a very small metal particle (*arrow*) which is just visible on the lateral radiograph

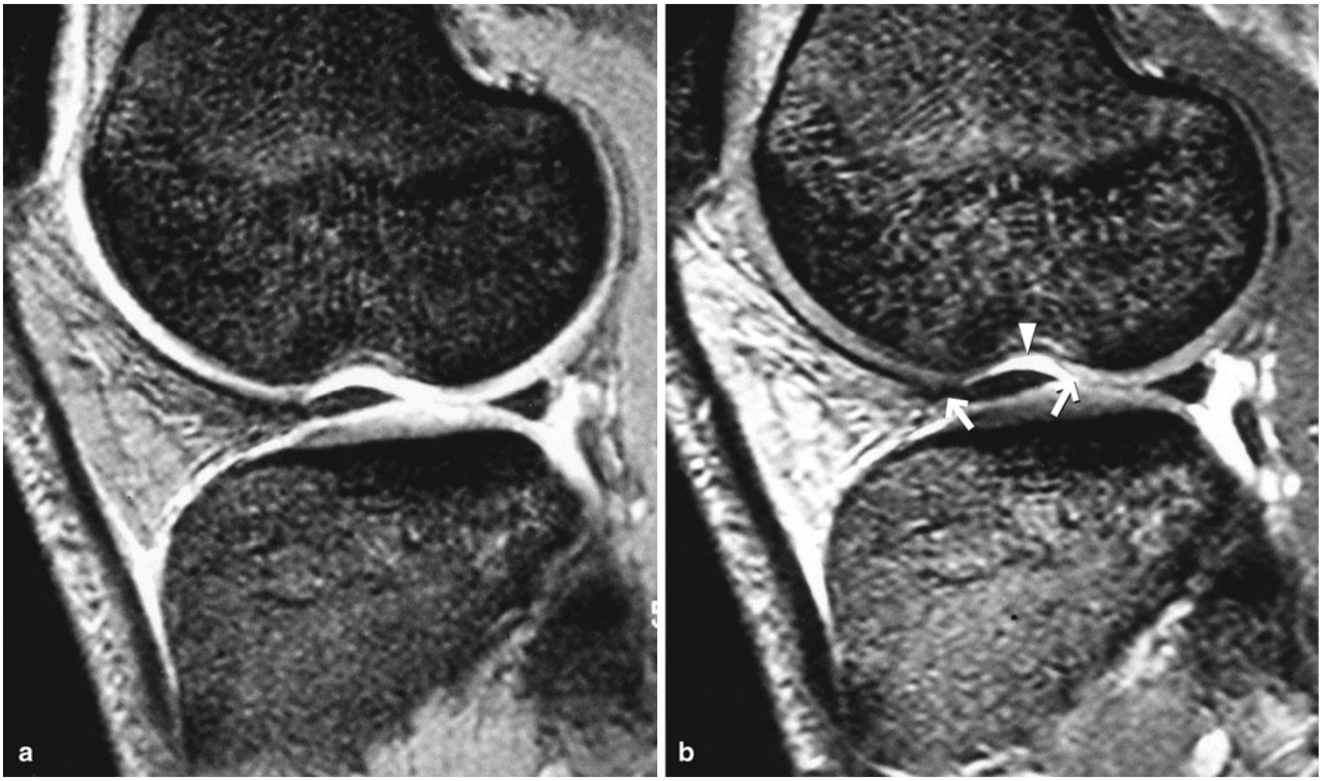

Fig. 2.12 **Delineation of cartilage using the MTC method**. (**a**) T2*WI (GRE, 545/15, flip angle 30°) and (**b**) T2*WI with added MTC (same parameter as **a**). In T2*WI, cartilage and joint fluid are both exhibiting hyperintensity. By addition of MT effect, cartilage signal is specifically suppressed (*arrows*) and improves the contrast against hyperintense joint fluid (*arrowhead*)

2.9 Magnetization Transfer Contrast (MTC) Method, MT Effect

- MRI mostly visualizes protons of free water molecules.
- Other than free water, there are water molecules that are bound to high-molecular-weight proteins, and their resonance frequency ranges a few thousand Hz.
- In MTC method, contrast is created by suppression of signals from free water by irradiating off-resonance pulse (i.e., the pulse that is more than a few thousand Hz away from the resonance frequency of free water molecules).
- MTC method improves the contrast on T2-weighted images between joint fluid and hyaline cartilage, which is mainly composed of collagen and proteoglycan, by specifically suppressing signals from cartilage (Fig. 2.12). However, by irradiating MT pulses:
  1. Heat will be generated in the body as determined by the specific absorption rate (SAR)
  2. Scan time will be slightly prolonged
- FSE techniques that utilize many 180 degree pulses also involve the MT effects

2.10 Imaging Techniques for Cartilage

- The two most commonly used MR sequences for cartilage imaging are the following (Table 2.4) (Fig. 2.13):
- Balanced steady-state free precession (3D balanced gradient echo) technique offers a new method to delineate cartilage and includes sequences such as TrueFISP (Siemens) and Balanced FFE (Philips). Use of a relatively large flip angle leads to depiction of joint fluid as hyperintensity and enables acquisition of high-contrast images. Also, TR can be shortened and thus high-quality cartilage imaging within a short scan time can be achieved.

Table 2.4 Comparison of diagnostic performance of T2-weighted FSE and T1-weighted GRE sequences

	Sensitivity for cartilage defect detection	Specificity for cartilage defect detection
T2-weighted FSE with MTC	94%	99%
Fat-suppressed T1-weighted GRE	75–85%	97%

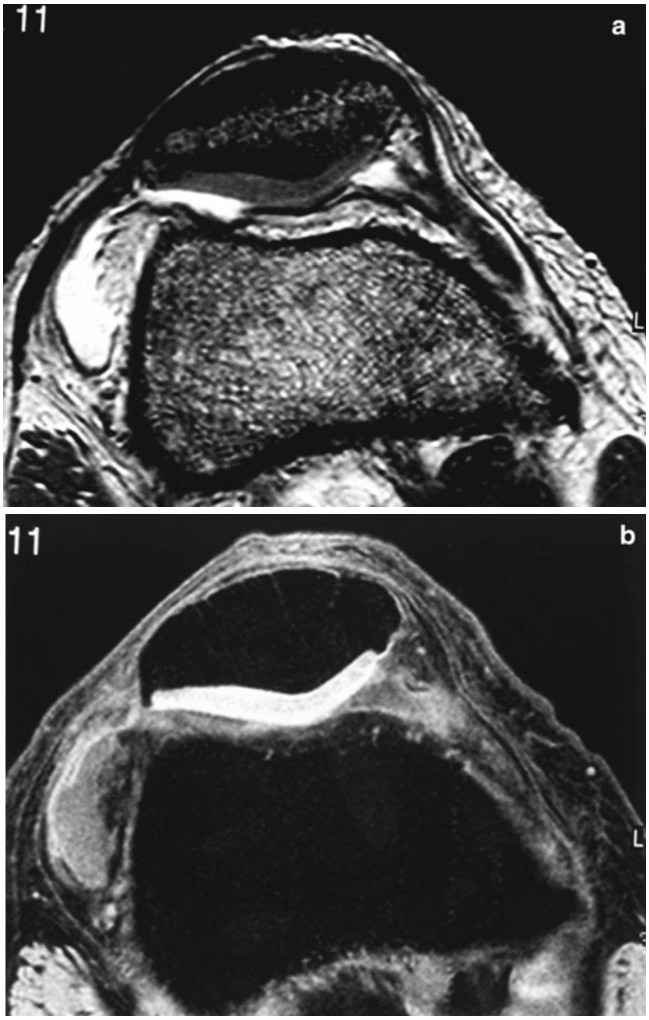

Fig. 2.13 Imaging of hyaline cartilage. In FSE T2WI with MTC (**a**), cartilage appears hypointense in contrast to hyperintense joint fluid. In FS GRE T1WI (**b**), cartilage appears hyperintense. (**a**) FSE T2WI with MTC (TR/TE = 38/14, flip angle 30°, off-resonance MTC, scan time 4 min 32 s). (**b**) FS GRE T1WI (TR/TE = 32/6.8, flip angle 25°, fat suppression, scan time 5 min 03 s). Both were 1.5 mm slice thickness, 130 mm FOV, and 256 x 512 matrix

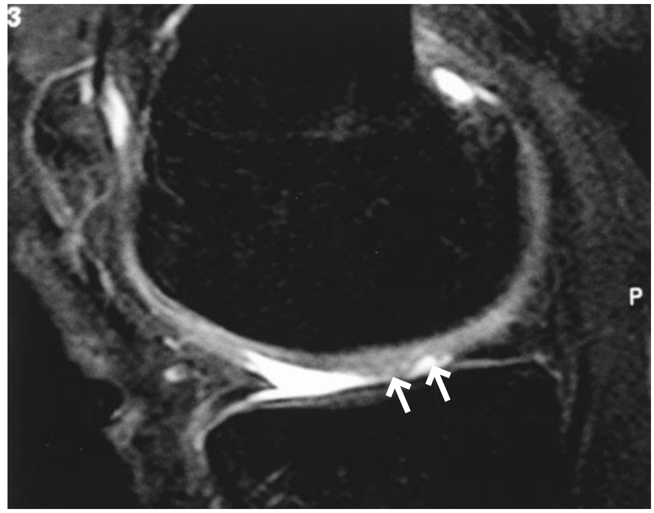

Fig. 2.14 Delineation of cartilage using 3D balanced gradient-echo sequence. Balanced FFE (TR/TE = 12/6.0, flip angle 70°, 1-3-3-1 selective water excitation applied, slice thickness 1.6 mm, FOV 140 mm, matrix 256 × 512, scan time 4 min 06 s). Joint fluid appears hyperintense, creating a good contrast against superficial cartilage damage (*arrow*)

Reference

Disler DG, et al. Fat-suppressed three-dimensional spoiled gradient-echo MR imaging of hyaline cartilage defects in the knee: comparison with standard MR imaging and arthroscopy. AJR. 1996;167:127–32.

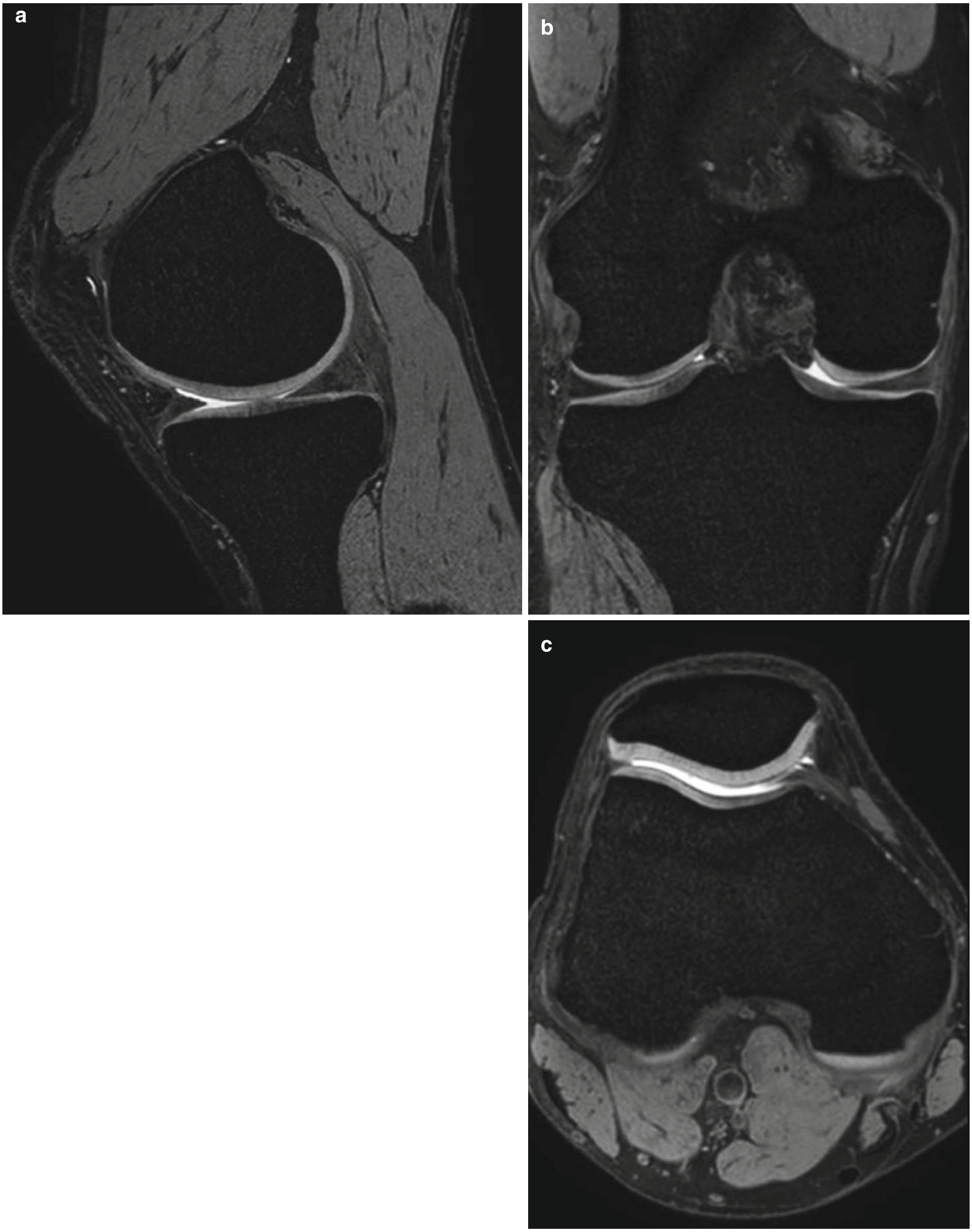

Fig. 2.15 3D FS GRE T2*WI of the knee. (**a**) sagittal (TR/TE = 19/7.0 + 13.3), (**b**) coronal reconstruction image, and (**c**) axial reconstruction image. (**b**) and (**c**) were reconstructed from the sagittal image (260–320 slices, depending on the size of the knee) to enable evaluation of cartilage, menisci, synovium, and intra-articular free bodies

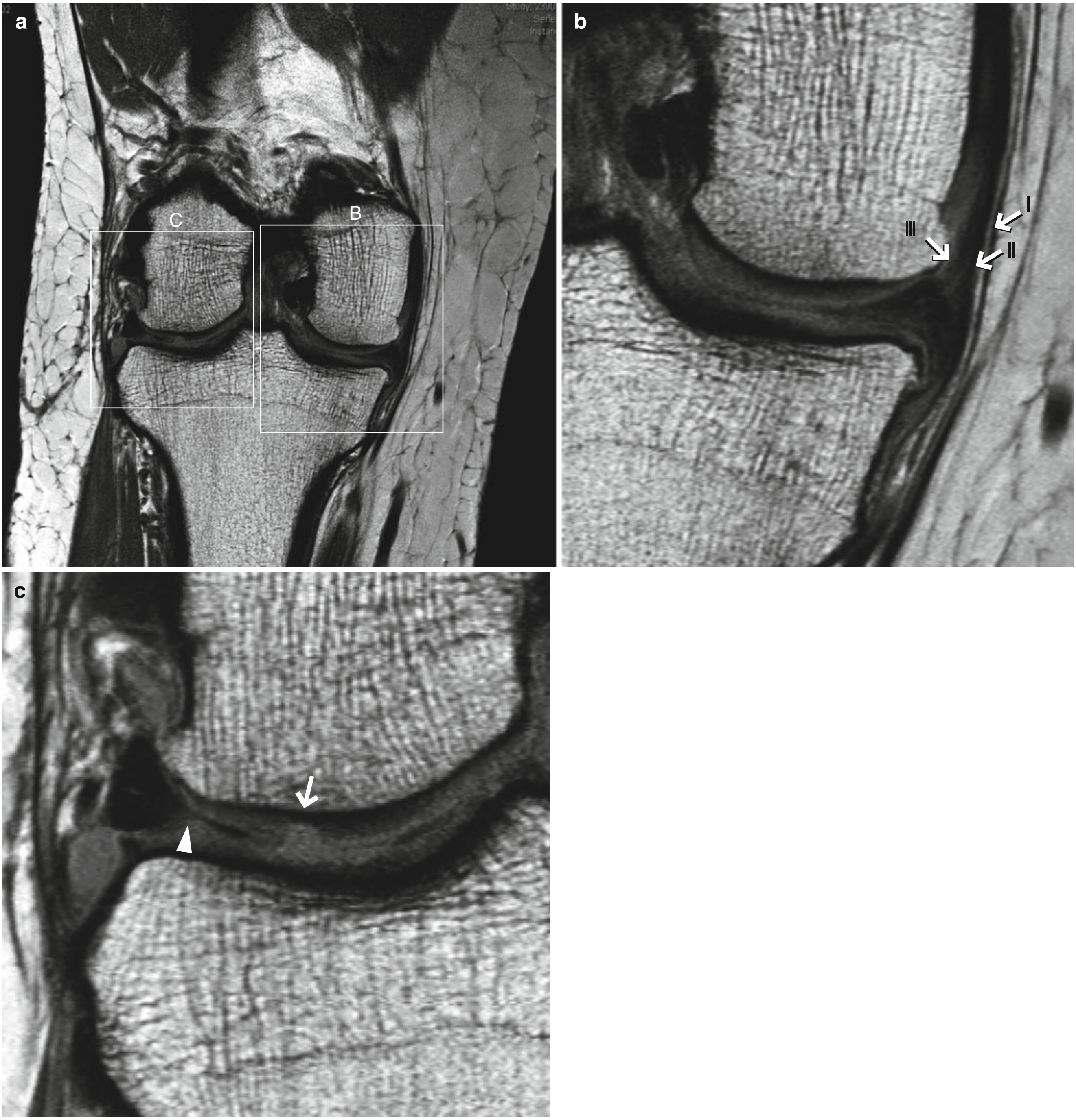

Fig. 2.16 **3.0 T MRI of the knee**. Coronal image (**a**) and the magnified images (**b** and **c**). (**a**) FSE 2,025/20, 3.0/0.3, FOV 160, matrix 1024 × 1024. (**b**) Magnified image of the medial compartment shows three layers of the medial collateral ligament (I, II, III, *arrows*). The quality of image is equivalent to that offered by high-resolution images acquired using microscopy coil (see Chap. 5, Fig. 5.3). (**c**) Magnified image of the lateral compartment clearly shows focal cartilage defect of the lateral femoral condyle (*arrow*) and distortion of lateral meniscal free edge (*arrow head*)

Advantages and Disadvantage of 3 T MRI

- Improved signal-to-noise ratio:
  - High-resolution image: thin slice thickness, small FOV, 1024 matrix size
  - Shorter scan time, increased acquisition series
- Prolongation of T1 values and slight shortening of T2 values (but this is not a significant disadvantage for knee imaging)
- Chemical shift becomes more notable (and thus adjustment of bandwidth and the use of fat suppression is required)
- Lower RF infiltration, signal inhomogeneity (multichannel, parallel imaging may be needed)
- Increased magnetization effect (increased metal-related artifact, application to susceptibility imaging)
- Increased SAR (beware of excessive heat production)

Reference

Ramnath RR, et al. Accuracy of 3-T MRI using fast spin-echo technique to detect meniscal tears of the knee. AJR. 2006;187:221–5.

Image Acquisition Protocol for the Most of Images Used in This Book

1.5 T

Slice thickness 3.0–3.5 mm, slice gap 0.3–0.5 mm
Sagittal images: 23 slices, coronal and axial images: 18 slices
FOV 140–150 mm, matrix 512 × 256 or 864 × 512

- Intermediate-weighted (close to proton density-weighted, and thus in this book, it will be called "proton density-weighted") FSE: 1,300–2,500/13–17, ET 4–6 (+DRIVE if appropriate).
- Fat-suppressed proton density-weighted images: fat-suppression (e.g., 1-3-3-1 water excitation pulse) is added to the above sequence.
- T2*-weighted image: GRE 500–700/14–15, flip angle 25–35°.
- T2-weighted images: FSE 2,500–3,500/90–100, ET 10–15.
- T1-weighted images (tumors and bone marrow pathologies, only with contrast-enhanced imaging): SE 350–500/11–17.

3.0 T

2D imaging
Slice thickness 2.0–2.5 mm, slice gap 0.2–0.3 mm
Sagittal images: 26–30 slices, coronal and axial images: 26 slices
FOV 150 mm, matrix 864 × 512 or 1024 × 864

- Proton density-weighted FSE: 2,400–2,800/17–30, ET 4–7 (+DRIVE if appropriate).
- Fat-suppressed proton density-weighted images: fat suppression (e.g., 1-3-3-1 water excitation pulse) is added to the above sequence.
- T2-weighted and T1-weighted images: almost identical to 1.5 T imaging.

3D imaging
Slice thickness 0.6 mm/–0.3 mm (overlapping)
Sagittal images: 280 slices, coronal and axial images: reconstructed from the sagittal images, FOV 150 mm, matrix 512 × 512 (0.3 × 0.3 × 0.3 mm isovoxel)

- Fat-suppressed T2*-weighted 3D GRE: 19/7.0 + 13.3 (addition of first echo and second echo), fat suppression (e.g., 1-3-3-1 water excitation pulse)

Abbreviations: *SE* spin echo, *FSE* fast spin echo, *GRE* gradient echo, *ET* echo train length

3 Anterior Cruciate Ligament (ACL)

3.1 Anatomy

- ACL is an intra-articular extrasynovial structure.
- Its mean length is 38 mm and width is 11 mm. Its fibers run in a spiral fashion for the entire length.
- Volume of ACL is larger in men than women, in proportion to the difference in height.
- ACL has two main fiber bundles: anteromedial bundle (AMB) and posterolateral bundle (PLB) (Fig. 3.1). On MRI, it may occasionally be possible to differentiate these two bundles (Fig. 3.2).
- AMB forms the anterior border of the ACL, and it is easily visualized in sagittal images and also easily damaged.
- ACL runs diagonally from intercondylar region of the femur from posterolateral to anteromedial direction.
- ACL will be subject to the maximum tension at maximum extension and at 90-degree flexion. This tension mainly acts on AMB. At 45-degree flexion, ACL becomes slightly relax.
- Femoral attachment of the ACL is approximately 23 mm long, which is smaller than tibial attachment site, making it more vulnerable to injury. About 80% of ACL damage in skiing injury occurs at the femoral attachment site (Fig. 3.3a).
- ACL attaches to the tibia at the site spreading like a fan between the tibial spine and the anterior horn of the medial meniscus. The length of the attachment site is on average 30 mm (i.e., larger than that at the femoral attachment, Fig. 3.4).

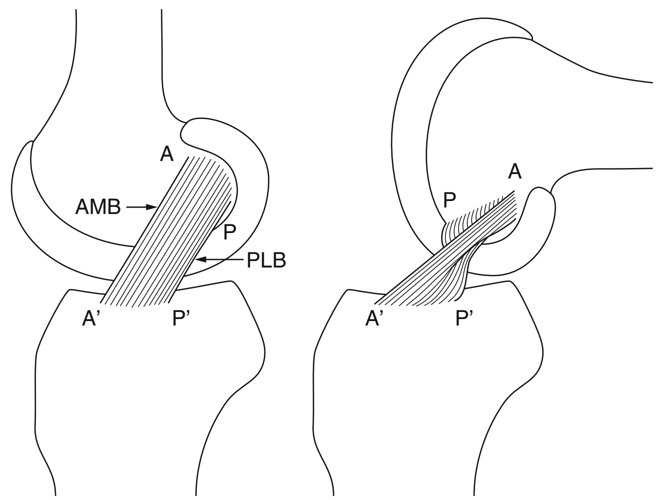

Fig. 3.1 Two fiber bundles of ACL. The anteromedial bundle (*AMB*) forms the anterior portion of the ACL, while the posterolateral bundle (*PLB*) forms the posterior portion. Overall, ACL is subject to the maximum tension at the maximum extension and 90-degree flexion, and the tension mainly acts on the AMB, resulting in frequent injury of AMB (Figure modified from Girgis et al. 1975)

References

Fayad LM, Rosenthal EH, Morrison WB, Carrino JA. Anterior cruciate ligament volume: analysis of gender differences. J Magn Reson Imaging. 2008;27:218–23.

Girgis FG, Marshall JL, Monajem A. The cruciate ligaments of the knee joint. Anatomical, functional and experimental analysis. Clin Orthop Relat Res. 1975;106:216–31.

Kennedy JC, Weinberg HW, Wilson AS. The anatomy and function of the anterior cruciate ligament. J Bone Joint Surg. 1974; 56-A:223–35.

M. Niitsu et al., *Magnetic Resonance Imaging of the Knee*,
DOI 10.1007/978-3-642-17893-1_3, © Springer-Verlag Berlin Heidelberg 2013

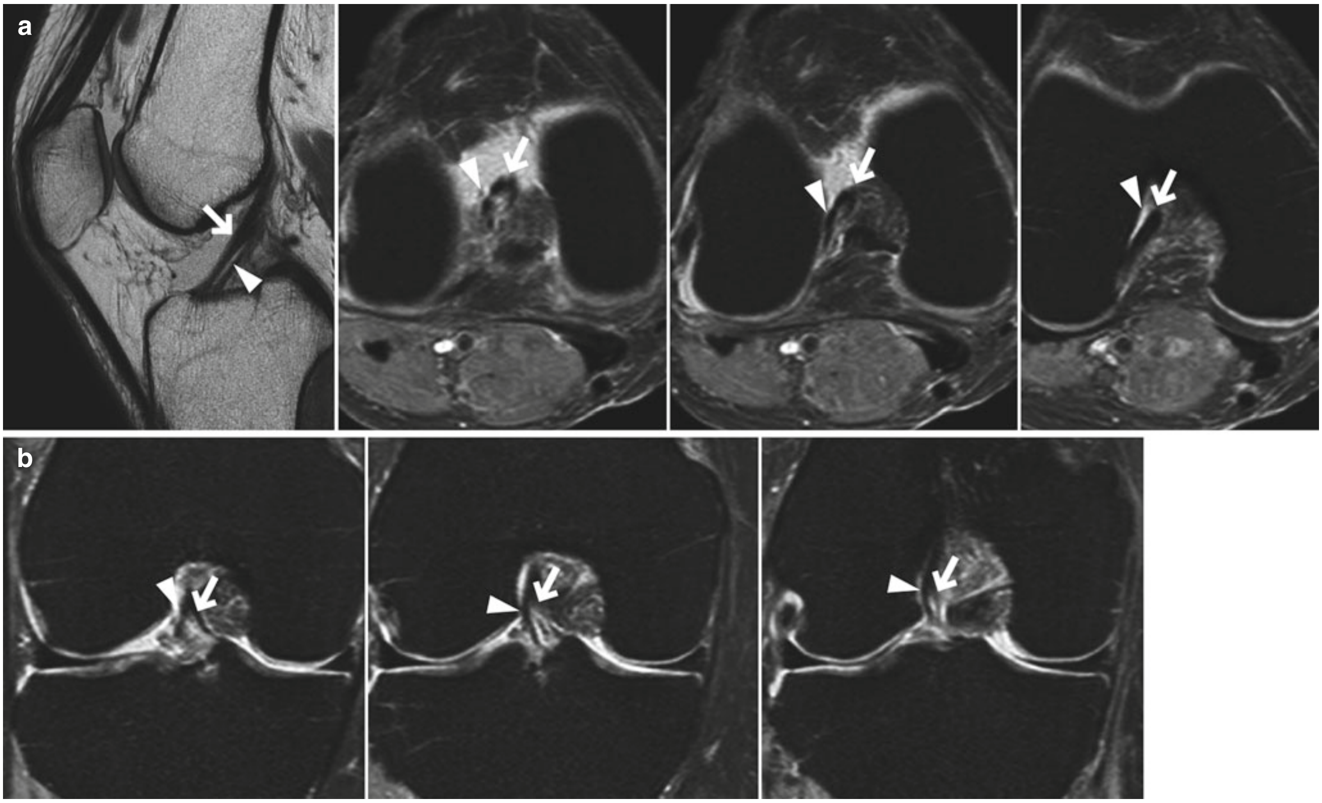

Fig. 3.2 Two fiber bundles of ACL on MRI. AMB (*arrows*) and PLB (*arrowheads*) can sometimes be differentiated on MRI. These bundles spread out at the tibial attachment site, but the fibers run in a spiral fashion and may appear as one bundle at the femoral attachment site

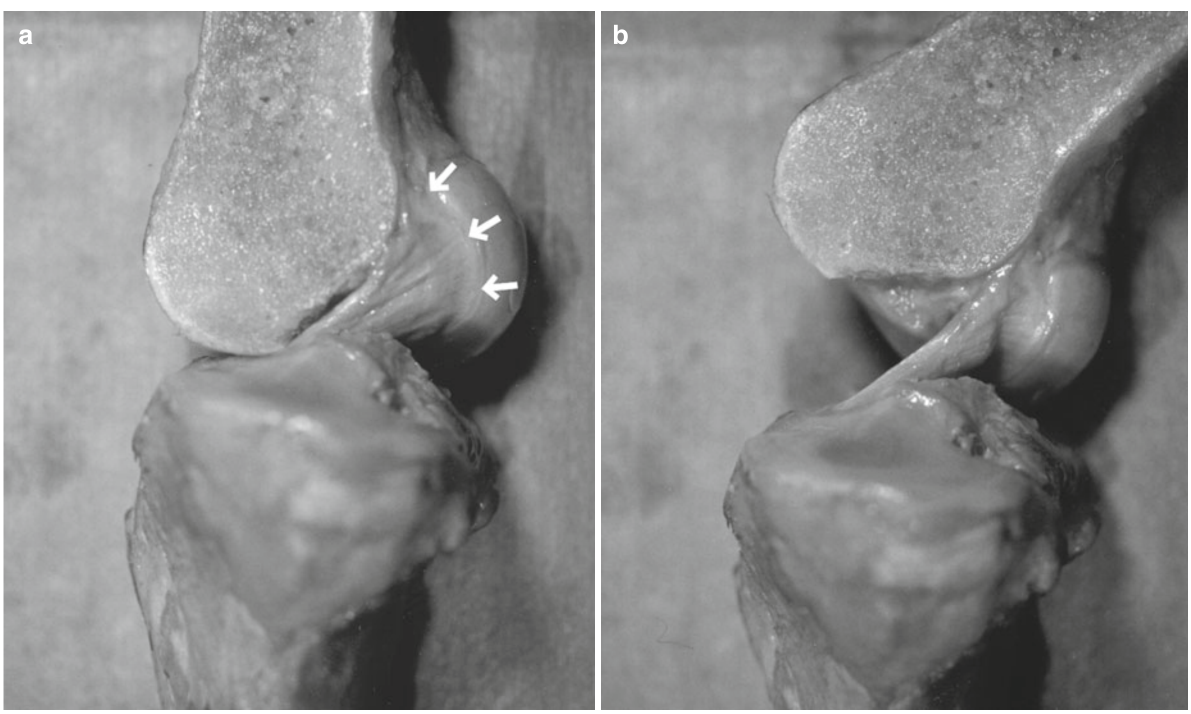

Fig. 3.3 ACL of the cadaveric knee. (**a**) Extended and (**b**) lightly flexed cadaveric knee joint. ACL is a ligament that runs diagonally within the intercondylar space. At the femoral attachment site, peripheral portion of the fiber bundle attaches to the medial surface of the lateral femoral condyle, in a fanlike fashion (**a**, *arrows*). When the knee is flexed, ACL becomes distant from the ceiling of the intercondylar space, and it appears thicker, making it easier for us to visualize it in the sagittal MRI (**b**)

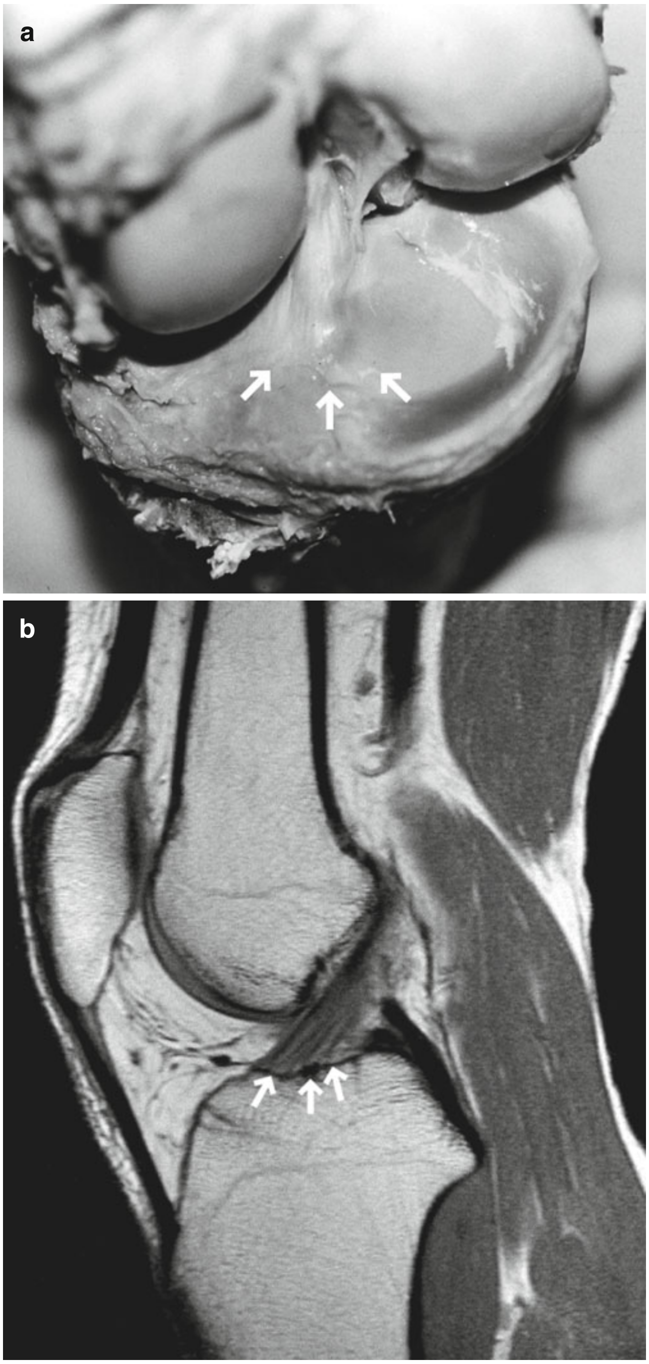

Fig. 3.4 **Tibial attachment site of the ACL**. (**a**) Cadaveric knee and (**b**) PDWI of a human subject. ACL attaches to the tibia at the site spreading like a fan between the tibial spine and the anterior horn of the medial meniscus (*arrows*). This configuration enables a firm attachment

3.2 Image Acquisition

- Most vendors supply a dedicated cylindrical knee coil.
- When the knee is imaged using the cylindrical knee coil, the knee tends to be fixed in an extended position (Fig. 3.5a).
- If the sagittal images of the extended knee is acquired:

1. The anterior border of the ACL will be in touch with the ceiling of the intercondylar space, making it difficult to grasp the overall picture of the ACL. This is an important issue because AMB forms the anterior portion of the ACL and is vulnerable to injury.
2. Visualization of the femoral attachment site of the ACL becomes unclear due to partial volume effect between ACL and the medial surface of the lateral femoral condyle.
3. Intrasubstance hyperintensity is often observed within ACL, and this is thought to be due to magic angle effect (see Chap. 2).

- By using a pad or other supporting objects, the knee can be fixed at max 30° (average 15°) of flexion while using the knee coil inside the superconducting magnet (Fig. 3.5b).
- When the knee is lightly flexed, ACL becomes distant from the ceiling of the intercondylar space, and it appears thicker, making it easier for us to visualize it in the sagittal MRI. The flexed position also enables clearer visualization of the femoral attachment site of ACL (Fig. 3.6).
- In analogy, the ACL looks like a flat tape at the femoral attachment site, but as it becomes more distant from the ceiling of the intercondylar space, it becomes like a rope as the fibers are twisted around the longitudinal axis. This is why visualization of ACL in sagittal MRI becomes easier when the knee is slightly flexed.
- Slight knee flexion does not adversely affect the visualization of PCL or menisci.

Reference

Niitsu M, Ikeda K, Fukubayashi T, et al. Knee extension and flexion: MR delineation of normal and torn anterior cruciate ligaments. J Comput Assist Tomogr. 1996;20:322–7.

Appropriate Clothes for MRI Examination

- Stockings or socks covering the knee should be removed because they can lower the image quality.
- A "pants-style" examination costume should be used so that the cables from coil do not touch the patient's skin to cause burns.
- Dignity should be preserved during examination (especially female patients).

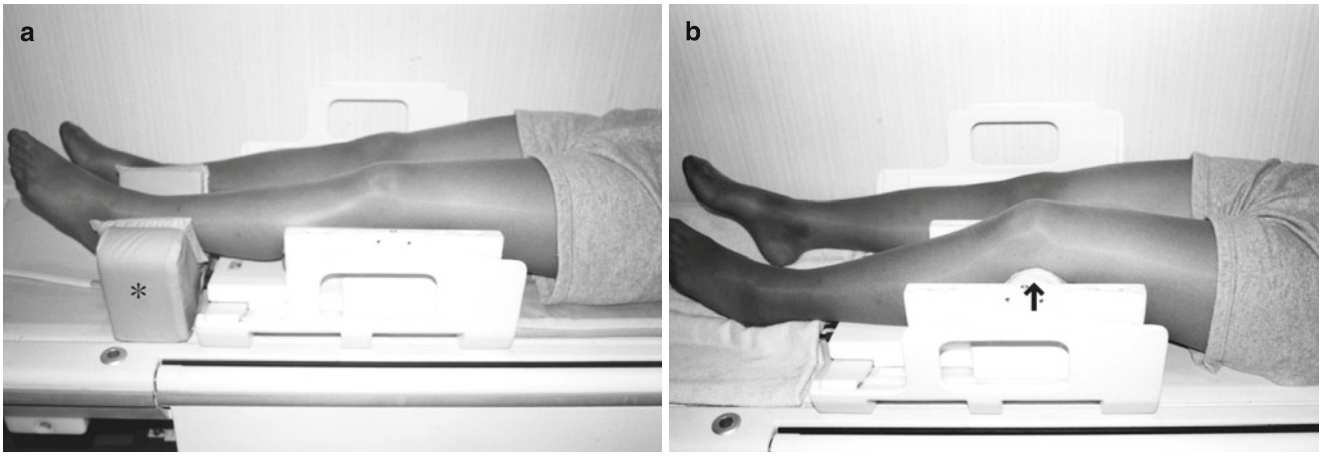

Fig. 3.5 (**a**) **Cylindrical knee coil with an ankle holder**. Most vendors supply a cylindrical knee coil with an ankle holder. Using these by following manufacturer's user instruction, the knee tends to be fixed at an extended position. (**b**) **Cylindrical knee coil with a small knee pad**. A small pad is placed in the popliteal fossa (*arrow*), and the ankle holder is removed. The knee is now flexed by 15°

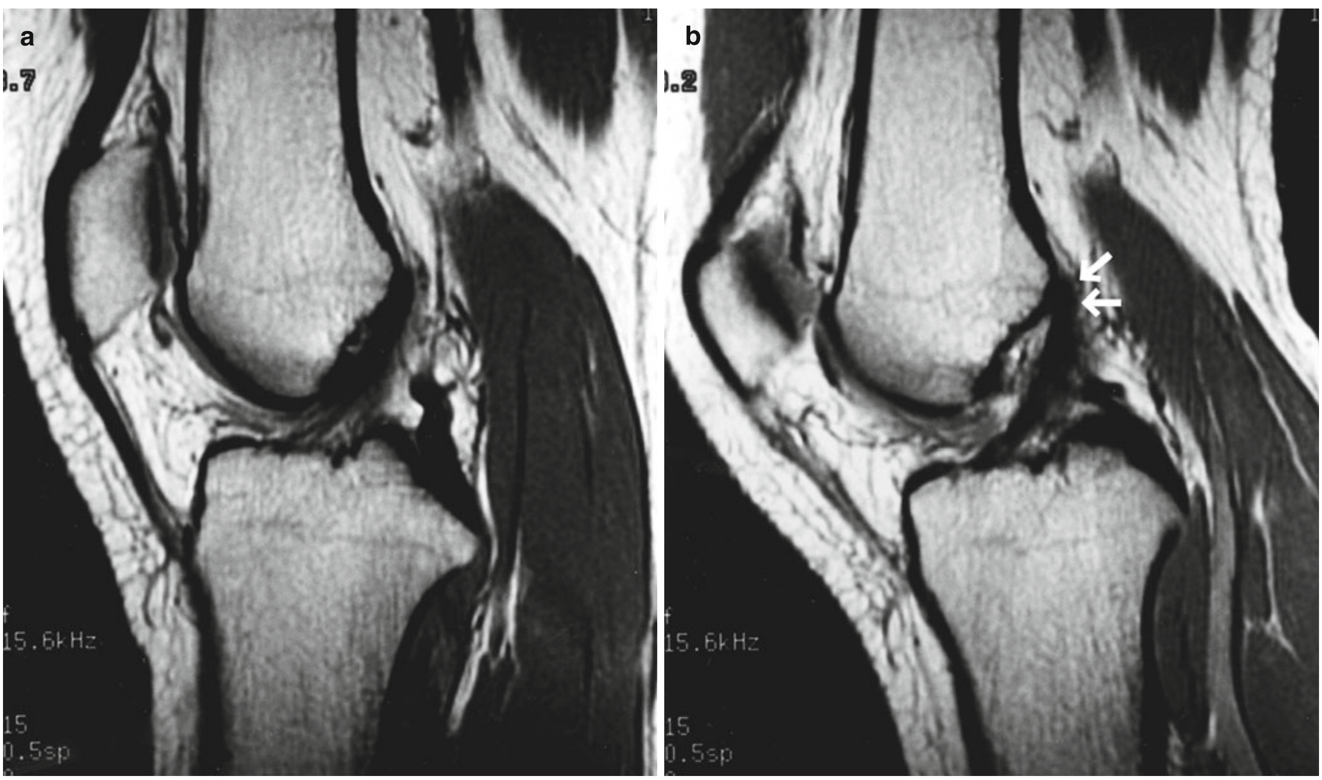

Fig. 3.6 **Differences of ACL appearance when the knee is extended and flexed as shown in Fig. 3.5**. (**a**) Knee was fixed in an extended position, corresponding to the Fig. 3.5a. (**b**) Knee was fixed in a flexed position, corresponding to the Fig. 3.5b. When the knee is lightly flexed, ACL becomes distant from the ceiling of the intercondylar space, and it appears thicker, making it easier for us to visualize it in the sagittal MRI. The flexed position also enables clearer visualization of the femoral attachment site of ACL (*arrows*)

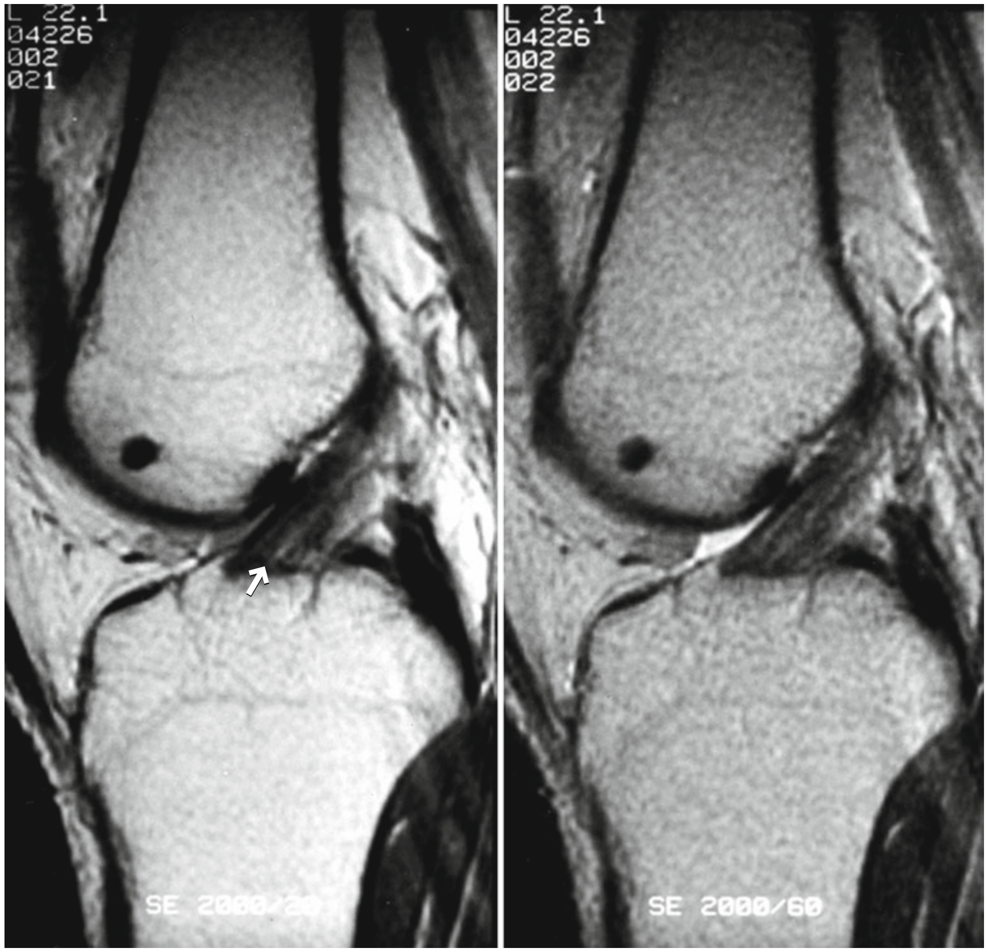

Fig. 3.7 **Normal ACL**. PDWI (*left*, SE 2,000/20) and T2WI (*right*, SE 2,000/60) of the knee. In sagittal images, the anterior border of the ACL is smooth and shows hypointensity in all sequences. This corresponds to the fibers of AMB. The middle and posterior portion of the ACL may show mild hyperintensity due to some fat tissue (*arrow*) that is present within the ACL fibers

3.3 MRI Findings of Normal ACL

- ACL runs within the intercondylar space between the femoral and tibial attachment sites in a curved fashion.
- In sagittal images, the anterior border of the ACL is smooth and shows hypointensity in all sequences (Fig. 3.7). This corresponds to the fibers of AMB. The middle and posterior portion of the ACL may show mild hyperintensity due to some fat tissue that is present within the ACL fibers, which is less dense at these locations compared to the anterior portion.
- ACL tends to appear generally more hyperintense than PCL.

3.4 Characteristics of ACL Tear

- ACL tear is common ligamentous tear.
- This is due to the fact that ACL is more vulnerable to injury than PCL due to thinner fiber bundles and a smaller attachment.
- Women are 4–8 times more likely to sustain ACL tear than men, and an association with female sex hormone has been suggested.
- In a typical scenario, a patient feels a "pop," and a rapidly enlarging hematoma is seen. 60–80% of hemarthrosis of the knee coexists with ACL tear. If there is a fracture, fat droplets can also be seen within the hematoma.
- ACL tear may have already been clinically diagnosed before MRI examination, but clinical symptoms associated with ACL tear can be variable.

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Causes of ACL Tear

Commonly occurs following sports injuries

1. Knee flexion, valgus injury, and lateral rotation of the distal lower limb (e.g., skiing accident)
2. Overextension of the knee
3. Stopping or jumping while the knee is slightly flexed (e.g., characteristic to basketball and volley ball and more common in female athletes)

3.5 Complete Tear of ACL

- Complete tear of all fibers of the ACL.
- Approximately 70% occurs at the central portion of the ACL (Fig. 3.8). Approximately 20% occurs at the femoral attachment site (Fig. 3.9).
- Complete tear at the tibial attachment site is rare.

MRI findings

- Discontinuation of ACL fibers.
- It is relatively easy to diagnose a complete tear on MRI (sensitivity >90%).

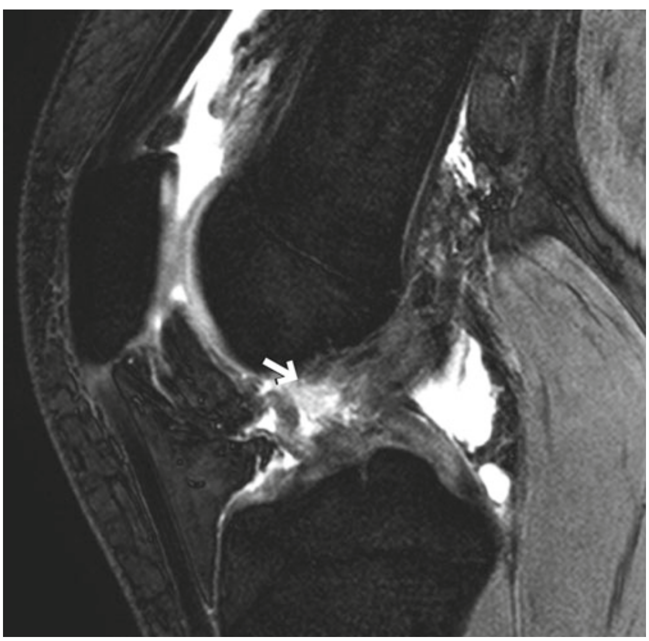

Fig. 3.8 Complete tear of ACL at the central portion. T2*WI of a teenage man. A complete loss of continuity of ACL at the central portion (*arrow*)

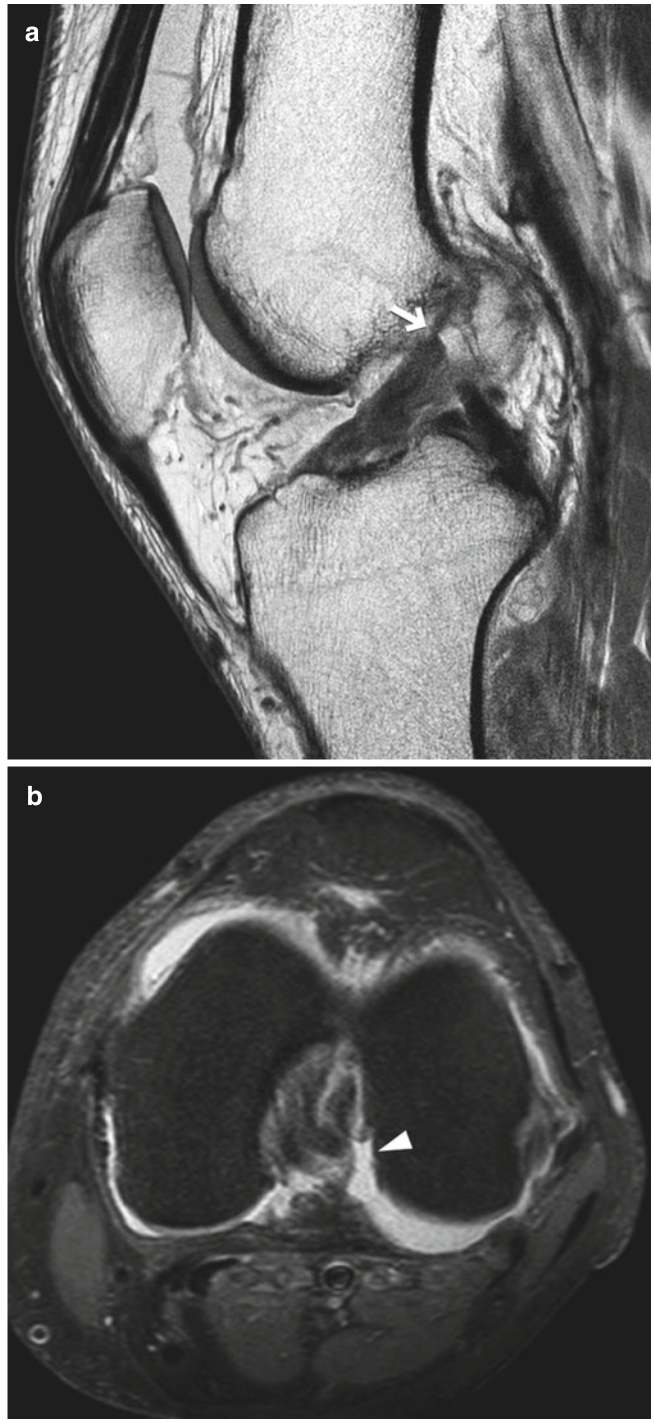

Fig. 3.9 Complete tear of the ACL at the femoral attachment site. (**a**) PDWI and (**b**) axial FS PDWI of a man in his forties. ACL has lost its continuity at the femoral attachment site (*arrow*). It is important to confirm this in all three planes (i.e., sagittal, coronal, and axial, *arrowhead*)

3.6 Partial Tear of ACL

- Partial tear of ACL occurs if only AMB or PMB, either entirely or partially, is torn. However, it is difficult differentiate these two bundles on MRI, and clinically all tears that are not complete are classified as partial tear.
- Diagnosing partial tear of ACL on MRI is said to be very difficult.
- AMB is more commonly affected than the PMB.

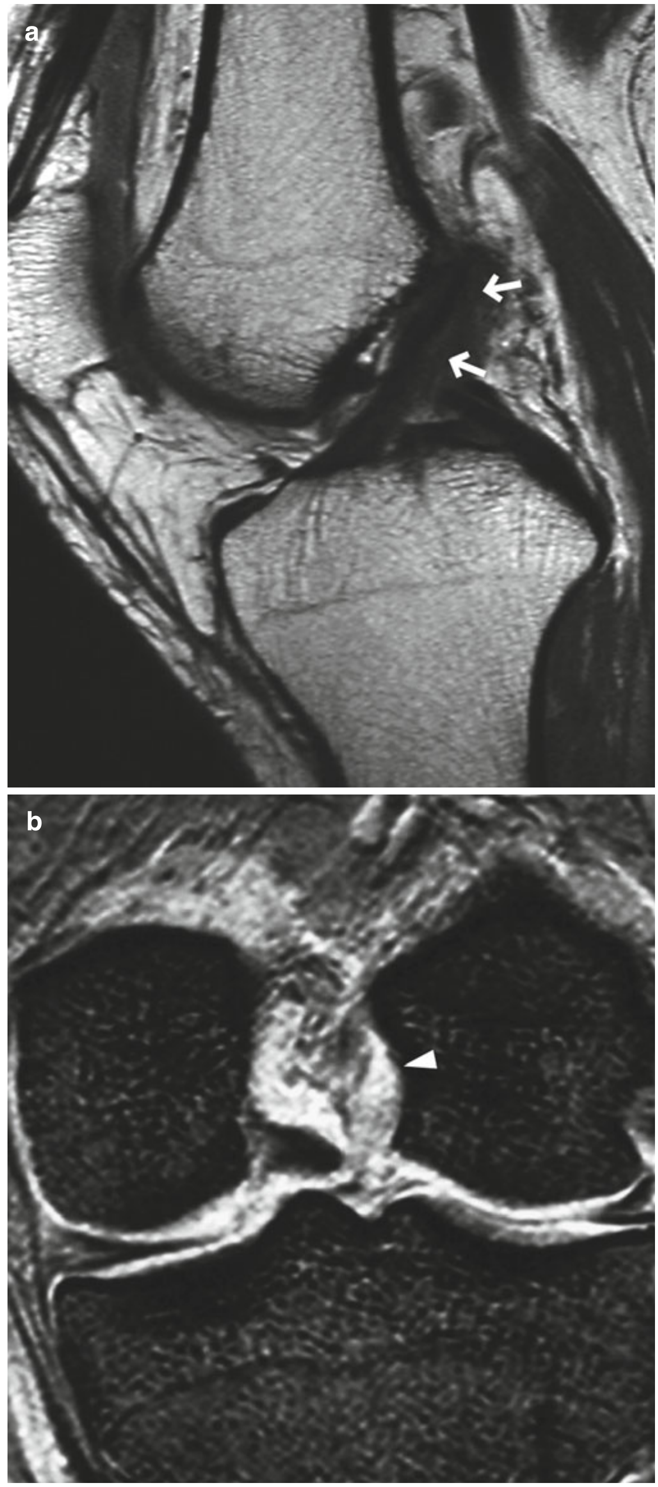

Fig. 3.10 **Partial tear of ACL**. (**a**) PDWI, (**b**) coronal T2*WI, and (**c**) axial T2WI of the knee in a man in his 50s. The sagittal image shows the ACL at the femoral attachment site is not clearly delineated (*arrow*), which is suspicious for ACL tear, but it is difficult to confirm the diagnosis with this image alone. Looking at the cross-section of the ACL on both coronal and axial images reveal a localized hyperintensity within the ACL at the femoral attachment site (*arrowhead*, **b** and **c**), confirming the diagnosis of partial ACL tear

References

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MRI findings

- Fibers may appear continuous.
- Fine intrasubstance hyperintensity within the ACL or angulation of the ligament may be seen.
- Immediately following an acute injury, edema, hemorrhage, and synovial thickening may hinder the imaging diagnosis, making it difficult to differentiate between partial and complete tear.

Pearls

- Fix the knee in a slightly flexed position, as described earlier, to better delineate the anterior border of the ACL (Fig. 3.10)
- Acquire images which are as thin as possible and with highest possible anatomical resolution

Importance of Knee Positioning

It is essential to lightly flex the knee to better delineate the ACL when using a cylindrical knee coil. Place a pad in the popliteal fossa so that the distal lower limb does not move while scanning. If the padding is too little, the image will be affected by motion artifact, and if there is too much padding, the patient will complain of pain after about 20 min, resulting in suspension of the scanning. It is necessary to explain to the patient that their cooperation (i.e., not to move) is of paramount importance and ensure to talk to the patient during the scanning session for patients who are of nervous predisposition. If fat suppression is to be applied, pads that can compensate for magnetic field inhomogeneity should be used and try to position the coil in the center of the magnetic field as much as possible. In any case, the pre-imaging preparation and knee positioning are very important.

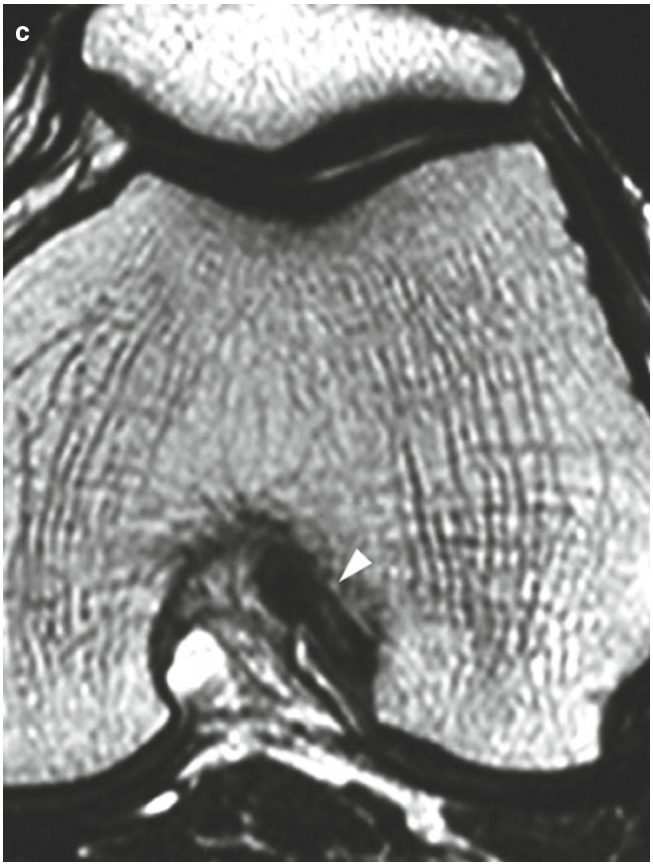

Fig. 3.10 (continued)

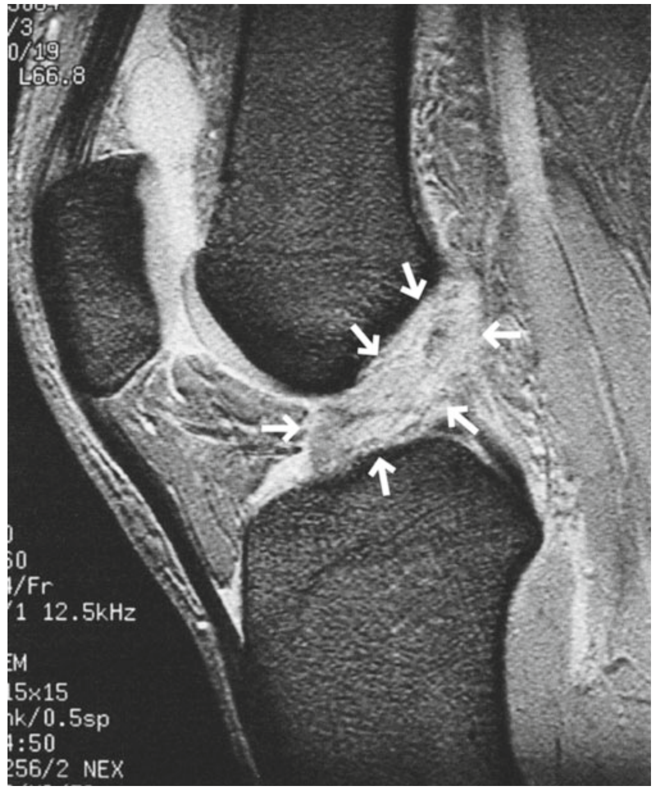

Fig. 3.11 **Acute tear of ACL**. T2*WI of a teenage man. ACL appears discontinuous and appear swollen for its entire length (*arrows*)

3.7 Acute Tear of ACL

Definition: “Acute” tear means that less than 2 weeks has passed since the time of injury.

MRI findings

- ACL appears swollen and discontinuous (Fig. 3.11).
- Intraligamentous linear hyperintensity is said to represent interstitial tear.
- Torn femoral attachment site may appear like a mass due to the presence of hematoma or synovial tissue. Moreover, partial volume effect due to the proximity of ACL and lateral femoral condyle makes visualization of ACL unclear. This last, however, can be prevented by slight flexion of the knee during the MRI scan.
- It is rare to miss ACL damage, but differentiating between acute complete and partial tear may be difficult.

3.8 Chronic Tear of ACL

Definition: “Chronic” tear means that more than 8 weeks has passed since the time of injury. At this stage, imaging appearance of ACL tear becomes variable.

3.8.1 Loss of ACL

- Torn ligament gradually gets absorbed, and after a few years, ACL fibers may not exist any longer within the intercondylar space (Fig. 3.12). Imaging diagnosis is not difficult in such cases.

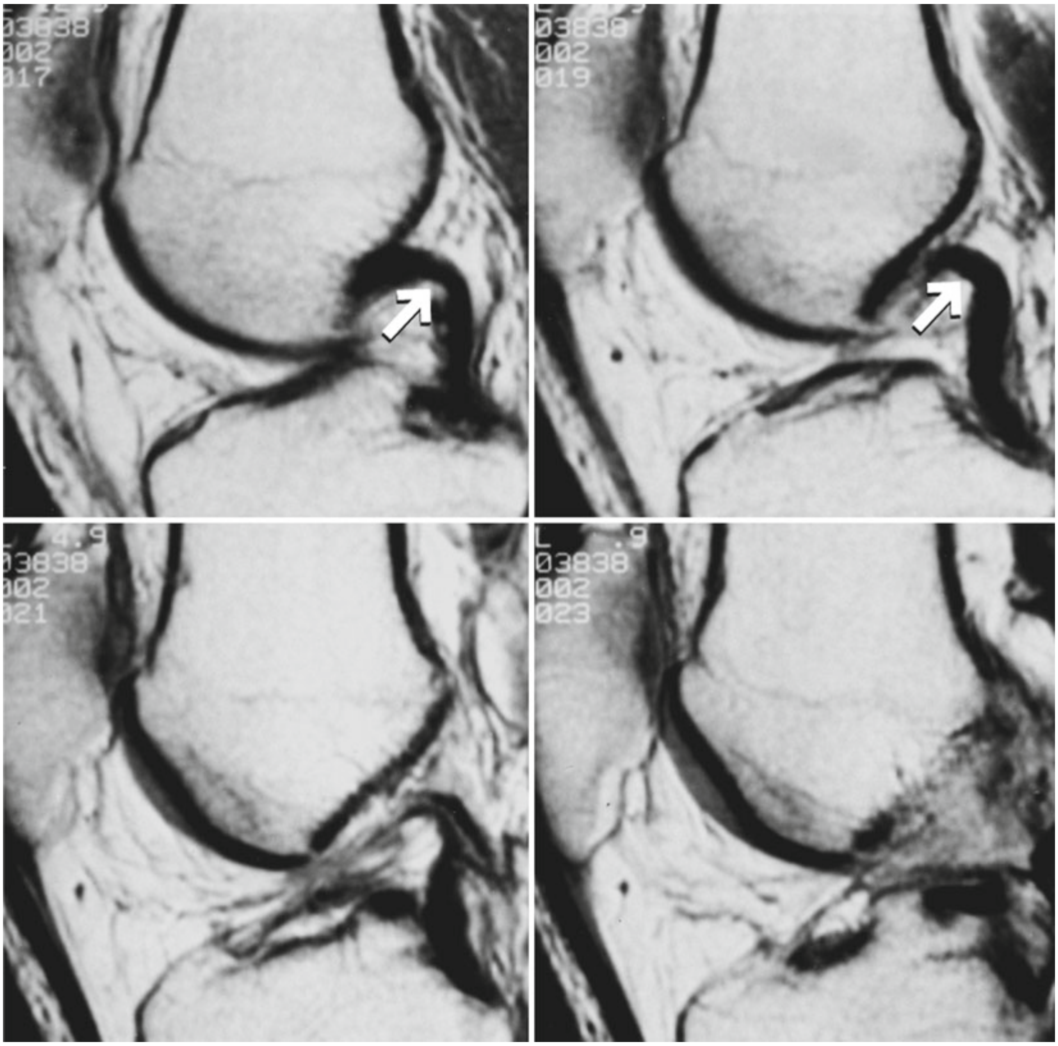

Fig. 3.12 Chronic complete tear of ACL. Four consecutive sagittal slices of PDWI in a man in his 30s, 2 years after the injury. Within the intercondylar space, ACL is no longer visible, except for small band-like remnants. This is consistent with chronic stage of complete ACL tear. PCL is bent at an acute angle (*arrows*), consistent with secondary findings associated with ACL tear

3.8.2 Discontinuous Band

- Remnant of the torn ACL appears as a band-like structure.
- Tear of ACL at the femoral attachment site is common, and thus the remaining ACL is commonly seen attached to the tibia (Fig. 3.13).
- Reflecting the abundance of vascular supply to the ACL, the torn edge (femoral side) may be seen attached to the PCL (Fig. 3.14). If the torn ACL attaches to the PCL at a relatively high position within the intercondylar space, one may mistake it as a normal ACL (pseudoligament) after looking at sagittal images only. The torn edge of the ACL may also attach to the ceiling of the intercondylar space (Fig. 3.15).

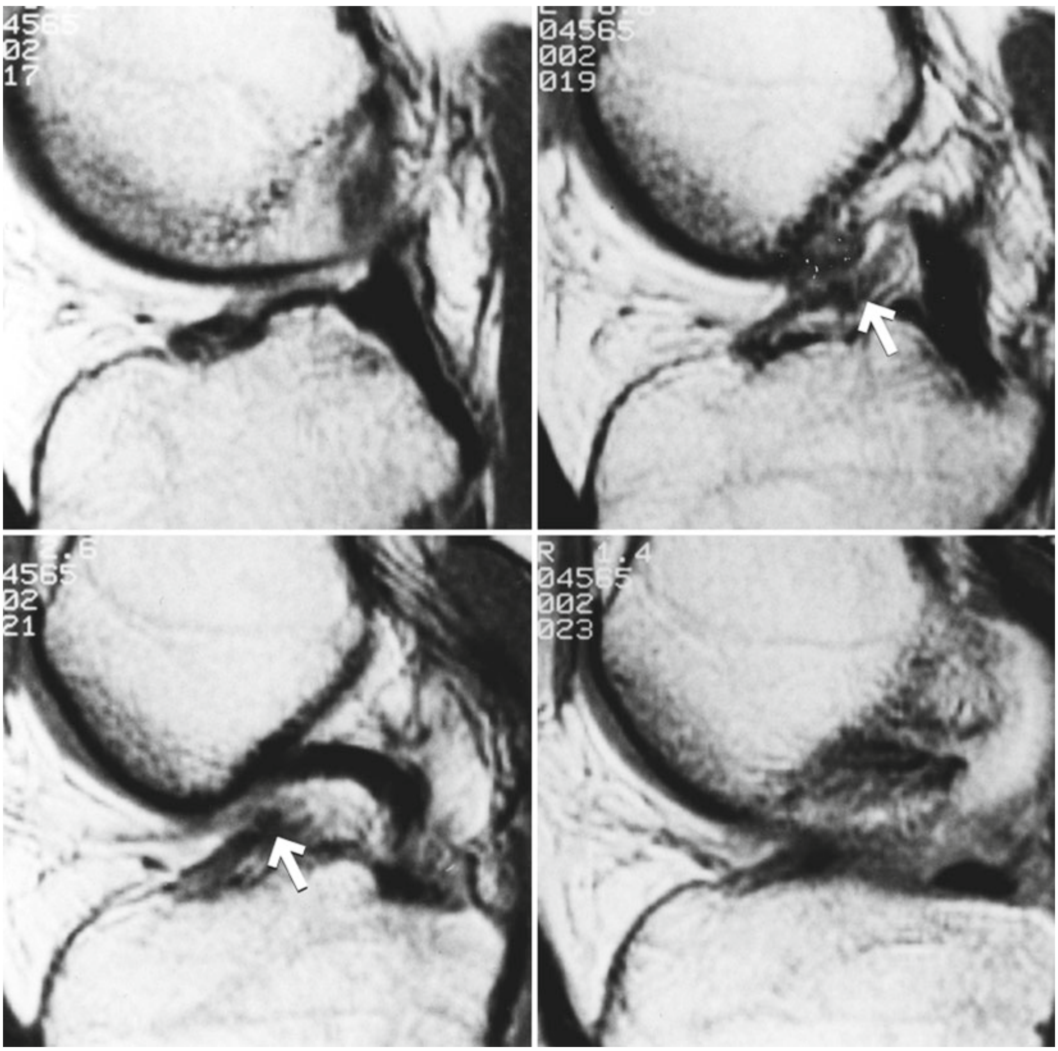

Fig. 3.13 Remnant of the torn ACL attached to the tibia. Four consecutive sagittal slices of PDWI in a woman in her 20s. A short remnant of ACL (*arrow*) is seen attached to the tibia

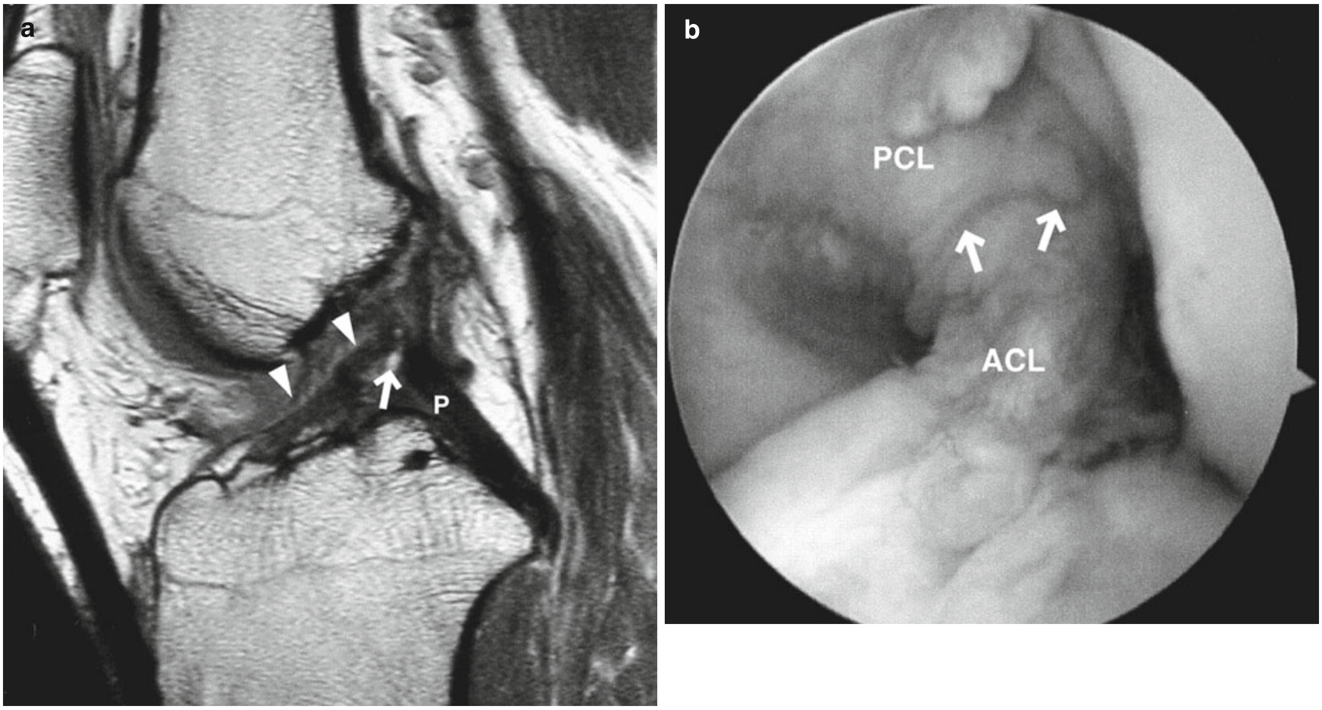

Fig. 3.14 **Remnant of the torn ACL attached to the PCL**. (**a**) PDWI and (**b**) arthroscopic image of a man in his 20s. ACL remnant (*arrowheads*) runs diagonally toward the PCL, and the torn edge (femoral side) is seen attached to the PCL (*P*, *arrows*)

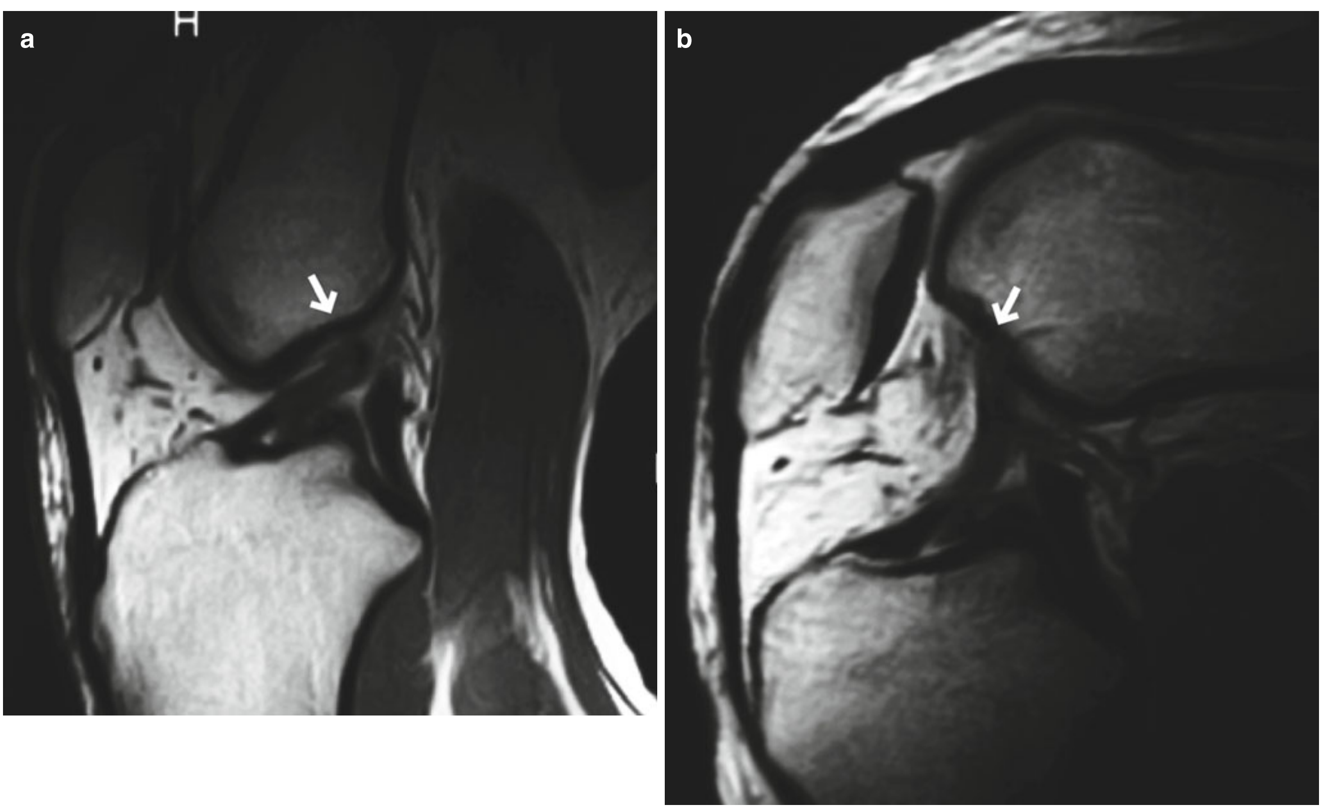

Fig. 3.15 **Remnant of the torn ACL attached to the ceiling of the intercondylar space**. A teenage man with a chronic ACL tear. PDWI acquired while the knee was extended (**a**) and flexed (**b**), and an arthroscopic image (**c**). The torn edge of the remnant of ACL is seen attached to the ceiling of the intercondylar space (*arrow in* **b**) but this is not obvious in (**a**). Arthroscopy (**c**) confirmed the MRI finding in the flexed knee (**b**) and revealed the remnant of ACL being angulated unnaturally (Images courtesy of Dr. Kotaro Ikeda, Department of Orthopedics, Ichihara Hospital, Japan)

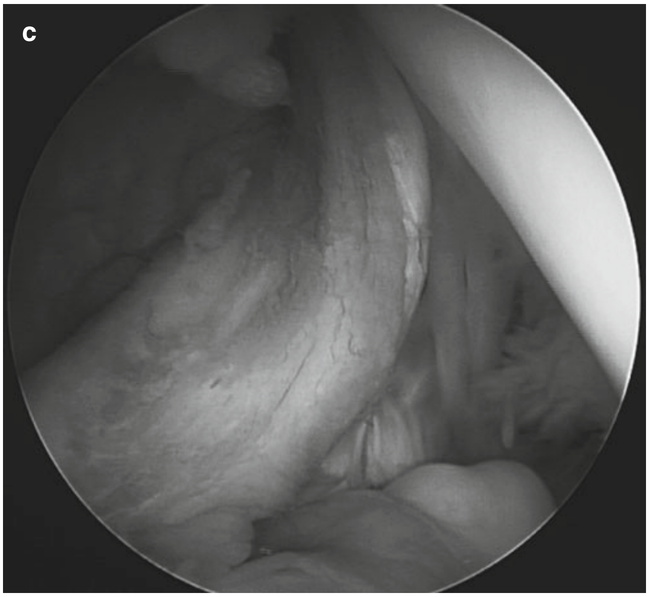

Fig. 3.15 (continued)

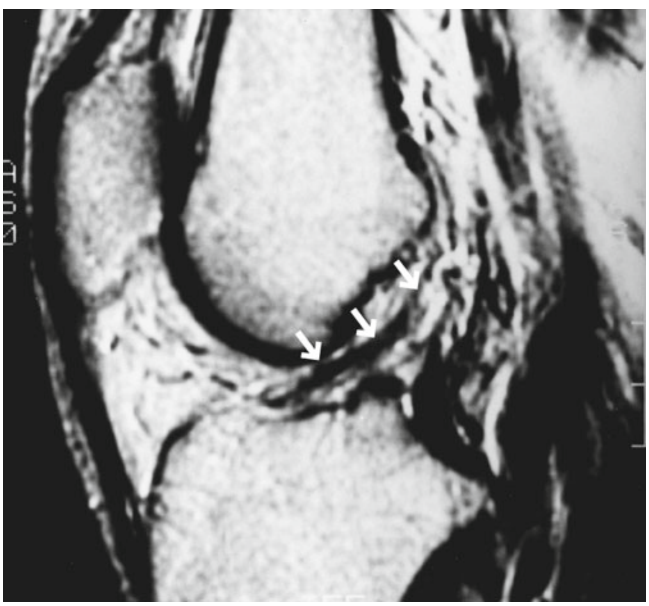

Fig. 3.16 Bridging fibrous scar. T2WI of a teenage man. An elongated continuous band-like structure is seen (*arrows*) within the intercondylar space. This is a scar tissue that replaced the torn ACL

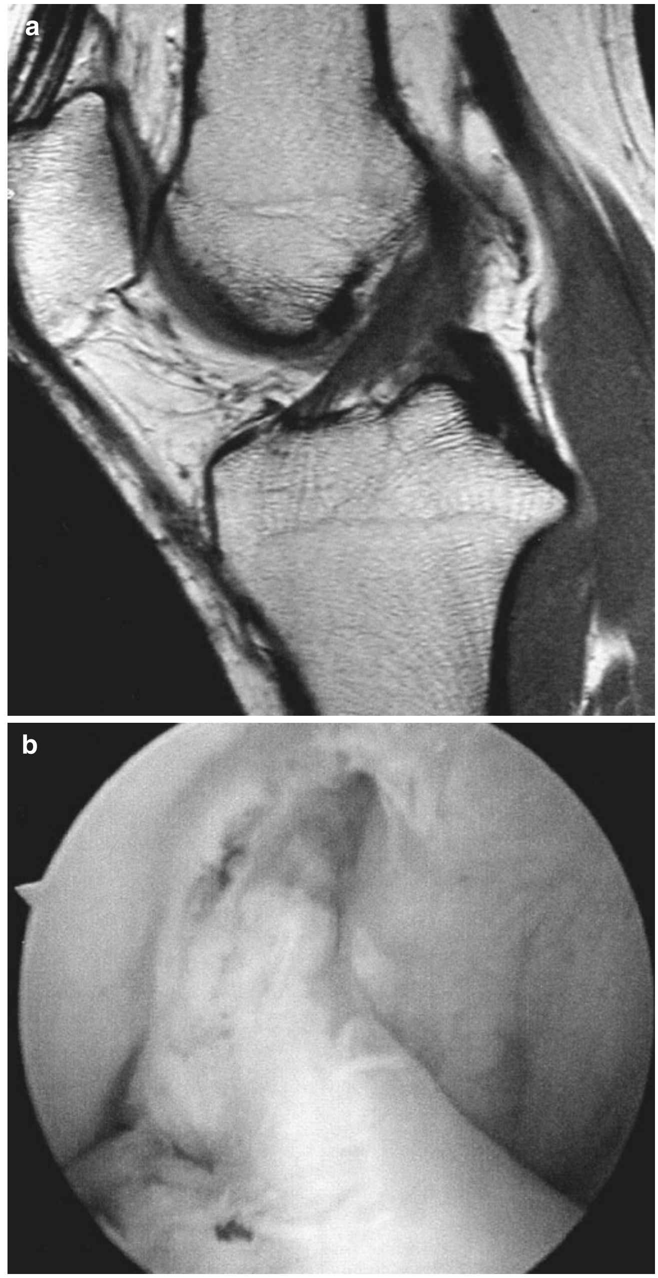

Fig. 3.17 Bridging fibrous scar with the "pseudoligament" appearance. (**a**) PDWI and (**b**, **c**) arthroscopic images of a man in his 20s. The MRI shows as if there is a normal ACL. The first glance at the arthroscopy (**b**) also shows a continuous ligamentous structure (pseudoligament) resembling a normal ACL, but exploration with a probe (**c**) reveals this is a bridging fibrous scar

3.8.3 Continuous Band with Elongation

- Continuous but elongated ligamentous structure is seen in the intercondylar space.
- This is so-called bridging fibrous scar that replaced the torn ligament (Fig. 3.16).
- If the elongation is not obvious, one can easily mistake it as a normal ACL (pseudoligament) (Fig. 3.17).

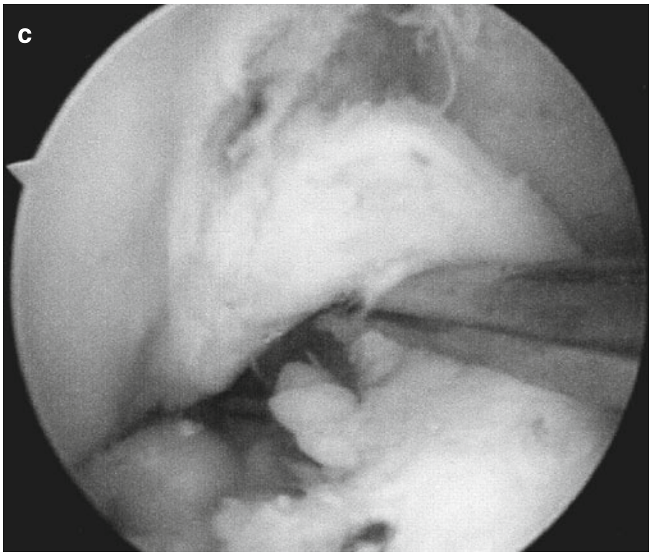

Fig. 3.17 (continued)

Chronic Tear of ACL with the "Pseudoligament" Appearance

1. Remnant of the ACL with its torn edge attached to the PCL at a high position.
2. Remnant fibers are present for the almost entire length of the ACL.
3. Bridging fibrous scar with little "sagging."

3.9 Degeneration of ACL

- Ageing or accumulation of microtrauma may lead to mucoid degeneration within the ACL.
- If the degeneration progresses to an advanced degree, the entire ACL becomes swollen and shows hyperintensity, and part of the fibers may become visible on MRI. This state of ACL is called "celery stalk ACL" (Fig. 3.18).
- Cystic changes within the ACL leads to ACL ganglion (see Chap. 12).
- These mucoid and cystic changes may occur together, but it is not thought that they affect the knee stability (Fig. 3.19).

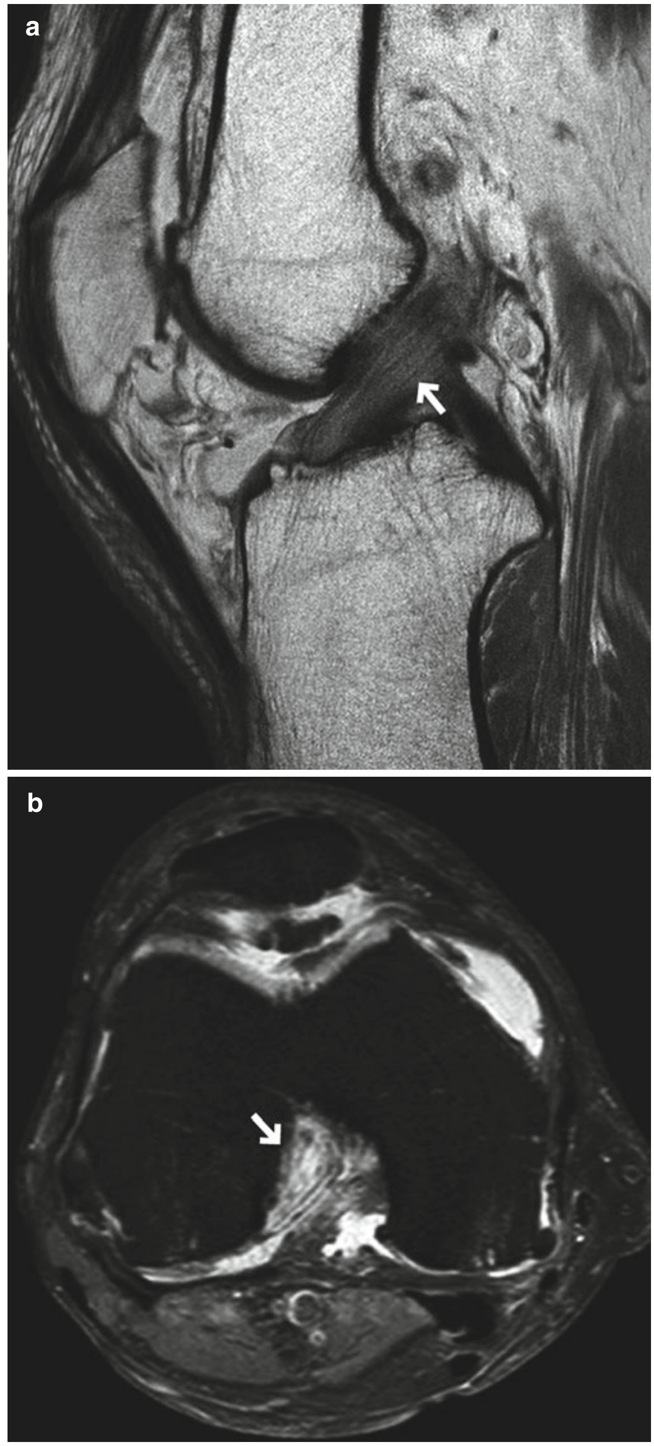

Fig. 3.18 **Celery stalk ACL (mucoid degeneration of ACL).** (**a**) PDWI and (**b**) axial FS PDWI of a woman in her 70s. The ACL generally appears swollen and hyperintense (mucoid degeneration), and some fibers can be visualized, creating a so-called celery stalk ACL (*arrow*)

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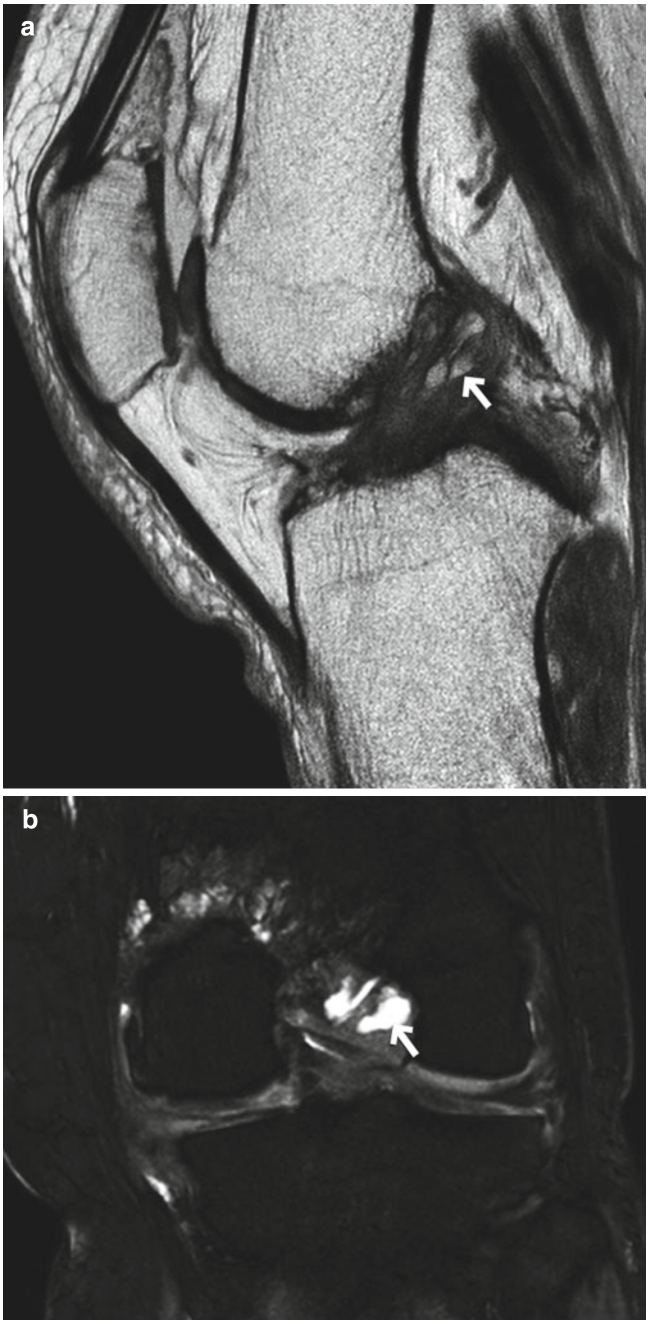

Fig. 3.19 **Coexistence of mucoid degeneration and ACL ganglion.** (**a**) PDWI and (**b**) coronal FS T2*WI of a woman in her 70s. The ACL appears generally swollen and hyperintense (mucoid degeneration). In addition, there is a coexistent ganglion cyst (*arrow*). Clinically, there was no knee instability in this patient

3.10 Secondary Signs Suggesting ACL Tear

- MRI of the knee reveals not only the pathology of ACL itself but also secondary signs of ACL tear, which include:

1. Anterior displacement of the tibia: ACL prevents the anterior displacement of the tibia, which occurs as a consequence of

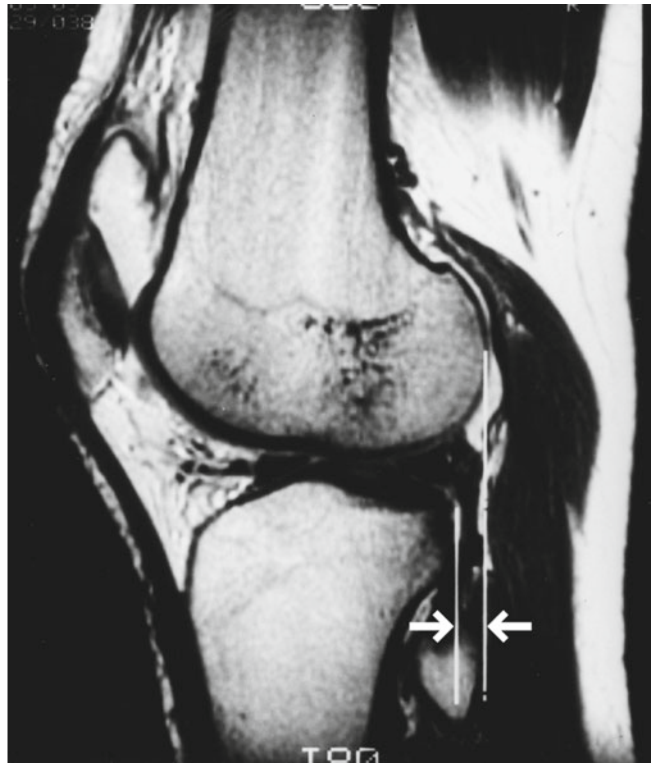

Fig. 3.20 **Anterior displacement of the tibia**. If the posterior border of the tibia is located anterior to that of the femoral head by greater than 5.0 mm (*arrows*) in a sagittal slice acquired at the mid-position of the lateral femoral condyle, one may conclude the tibia is anteriorly displaced. This is a secondary sign of ACL tear

ACL tear. If the posterior border of the tibia is located anterior to that of the femoral head by greater than 5.0 mm in a sagittal slice acquired at the mid-position of the lateral femoral condyle (Fig. 3.20), one may conclude the tibia is anteriorly displaced. However, depending on the knee positioning and the shape of the coil used to acquire the image, the threshold value may need to be changed.

2. PCL bowing: PCL appears bent at an acute angle (Fig. 3.21). This may be associated with the findings as described in 1.
3. Bone bruise: Due to the loss of ACL function to prevent the anterior displacement of the tibia, the lateral femoral notch in the lateral condyle and the posterior aspect of the tibial plateau collide with each other (Fig. 3.22). This phenomenon is called “kissing contusion” and results in bone bruise, which include microfracture, microhemorrhage, and bone edema. Resultant deep lateral femoral notch may be seen. However, in young people whose ACL still retains elasticity, these findings do not always suggest ACL tear (Fig. 3.23).
4. Segond fracture: Avulsion fracture of the lateral tibial plateau below the articular surface, which very frequently accompanies ACL tear (almost 100%).
5. Damage to the posterior aspect of the medial tibial plateau and avulsion fracture of semimembranous tendon insertion (Fig. 3.24).

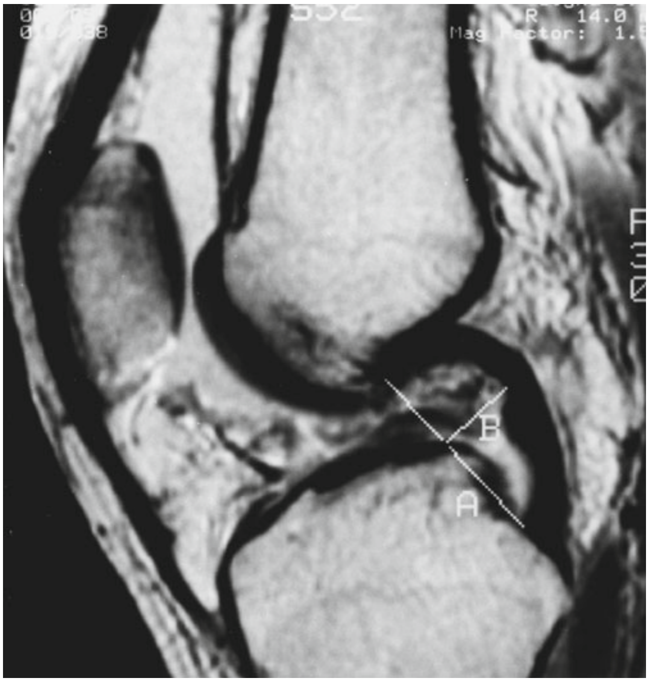

Fig. 3.21 **PCL bowing**. This is another secondary sign of ACL tear. The PCL is angulated at an abnormal angle. Several measurement methods have been proposed

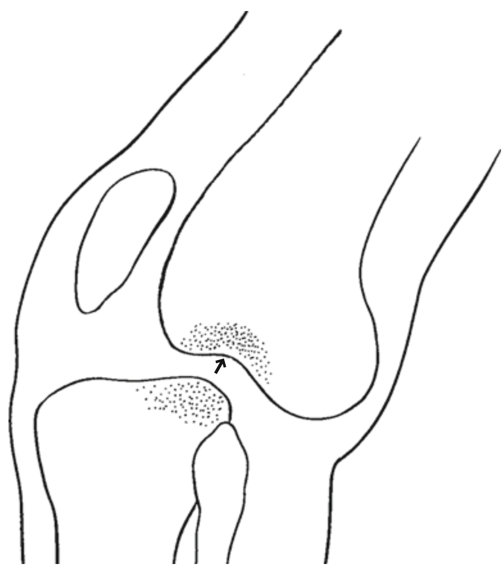

Fig. 3.22 **Kissing contusion**. The lateral femoral notch (*arrow*) in the lateral femoral condyle and the posterior aspect of the tibial plateau collide with each other, creating a bone bruise

Fig. 3.23 **Deep lateral femoral notch**. T2*WI with MTC of a man in his late teens with complete ACL tear. There is a deep lateral femoral notch (*arrow*) accompanied by localized full-thickness cartilage loss

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Secondary Signs Suggesting ACL Tear

1. Anterior displacement of the tibia (by >5 mm laterally)
2. PCL bowing
3. Bone bruise at lateral femoral condyle + posterolateral tibial plateau
4. Segond fracture
5. Avulsion fracture of semimembranous tendon insertion

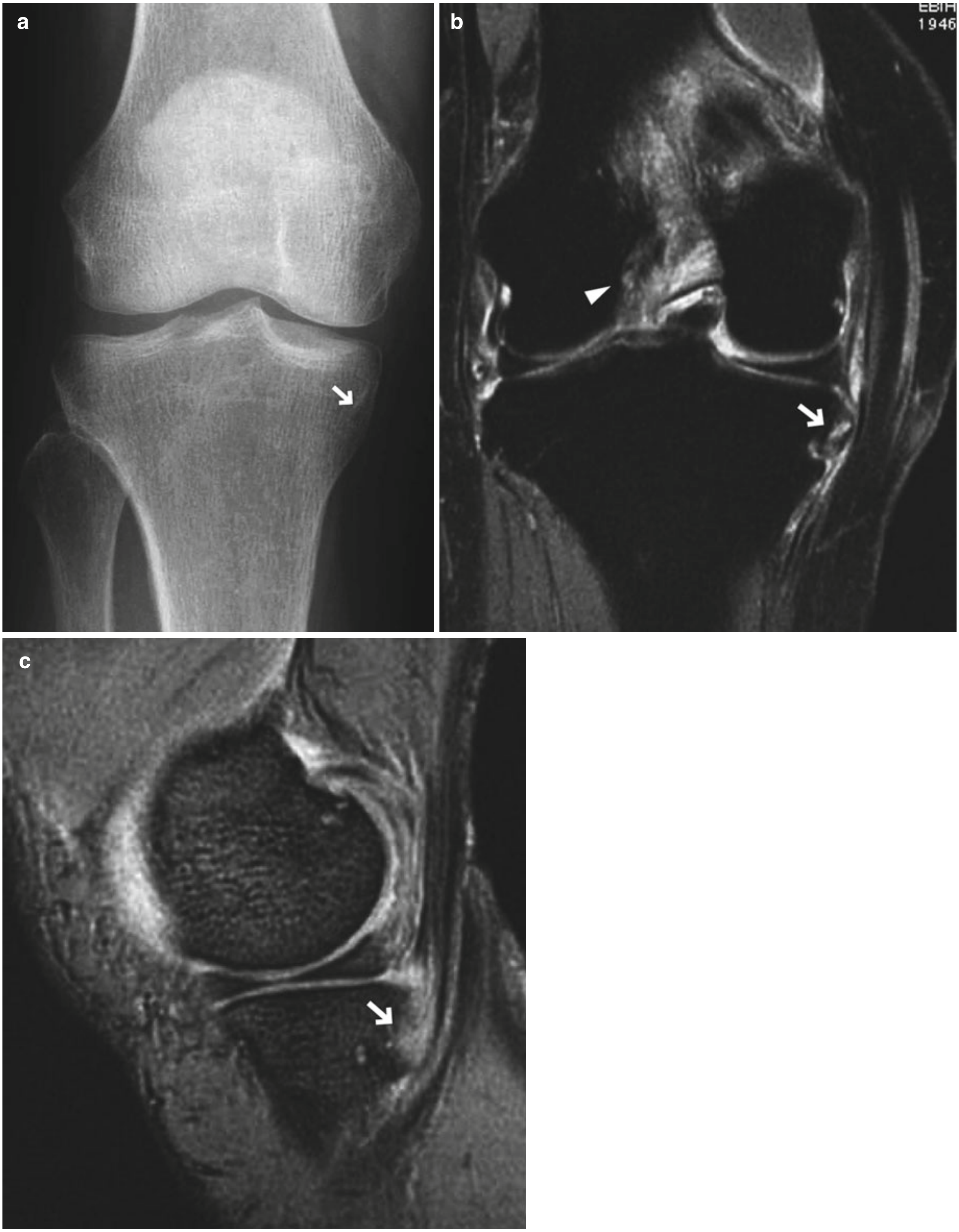

Fig. 3.24 Avulsion fracture of semimembranous tendon insertion. (**a**) Anteroposterior radiograph, (**b**) coronal FS PDWI, and (**c**) sagittal T2*WI of a woman in her 60s. Damage to the posterior aspect of the medial tibial plateau and avulsion fracture of semimembranous tendon insertion (*arrow*) can be seen. ACL tear is also seen (*arrowhead*, **b**)

3.11 Fracture of the Intercondylar Eminence

- ACL spreads out like a fan at the tibial attachment site and firmly attaches anterior to the intercondylar eminence (Fig. 3.4).
- In young persons with skeletal immaturity, avulsion fracture of the intercondylar eminence is likely to occur.
- Symptoms are similar to those seen with ACL tear.
- Avulsed bone fragment can be classified according to Meyers-McKeever classification (Fig. 3.25).
- If there is a free avulsed bone fragment within the joint (Type 3 or above), surgical therapy is indicated (Figs. 3.26 and 3.27).

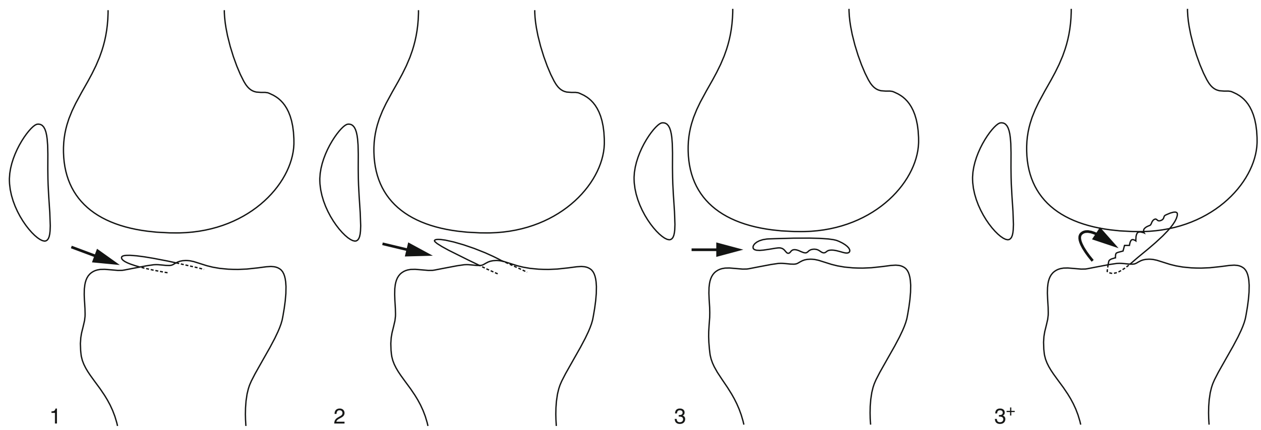

Fig. 3.25 Fracture of the intercondylar eminence. Illustration of Meyers-McKeever classification: *Type 1*: There is minimal displacement of the avulsed fragment and excellent bone apposition. *Type 2*: Displacement of the anterior third to half of the avulsed fragment from the intercondylar eminence produces a beaklike deformity in the lateral radiograph. *Type 3*: The avulsed fragment is completely separated from its bone bed in the intercondylar eminence and has no apposition of the fragment. *Type 3+*: The avulsed fragment is completely lifted from its bone bed of origin in the intercondylar eminence and rotated so that the cartilaginous surface of the fragment faces the raw bone of the bone bed, making union impossible (Figure adapted from Meyers and McKeever)

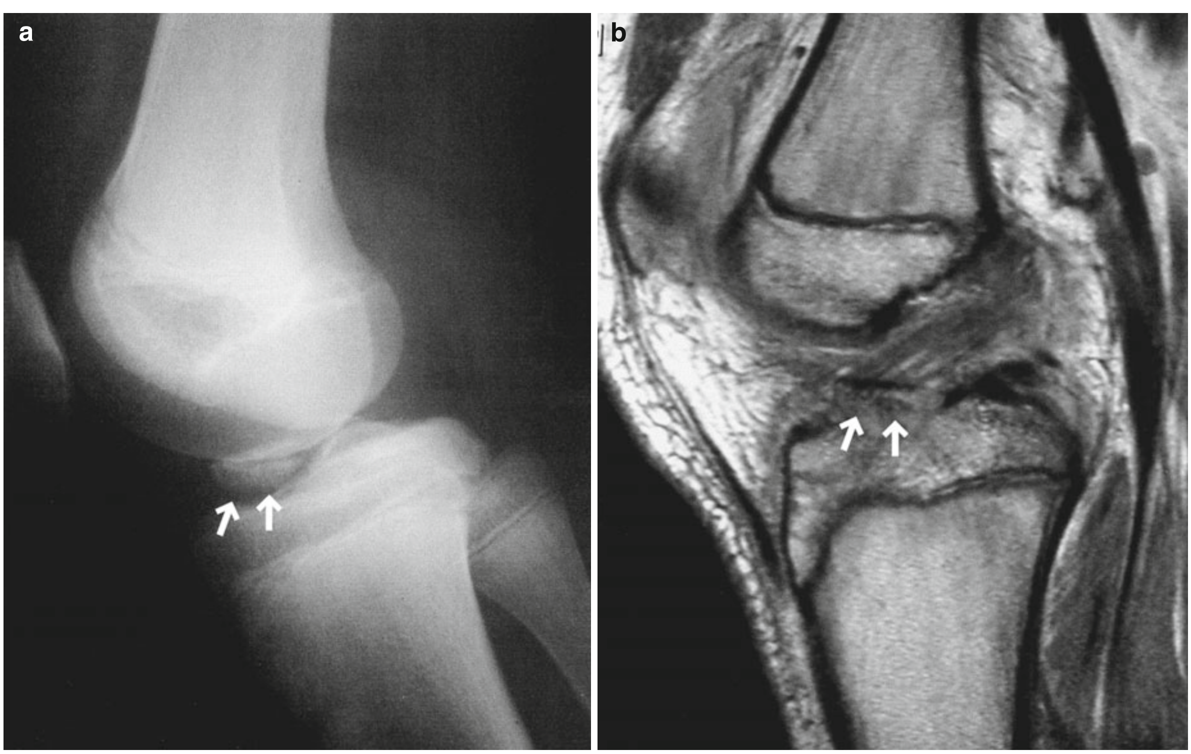

Fig. 3.26 Fracture of the intercondylar eminence. (**a**) Lateral radiograph and (**b**) PDWI of the 13-year old boy. In young persons with skeletal immaturity, avulsion fracture of the intercondylar eminence is likely to occur. In this example, the avulsed fragment (*arrows*) is completely separated from its bone bed in the intercondylar eminence (Meyers-McKeever Type 3). On MRI, the size and location of the fragment, as well as the presence of any damage to ACL itself, should be assessed

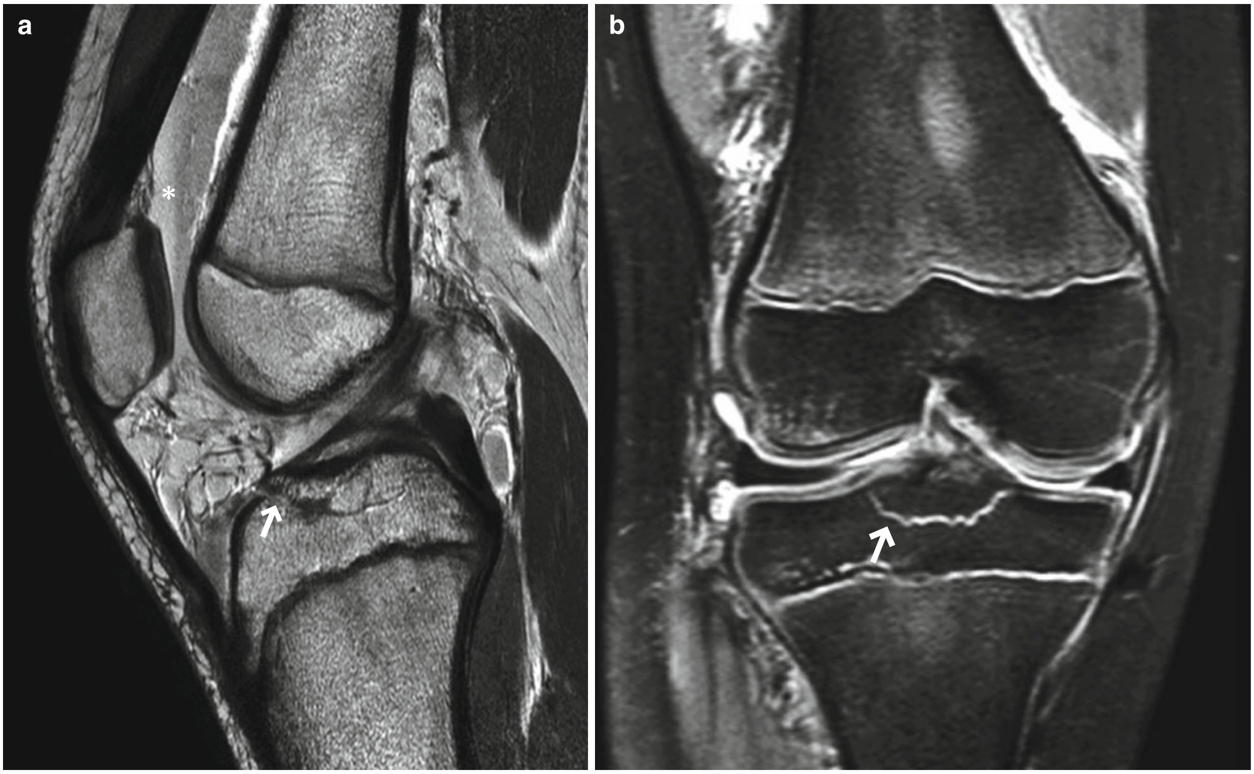

Fig. 3.27 **Fracture of the intercondylar eminence**. (**a**) PDWI and (**b**) coronal FS PDWI of a 9-year-old girl. There is minimal displacement of the avulsed fragment (*arrows*) and excellent bone apposition (Meyers-McKeever Type 1). Note the presence of hemarthrosis (*)

Key points for MRI interpretation

- If avulsed bone fragments cannot be clearly visualized on conventional radiograph, MRI should be performed to confirm the size and location of the fragment.
- Also check if there is any damage to the ACL itself.

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3.12 ACL Reconstruction

- Whether or not surgical ACL reconstruction is indicated depends on the degree of damage to the ACL, menisci, and other ligaments and the associated loss of function, patient's age and life style, and participation in sports.
- Reconstructive surgery is performed 3 weeks after the time of injury (or later), after the acute inflammatory response has subsided.
- Nowadays, it is common to perform arthroscopic surgery (Fig. 3.28).
  – Tissues used for the reconstruction includes:
    1. Hamstring tendon (Fig. 3.29)
    2. Iliotibial ligament
    3. Patellar tendon (bone-patellar tendon-bone technique)
  – The above techniques may be supplemented by the use of an artificial ligament

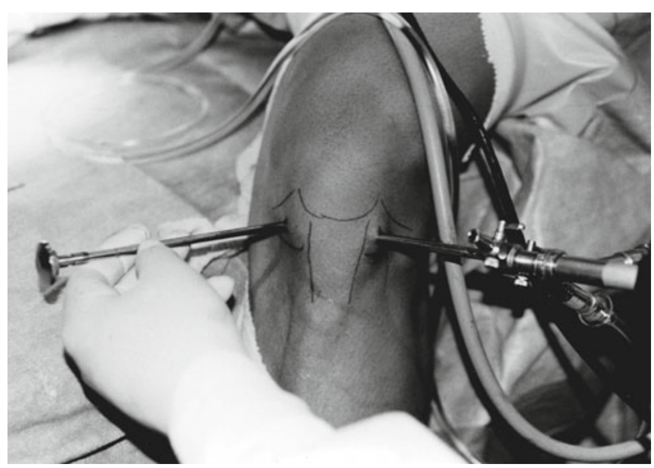

Fig. 3.28 **Arthroscopy of the knee**. Two portals are created, one lateral to and another medial to the patellar tendon as shown. Through these, a probe and an arthroscope are inserted. In ACL reconstruction, bone tunnels are created in the distal femur and proximal tibia, and incisions are made to harvest hamstrings or patellar tendon autograft

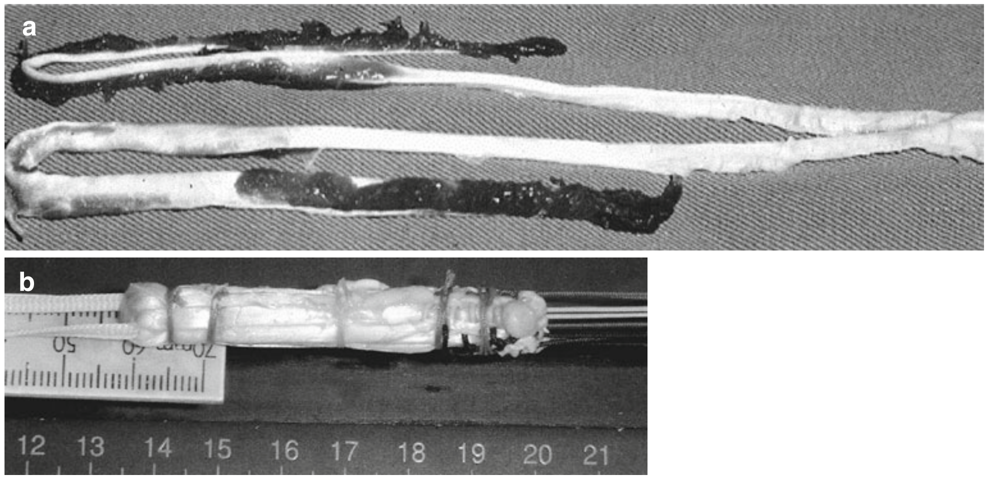

Fig. 3.29 Autograft using the hamstrings tendon. Semitendinosus tendon (longer one in the figure) and gracilis tendon (shorter one) are harvested (**a**). Semitendinosus tendon are folded four times, and gracilis tendon twice to create a graft to be inserted (**b**)

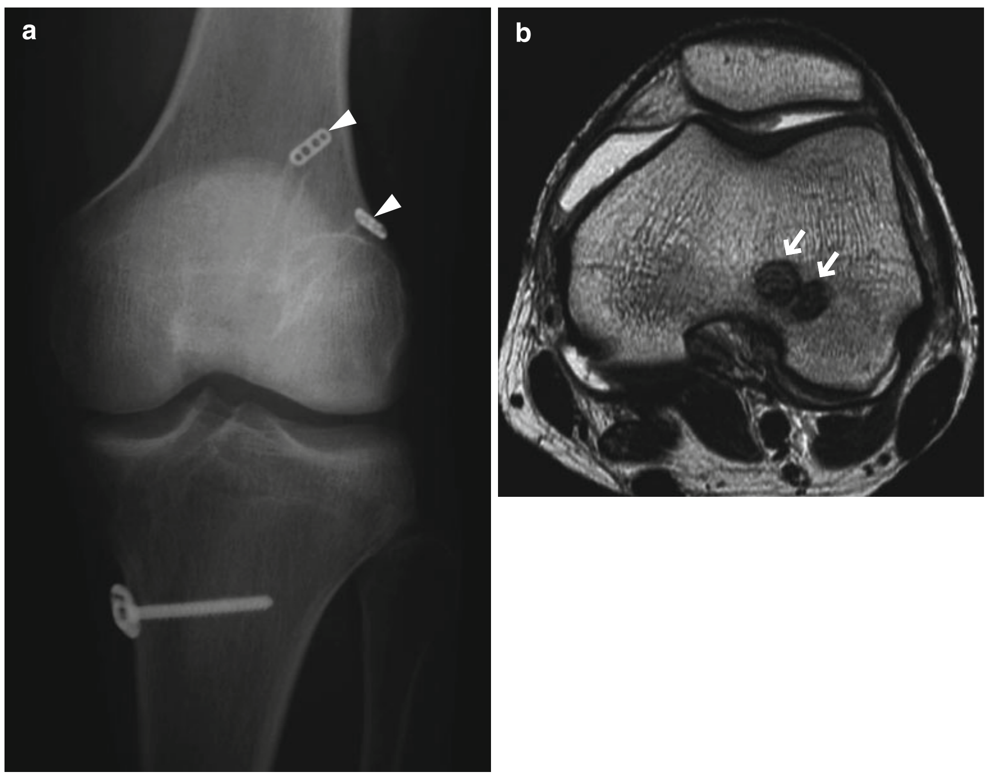

Fig. 3.30 ACL two-bundle reconstruction. (**a**) Anteroposterior radiograph and (**b**) axial T2WI. Two bone tunnels (*arrows*) are created to imitate the AMB and PLB of the native ACL. Endobuttons (*arrowheads*) are often used to fix the autografts to the femur

- The iliotibial ligament is not commonly used nowadays because of a risk of muscle hernia following the graft harvest.
- A tunnel is created in the distal femur and the proximal tibia, and the autograft is placed running through these tunnels and the intercondylar space.
- Two autografts, which resemble the native AMB and PLB, can also be used to reconstruct ACL (Fig. 3.30).
- Autografts can be fixed using staples, endobuttons, or screws
- Two key issues of the ACL reconstruction surgery are isometry of the reconstructed ligament and prevention of impingement.
- Isometry can be achieved by ensuring the correct positioning of the tunnels in the femur and tibia, through which the autograft runs.
- If the opening of the tibial tunnel is located too anteriorly, impingement of the autograft will occur between the tibia and the anterior wall of the femoral intercondylar space. If there is an osteophyte at this location, or the femoral

intercondylar space is narrow, notchplasty will be performed to widen the space.

- The long axis of the tibial tunnel should be parallel to the Blumensaat's line at the maximum extension.
- In postoperative MRI, small metallic particles or metallic nails used to fix the autograft cause metal-related artifacts, but these rarely hinder the interpretation of the image.
- Immediately postoperatively, the autograft will undergo avascular necrosis, but this is a temporary phenomenon and it will be covered by synovium within a few weeks. After several months, blood supply to the autograft will be established, and multiplication of fibroblasts and collagen fibers will occur.

References

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White LM, Kramer J, Recht MP. MR imaging evaluation of the postoperative knee: ligaments, menisci, and articular cartilage. Skeletal Radiol. 2005;34:431–52.

Indications for ACL Reconstruction

1. Complete ACL tear
2. Severe instability of the knee affecting the daily life
3. Athletes
4. Usually only performed in adults after closure of the growth plate

3.13 MRI Findings of Reconstructed ACL

- Postoperatively, normal autografts are depicted as a homogeneously hypointense band.
- If the autograft shows hyperintensity partially or completely, it may be due to reinjury or progression of degenerative process. However, it may also be due to revascularization of the autograft. Commonly, the autograft shows mild hyperintensity a few months after the surgery, but 1 or more year after the surgery it tends to revert to hypointensity that was observed at the immediate postoperative period (Fig. 3.31).
- Attempts have been made to measure the MR signal in the autograft for the purpose of longitudinal postoperative evaluation, but no definitive consensus has been reached to date.

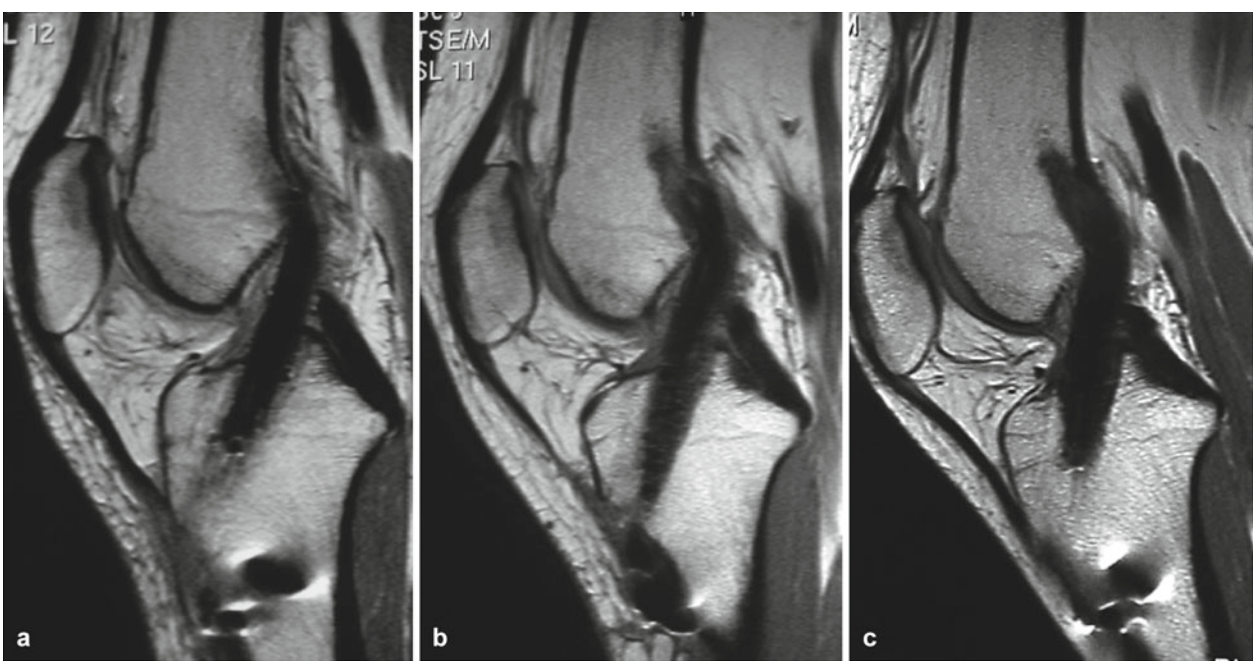

Fig. 3.31 Postoperative MRI of ACL reconstruction. PDWI acquired (**a**) 1 month postoperatively, (**b**) 3 months post-operatively, and (**c**) 1 year postoperatively. A few months after surgery, the autograft shows mild homogeneous hyperintensity as shown in (**b**), but after 1 year or more, it shows homogeneous hypointensity (**c**), which is similar to the immediate postoperative period (**a**). Metal-related artifacts are noted, but they rarely affect the interpretation of the image

References

Rak KM, Gillogly SD, Schaefer RA, Yakes WF, Liljedahl RR. Anterior cruciate ligament reconstruction: evaluation with MR imaging. Radiology. 1991;178:553–6.

Schatz JA, Potter MG, Rodeo SA, Hannafin JA, Wickiewicz TL. MR imaging of anterior cruciate ligament reconstruction. AJR. 1997;169:223–8.

3.14 ACL Graft Tear and Its Complications

- ACL graft tear is present when there is discontinuity of a hypo-intense band and intra-graft hyperintensity on MRI (Fig. 3.32).
- If the opening of the tibial tunnel is located too anteriorly, the graft will be impinged between the tibia and the

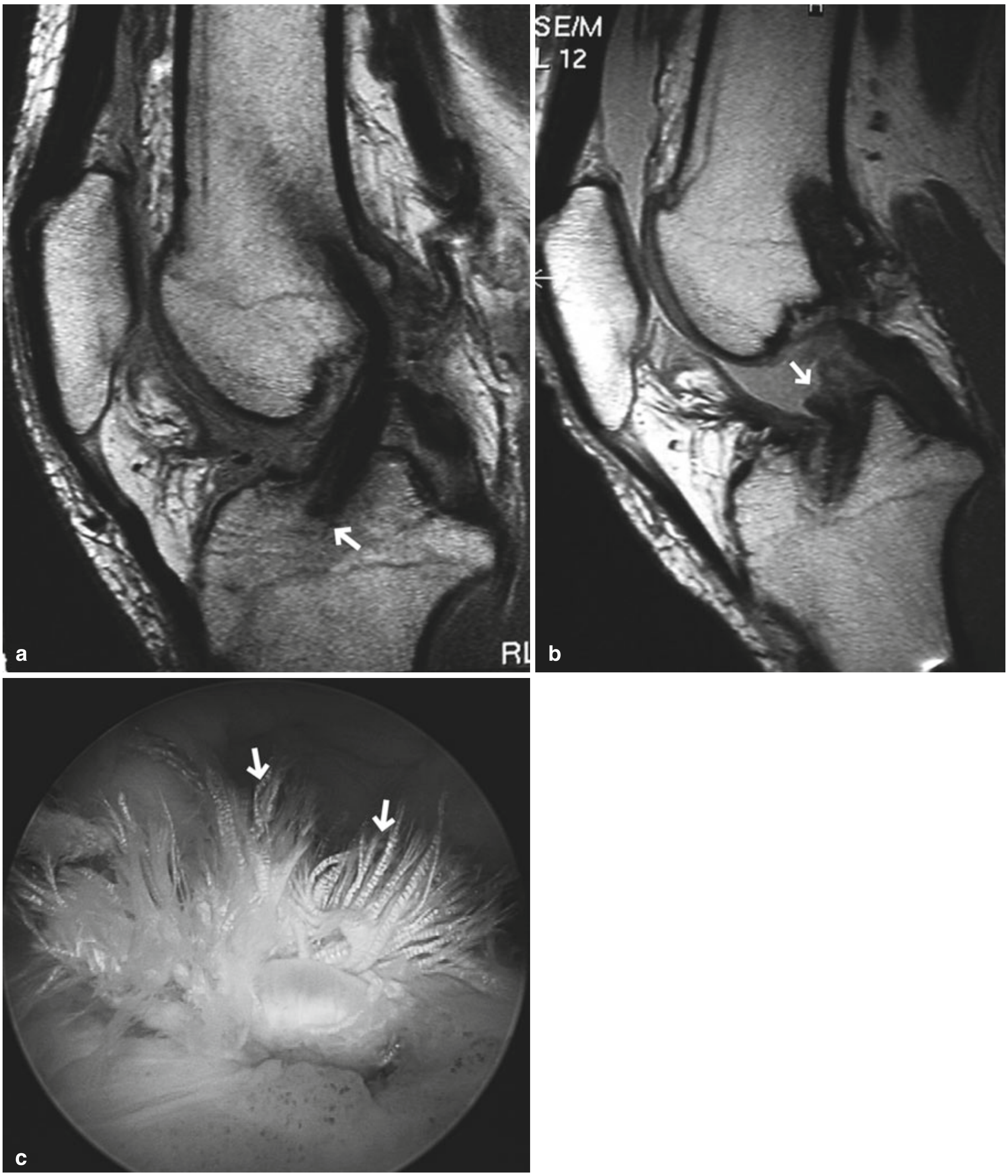

Fig. 3.32 Torn autograft following ACL reconstruction. PDWI acquired (**a**) 2 weeks postoperatively and (**b**) 6 months postoperatively. In this patient, autograft was anchored to the entry point of the tibial tunnel (*arrow*, **a**) using a tape. This technique can minimize the length of graft that needs to be harvested and the length of the tunnel that needs to be created. Use of endobuttons will reduce the amount of metal-related artifact in the postoperative MRI; 6 months after the surgery, the autograft was torn (*arrow*, **b**), and the MRI depicts hyperintensity and discontinuity of the graft within the intercondylar space. Arthroscopy confirmed the disruption of the graft fibers (*arrows*, **c**)

inferior border of the intercondylar portion of the femur, leading to frequent graft tear (Fig. 3.33).

- In case of a partial tear, part of the fibrous bundle is disrupted and elongated (Fig. 3.34).
- After a long period of time following reconstructive surgery, tibial tunnel may become enlarged (Fig. 3.35).

References

Horton LK, Jacobson JA, Lin J, Hayes CW. MR imaging of anterior cruciate ligament reconstruction graft. AJR. 2000;175: 1091–7.

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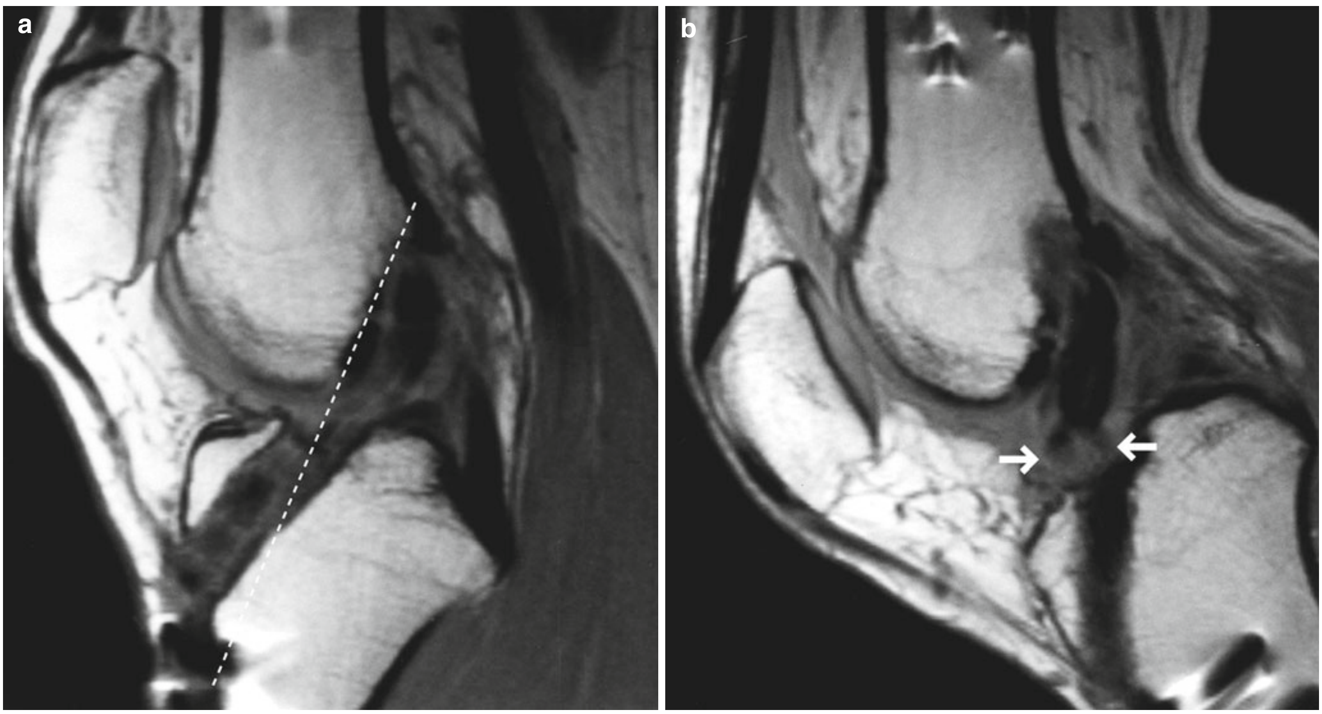

Fig. 3.33 **Torn autograft due to impingement**. PDWI of the knee acquired at (**a**) extended position and (**b**) flexed position. (**a**) Tibial bone tunnel is not parallel to the Blumensaat's line and is located too anteriorly. This led to impingement of the graft, resulting in the graft tear (*arrows*, **b**)

Fig. 3.34 **Partially torn autograft following ACL reconstruction**. (**a**) PDWI acquired 6 months postoperatively and (**b**) sagittal and (**c**) coronal PDWI acquired 1 year postoperatively in a man his 20s. At 6 months, the autograft appears homogeneously hypointense, consistent with normal postoperative appearance. However, at 1 year, intragraft hyperintensity is noted, and there is a kink (*arrow*) which is abnormal. This represents partial tear of the autograft

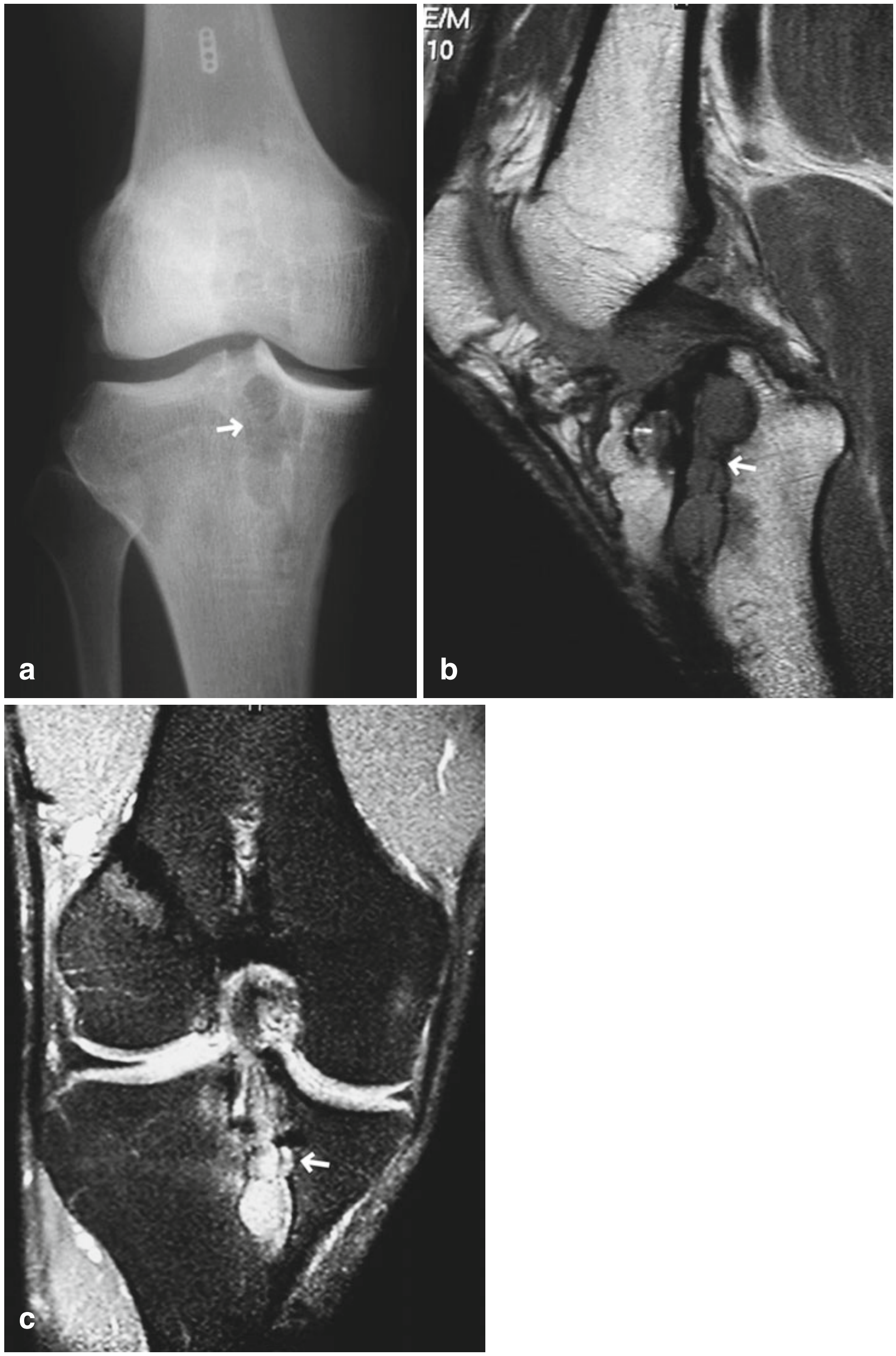

Fig. 3.35 Cystic changes of the autograft and enlargement of tibial bone tunnel. (**a**) Anteroposterior radiograph, (**b**) PDWI, and (**c**) coronal FS PDWI taken 3.5 years postoperatively in a man in his 20s. Enlargement of tibial bone tunnel (*arrow*, **a**) is visualized by radiography, and MRI reveals the presence of cystic lesions within the bone tunnel (*arrows*, **b** and **c**)

3.15 Post-arthroscopic Changes of Infrapatellar Fat Pad

- During the arthroscopic examination of the knee, at least two ports are created through infrapatellar (Hoffa's) fat pad. The sites of ports will become fibrosed, and scar tissue will form postoperatively. It will eventually be absorbed and disappear 1 or more years after the surgery in more than half of cases (Fig. 3.36).
- Rarely, the fibrous scar tissue persists (Fig. 3.37), but it does not usually cause any problems. In some cases, however, it can become inflamed and swollen.
- Fibrous thickening of the Hoffa's fat pad may occur anterior to the tibial bone tunnel. This may prevent complete extension of the knee and is called a cyclops lesion (Fig. 3.38).

References

Bradley DM, Bergman AG, Dillingham MF. MR imaging of cyclops lesions. AJR. 2000;174:719–26.
McCauley TR. MR imaging evaluation of the postoperative knee. Radiology. 2005;234:53–61.

What Is Cyclops?

- Cyclops, in Greek mythology, was a member of a primordial race of giants with a single eye, lived in the isle of Sicily, and fashioned thunderbolts for Zeus to use as weapons. On arthroscopy of the knee after ACL reconstruction, a protruded fibrous thickening appeared like a "single eye" of the cyclops, and thus this lesion was given its name.

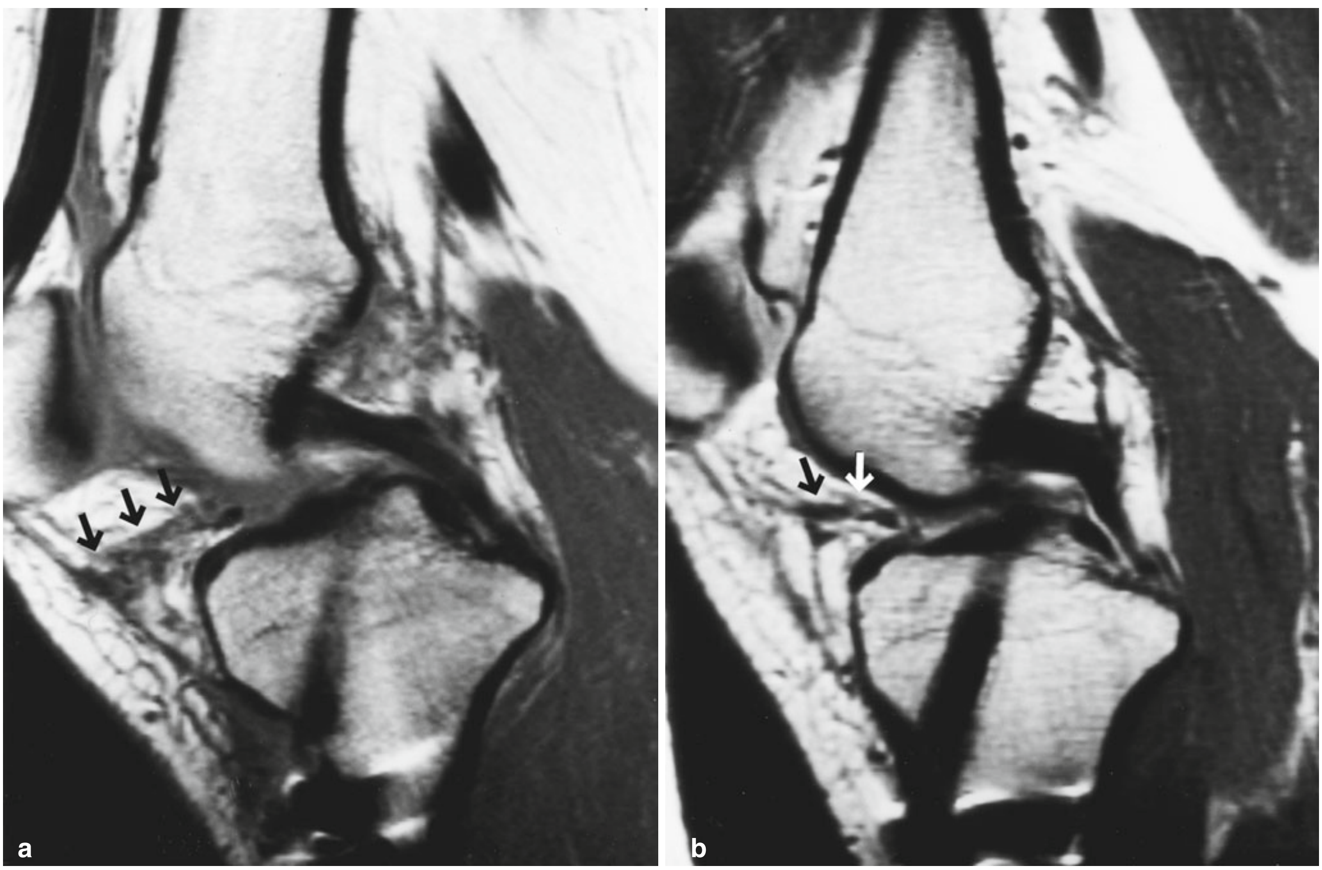

Fig. 3.36 Fibrous scar of Hoffa's fat pad following arthroscopic ACL reconstruction. PDWI of a woman in her 20s acquired (**a**) 3 months postoperatively and (**b**) 1 year postoperatively. The entry route (*arrows*) of the arthroscopic port forms scar tissue and eventually absorbed

Fig. 3.37 Fibrous scar of Hoffa's fat pad seen 4 years post-arthroscopy. T2*WI of a woman in her 30s. Fibrous scar that corresponds to the entry route of the arthroscopic port is still visible (*arrows*)

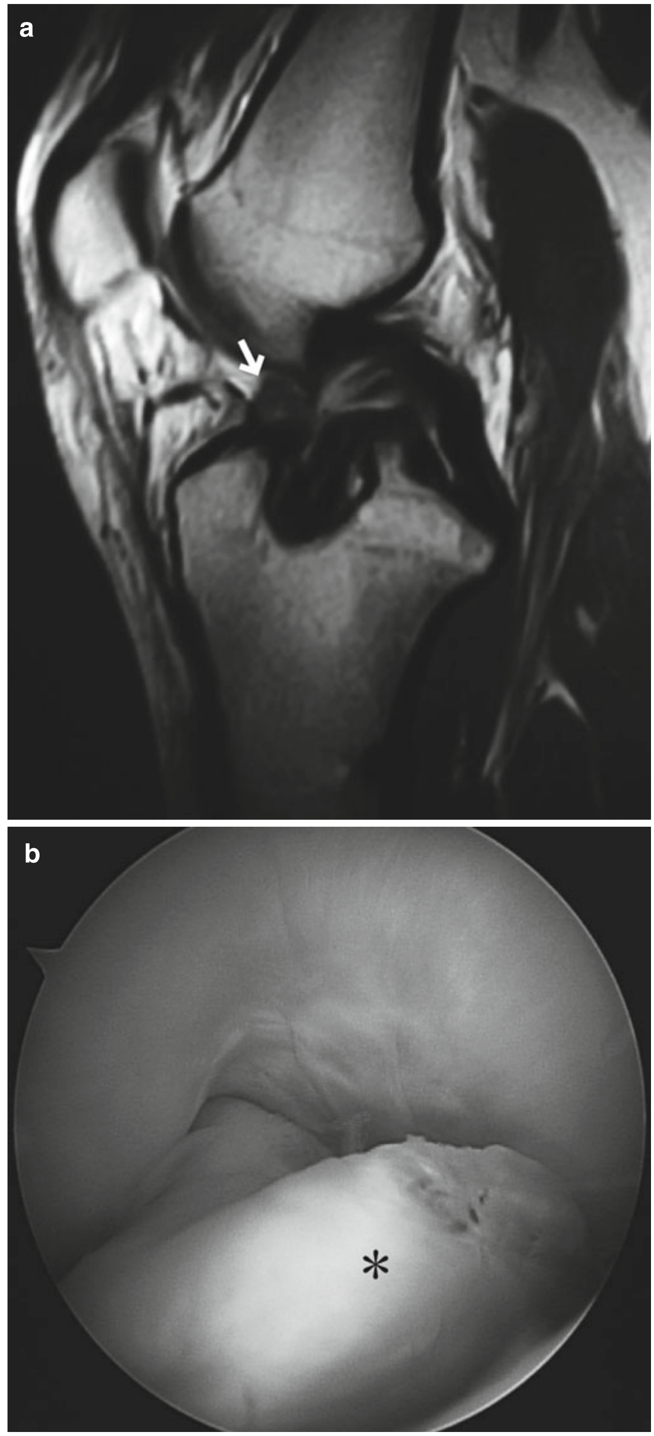

Fig. 3.38 Cyclops lesion. (**a**) PDWI and (**b**) arthroscopic image of a male patient in his 30s who underwent ACL reconstruction 1.5 year ago and had problems with knee extension. There is fibrous thickening of the Hoffa's fat pad (*arrow*, *), located anterior to the opening of the tibial bone tunnel (Images courtesy of Dr. Kotaro Ikeda, Department of Orthopedics, Ichihara Hospital, Japan)

3.16 Conservative Therapy of Torn ACL

- In cases of incomplete ACL tear in young patients whose growth plate has not closed or in elderly patients with limited activity level, conservative therapy may be a preferred option (Fig. 3.39).
- Soon after the injury, patients start exercise therapy while wearing a protective gear to promote the repair process of the damaged ligament.
- During careful follow-up, secondary meniscal or cartilage damage may occur. If reinjury of ACL itself occurs, surgical repair is often considered at that stage.

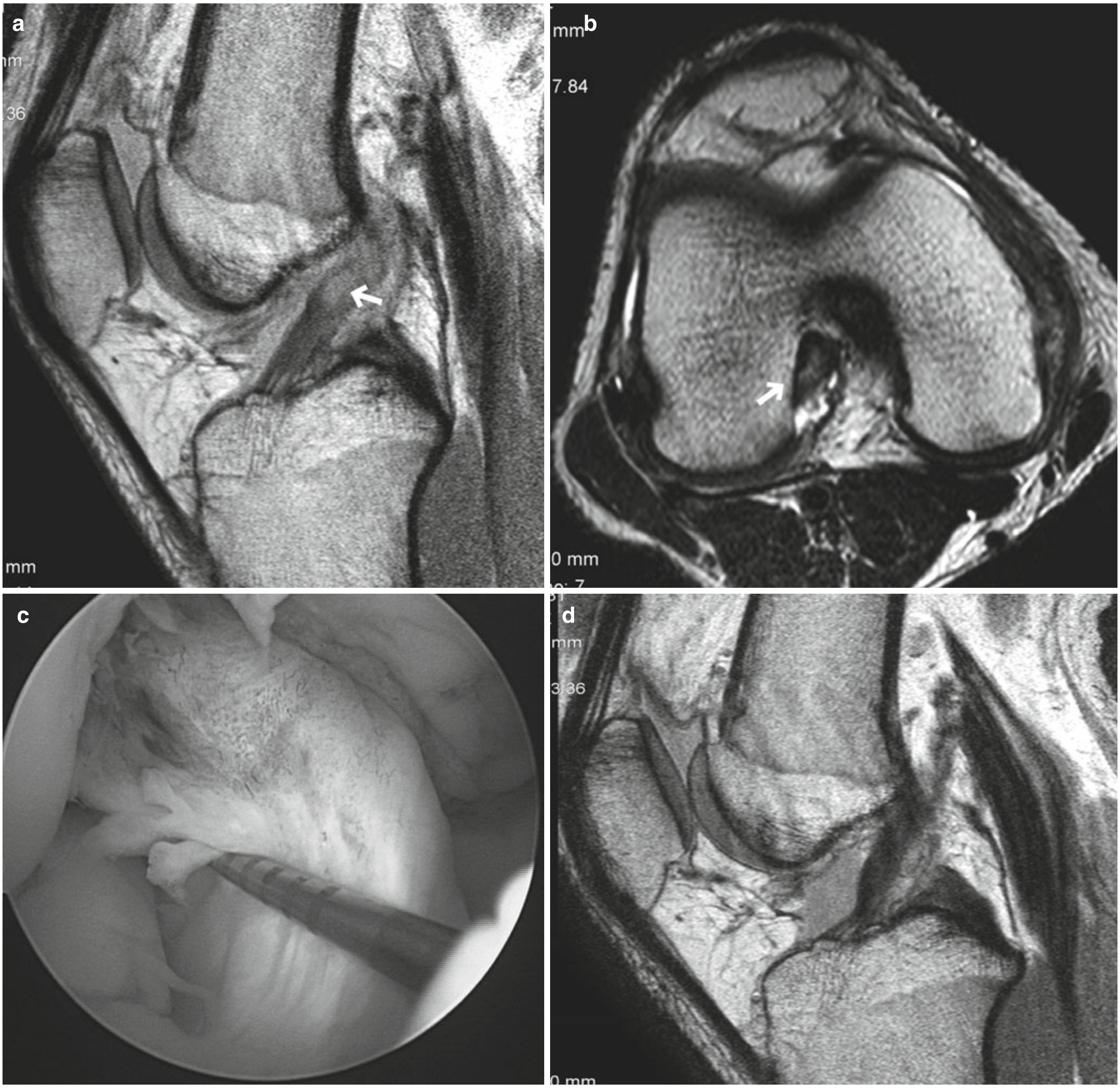

Fig. 3.39 **Conservative therapy of ACL tear**. A man in his late teens. (**a**) PDWI acquired immediately after injury. (**b**) Axial T2WI acquired immediately after injury. (**c**) Arthroscopic image immediately after injury. (**d**) PDWI acquired 6 months after injury. (**e**) Axial T2WI acquired immediately after injury. Immediately after the injury, ACL exhibits localized hyperintensity near the femoral attachment site, consistent with ACL partial tear (*arrows*, **a, b**). On arthroscopy, some loosening of ACL was observed, but its surface was covered by synovium (**c**). Conservative therapy was instituted, and after 6 months, the localized hyperintensity within ACL disappeared (**d, e**) and the function of the knee returned to normal (Images courtesy of Dr. Akihiro Kanamori, Department of Orthopedics, Tsukuba University, Japan)

Fig. 3.39 (continued)

Elite Athletes and Non-athletes

Diagnostic criteria for knee injury inevitably differ in elite athletes and nonathletes (laypersons). For elite athletes, such as Olympians and professional athletes, sustaining a knee injury may be "critical." For nonathletes, a small meniscal tear may not affect their daily life (except perhaps for refraining from sports activities until recovery), but the problem may be much more serious for athletes. Often, the knee of elite athletes has been exposed to much wear and tear, and some of them have osteoarthritis at young age. It is an uneasy moment for us to break bad news to them following MRI examination. However, as soon as the athlete is determined to compete in a competition (e.g., Olympics) regardless of the condition of the knee, as diagnosed by knee MRI, whatever we diagnose will become irrelevant anyway.

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Umans H, Wimpfheimer O, Haramati N, Applbaum YH, Adler M, Bosco J. Diagnosis of partial tears of the anterior cruciate ligament of the knee: value of MR imaging. AJR. 1995;165:893–7.

4 Posterior Cruciate Ligament (PCL)

4.1 Anatomy

- PCL is also an intra-articular, extra-synovial structure.
- Its mean length is 38 mm and mean width is 13 mm. It becomes thinner as it approaches the tibia, and it is partially embedded within the joint capsule. Its tibial attachment site is located 1 cm below the articular surface.
- PCL is twice as thick as ACL, and it has twice as strong tensile strength as other ligaments in the knee. It receives abundant vascular supply.
- PCL consists of two main fibrous bundles, that is, thicker anterolateral bundle and thinner posteromedial bundle. In normal condition, it is impossible to differentiate these two on MRI, and PCL appears as a one band with homogeneous texture. When PCL is damaged, only one of the two bundles may be torn (see later description).
- PCL receives tension at all angles during flexion and extension of the knee.
- PCL runs within the intercondylar space in the superior-inferior direction, almost in parallel to the long axis of the knee (Fig. 4.1). It is therefore easy to visualize it on sagittal MRI. It is extremely rare not to be able to delineate PCL in a routine MRI examination.
- Meniscofemoral ligament is also called "the third cruciate ligament" and crosses in front of and behind PCL. This ligament connects the posterior horn of the lateral meniscus

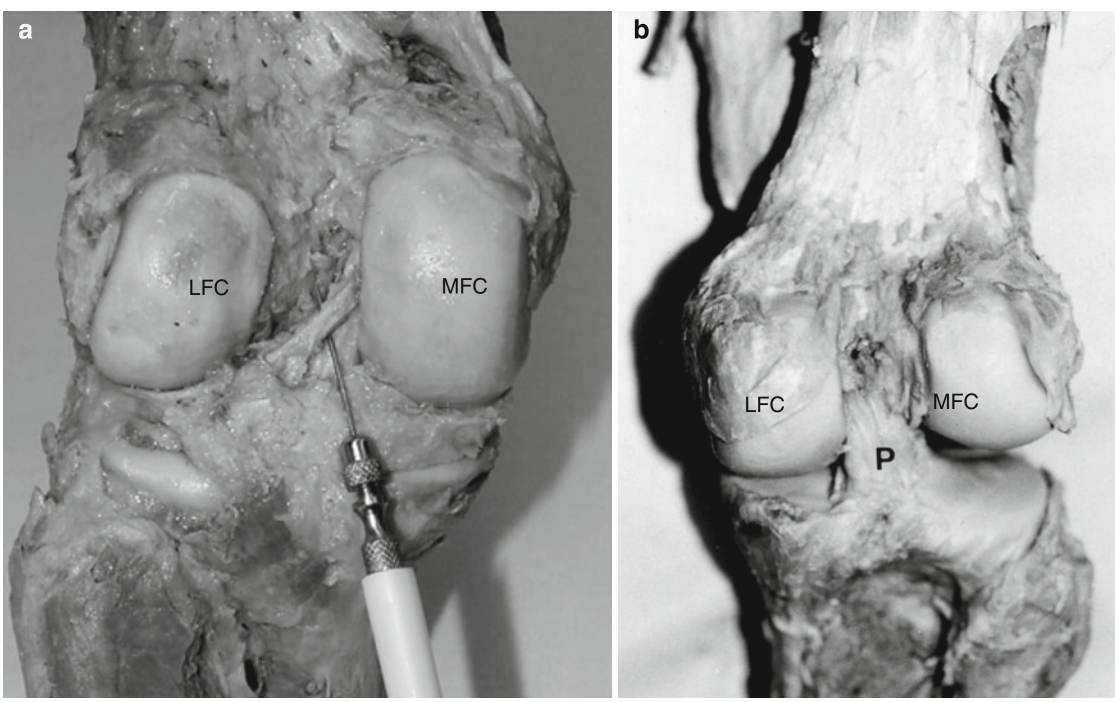

Fig. 4.1 Cadaveric specimen showing Wrisberg's ligament (a) and PCL (b). Wrisberg's ligament runs diagonally between the posterior horn of the lateral meniscus to the posterior surface of the medial femoral condyle (needle is inserted underneath the Wrisberg's ligament, **a**). Deep to the Wrisberg's ligament lies PCL, which runs vertically almost in parallel to the long axis of the knee (**b**). PCL is thick. *LFC* lateral femoral condyle, *MFC* medial femoral condyle, *P* PCL

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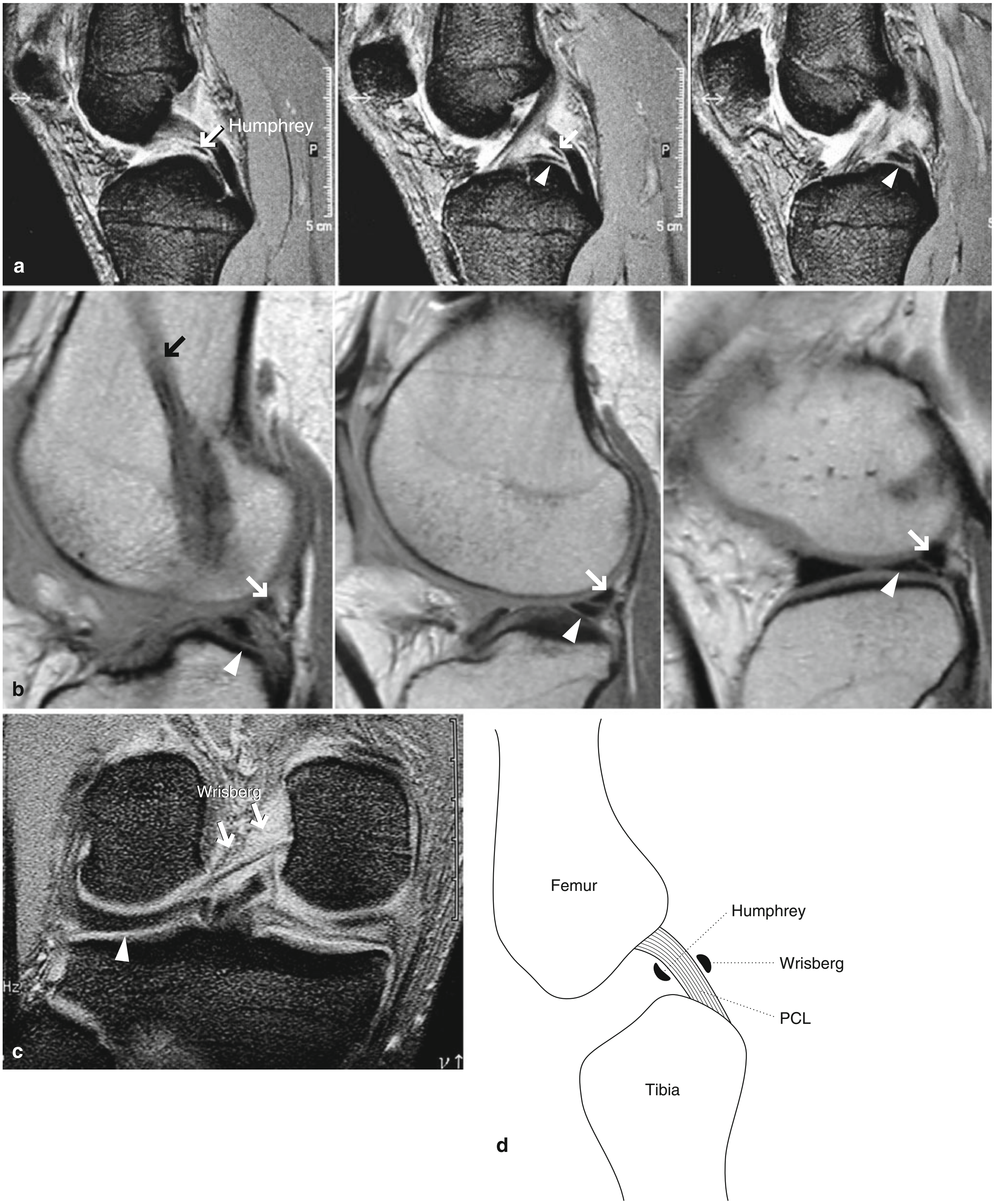

Fig. 4.2 Humphrey's and Wrisberg's ligaments. Sagittal MRI demonstrates meniscofemoral ligament (Humphrey's, white arrow in b, and Wrisberg's, white arrow in (**c**). Coronal MRI also demonstrates Wrisberg's ligament (**c**). These ligaments should not be mistaken as abnormalities of PCL or the lateral meniscus (*arrowheads*). The patient in (**b**) had ACL reconstruction (*black arrow*). (**d**) Schematic illustration showing the location of these ligaments

and the posterior surface of the medial femoral condyle. Note that it has the same name as the deep layer of the MCL (see later description). The portion of the meniscofemoral ligament that crosses in front of PCL is Humphrey's ligament, and that crosses behind PCL is Wrisberg's ligament. The latter is slightly larger than the former. Humphrey's ligament is found in approximately 24% of patients, Wrisberg's ligament in 23%, and both ligaments in 12% of patients (Fig. 4.2). These ligaments should not be mistaken as abnormality of PCL or menisci.

References

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Grover JS, Bassett LW, Gross ML, et al. Posterior cruciate ligament: MR imaging. Radiology. 1990;174:527–30.

4.2 PCL Tear

- PCL is thick and strong, and it is said to be less common than ACL tear (3–20% of all knee injuries, <1% of knee trauma requiring surgical intervention). However, this may be due to the fact that it is difficult to diagnose PCL tear clinically.
- To have PCL torn, an enormous force is required, which is mostly due to traffic accident and rarely due to sports injury.
- PCL injury alone is very rare, and often damages to ACL, collateral ligaments and menisci coexist.
- Even if PCL is damaged and its function impaired or lost, the knee instability upon weight-bearing is less commonly seen than in ACL tear, and patients may not be aware of any symptoms. Damages to menisci and cartilage secondary to PCL tear is less commonly seen than in ACL tear.

Mechanism of injury for PCL tear

1. Direct force to the anterior aspect of the tibia: This is seen in "dashboard injury" in car accidents. Direct force is applied to the anterior aspect of the tibia when the knee is flexed, and the tibia is forcefully displaced posteriorly. This is the most common cause of PCL tear. In this mechanism, PCL is torn in the middle portion, and the posterior joint capsule may also be disrupted. Bone bruise may be seen in the posterior surface of the lateral femoral condyle and the anterior part of the tibial plateau (Fig. 4.3).
2. Overextension of the knee: Avulsion fracture of the tibial attachment site of the PCL is likely to occur. In this mechanism, the PCL itself is commonly preserved without tear. It is more commonly seen in elderly persons, unlike ACL avulsion fracture which is more common in young persons. Overextension of the knee results in collision of the anterior aspects of the femur and tibia, resulting in bone bruise in those locations (Fig. 4.4).

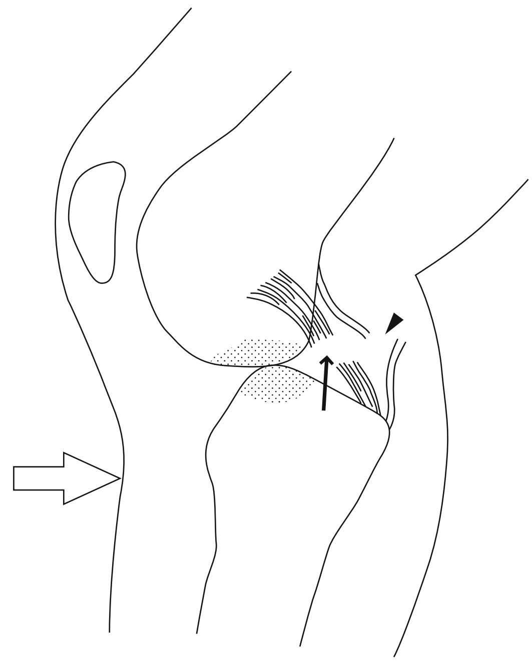

Fig. 4.3 Mechanism of PCL tear (1). Direct force (*large white arrow*) is applied to the anterior aspect of the tibia. The tibia is forcefully displaced posteriorly. PCL is torn in the middle portion (*arrow*), and the posterior joint capsule may also be disrupted (*arrowhead*). Bone bruise may be seen in the posterior surface of the lateral femoral condyle and the anterior part of the tibial plateau (Illustration adapted from Sonin et al. 1995)

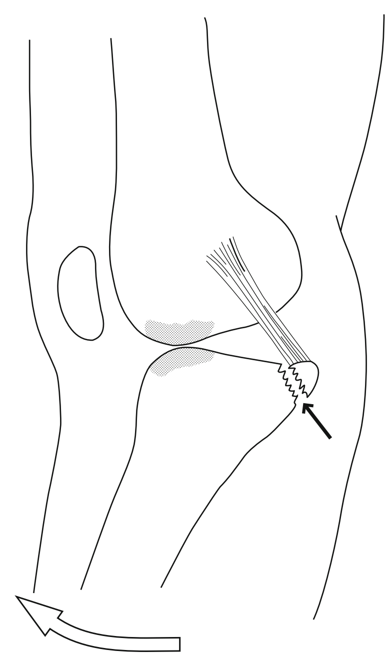

Fig. 4.4 Mechanism of PCL tear (2). Overextension of the knee. Avulsion fracture of the tibial attachment site of the PCL is likely to occur (*arrow*). Overextension of the knee results in collision of the anterior aspects of the femur and tibia, resulting in bone bruise in those locations (Illustration adapted from Sonin et al.)

3. Extreme internal or external rotation: In this mechanism, tear of both medial and lateral collateral ligaments occur, as well as tear of ACL and PCL.

Reference

Sonin AH, Fitzgerald SW, Hoff FL, et al. MR imaging of the posterior cruciate ligament: normal, abnormal and associated injury patterns. Radiographics 1995;15:551–61.

4.3 MRI Findings of PCL Tear

- Value of clinical examination is limited for the diagnosis of PCL tear. Therefore MRI plays an important role:
  1. Complete tear: Discontinuation or loss of ligament fibers (Fig. 4.5). However, as described earlier, PCL is thick and strong, and thus it is rare for a complete tear to occur.
  2. Partial tear (intrasubstance injury): Continuity of the ligament is retained, especially the peripheral part of PCL is commonly preserved. Most PCL tear exhibits this pattern. Generally, PCL will be swollen, and there will be intrasubstance hyperintensity for its entire length (Fig. 4.6). When ligaments of Humphrey and Wrisberg remain intact, they appear like a rope being tightly bound around the swollen PCL (Fig. 4.7). Intrasubstance hyperintensity can also be localized (Fig. 4.8). Only one of anterolateral bundle (ALB) and posteromedial bundle (PMB) may be torn and can be visualized on MRI (Figs. 4.9 and 4.10).
  3. Avulsion fracture of the PCL attachment site: Tibial attachment site of PCL is prone to avulsion fracture. In contrast to ACL tear which is common in young persons, PCL tear is more common in elderly persons (Fig. 4.11). The location of avulsion fracture may be relatively high.

Reverse Segond fracture

- PCL tear may be accompanied by avulsion fracture of the deep layer of MCL. This is due to avulsion fracture of meniscotibial ligament which attaches to the medial border of the tibia. This is called "reverse Segond fracture" (Fig. 4.12), in comparison to the Segond fracture which involves ACL tear and avulsion fracture of the lateral border of the tibia. Reverse Segond fracture occurs as a result of valgus and external rotation of the distal lower limb. Because of the proximity of the deep layer of MCL to the medial meniscus, reverse Segond fracture may be accompanied by medial meniscal tear.

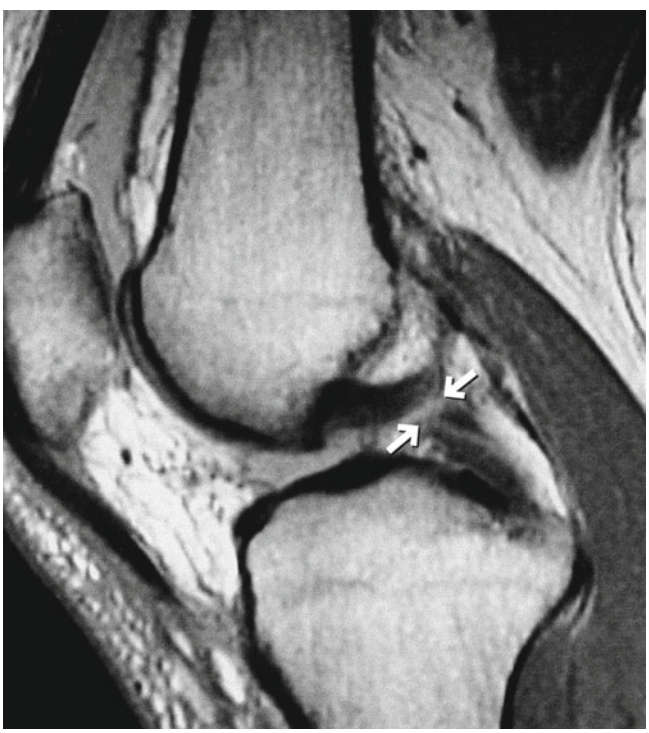

Fig. 4.5 Complete PCL tear. PDWI of a woman in her 30s shows complete tear of PCL at its mid-portion (*arrow*)

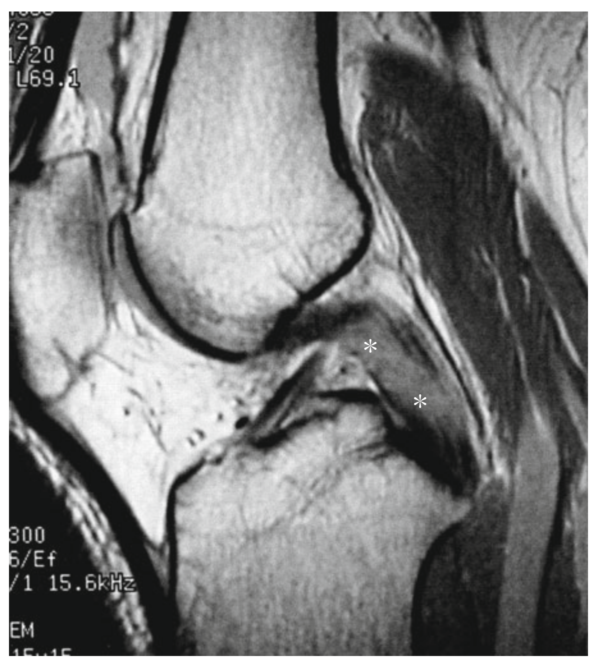

Fig. 4.6 Partial tear of PCL (intrasubstance injury) (1). PDWI of a man in his 30s shows partially torn PCL, which is swollen and shows hyperintensity (*) for the entire length, representing intrasubstance injury. Periphery of the PCL retains continuity of fibers

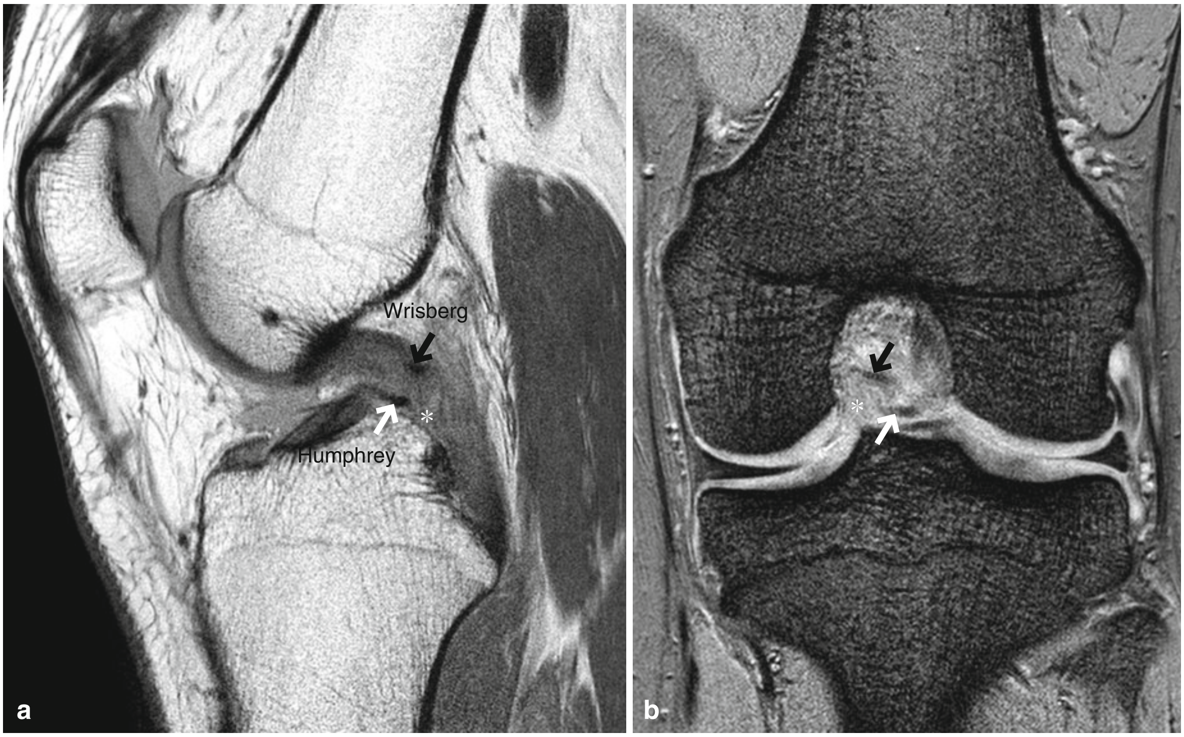

Fig. 4.7 Partial tear of PCL (intrasubstance injury) (2). (**a**) PDWI and (**b**) coronal T2*WI of a man in his 30s show swollen PCL with generalized intrasubstance hyperintensity (*) and intact ligaments of Humphrey (*white arrow*) and Wrisberg (*black arrow*), which appear like ropes tightly bound around the PCL

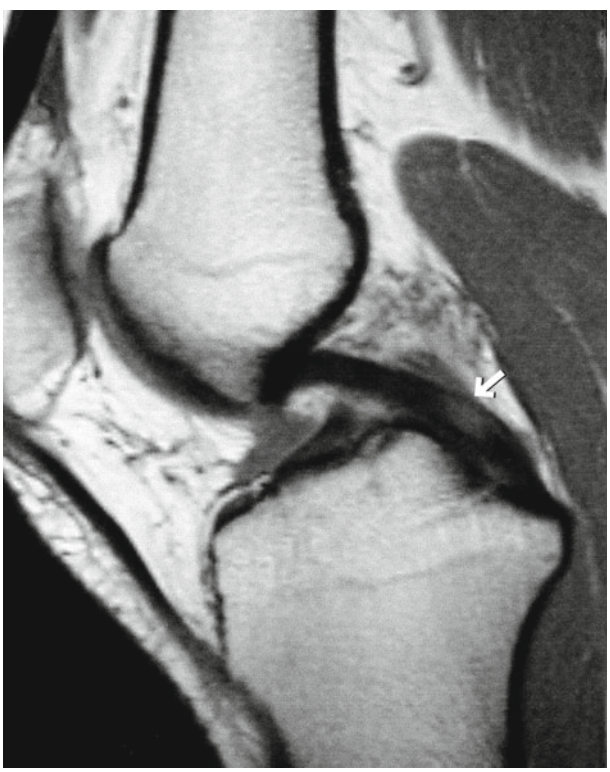

Fig. 4.8 Partial tear of PCL (intrasubstance injury) (3). PDWI of a woman in her twenties shows localized hyperintensity within the PCL near the tibial attachment site, representing partial tear of PCL (*arrow*)

Reference

Escobedo EM, Mills WJ, Hunter JC. The "reverse Segond" fracture: association with a tear of the posterior cruciate ligament and medial meniscus. AJR. 2002;178:979–83.

Fig. 4.9 **Partial tear of PCL (intrasubstance injury) (4), injury of anterolateral bundle**. (**a**) PDWI and (**b**) axial FS PDWl of a man in his 50s show selective swelling and intrasubstance hyperintensity within the anterolateral bundle of PCL (*arrow*)

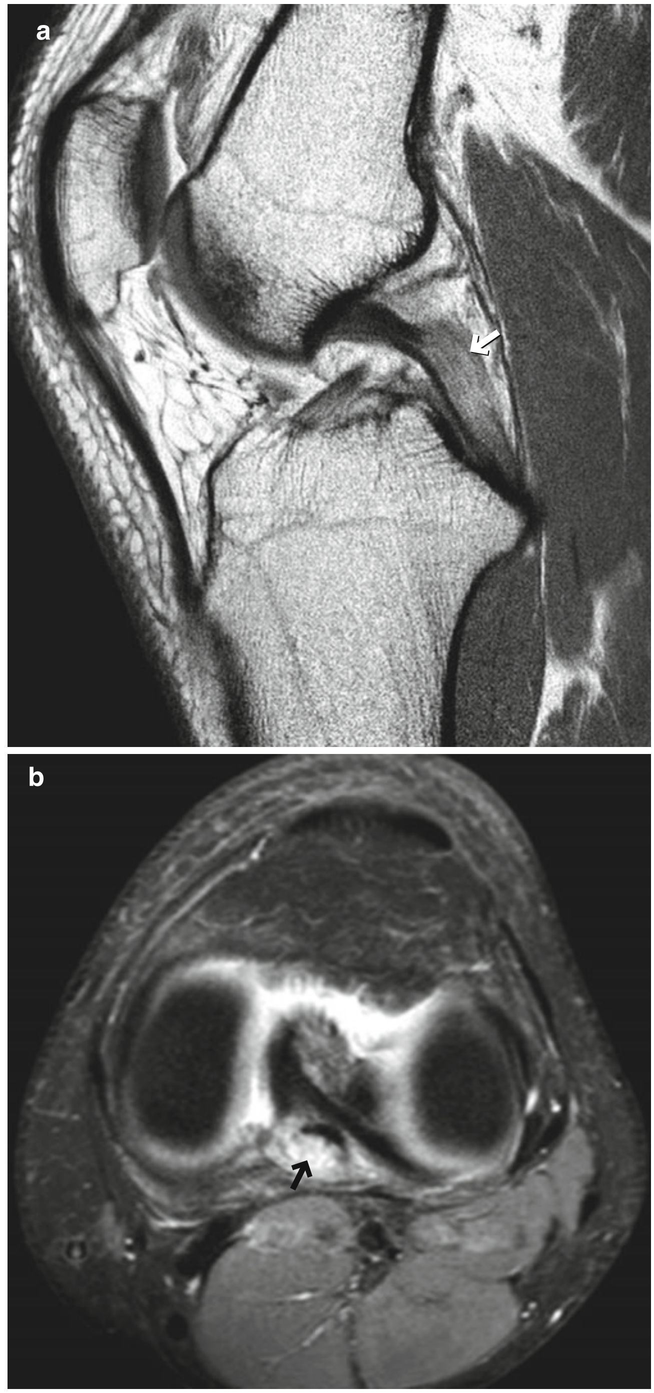

Fig. 4.10 **Partial tear of PCL (intrasubstance injury) (4), injury of posteromedial bundle**. (**a**) PDWl and (**b**) axial FS PDWI of a man in his 20s show selective swelling and intrasubstance hyperintensity within the posteromedial bundle of PCL (*arrow*)

Fig. 4.11 Avulsion fracture of PCL attachment site of the tibia. T2*WI of a woman in her 70s shows an avulsion fracture of the PCL attachment site of the tibia. A bone fragment with no MR signal (*arrows*) is seen

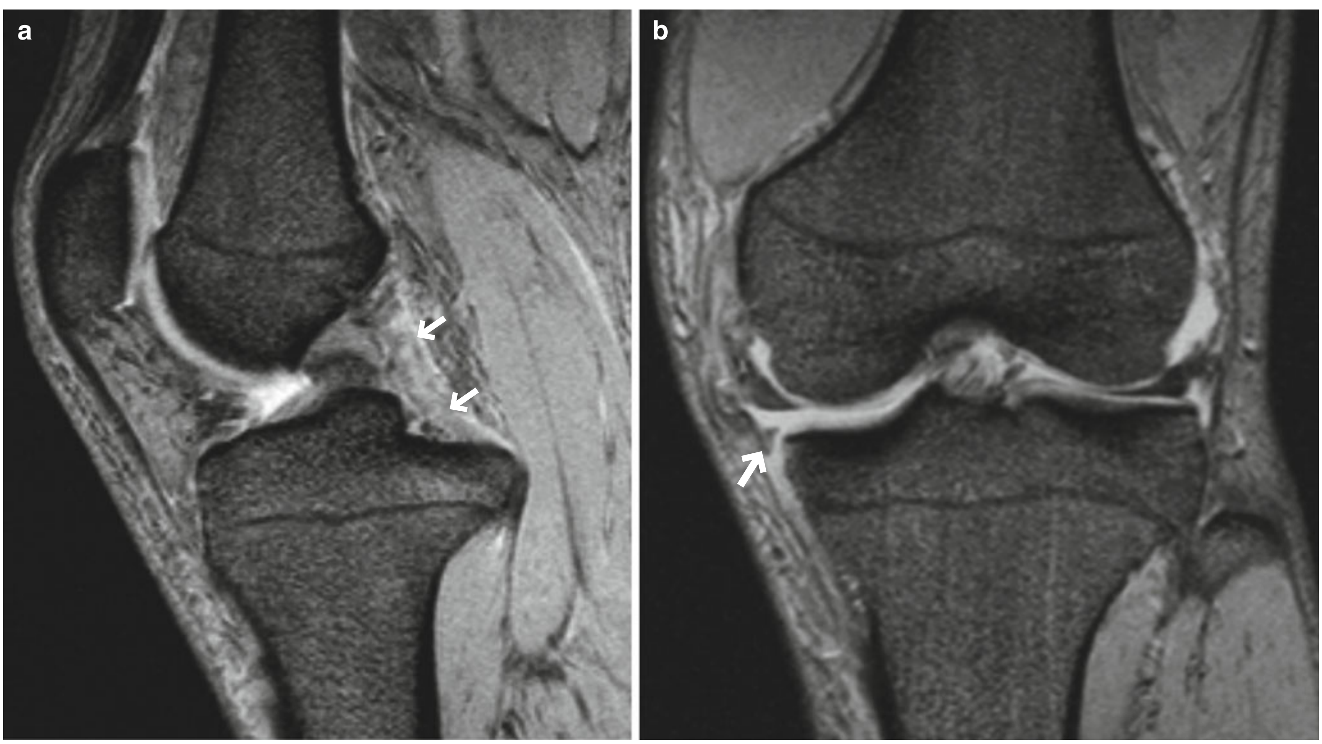

Fig. 4.12 Reverse Segond fracture. (**a**) Sagittal and (**b**) coronal T2*WI, (**c**) sagittal PDWI, and (**d**) anteroposterior radiograph of the knee of a man in his 30s. There is intrasubstance injury to the PCL (*arrows*, **a**), alongside with an avulsion fracture of the deep layer of the MCL (meniscotibial ligament, *arrows* in **b, d**) and medial meniscal tear (*arrow*, **c**)

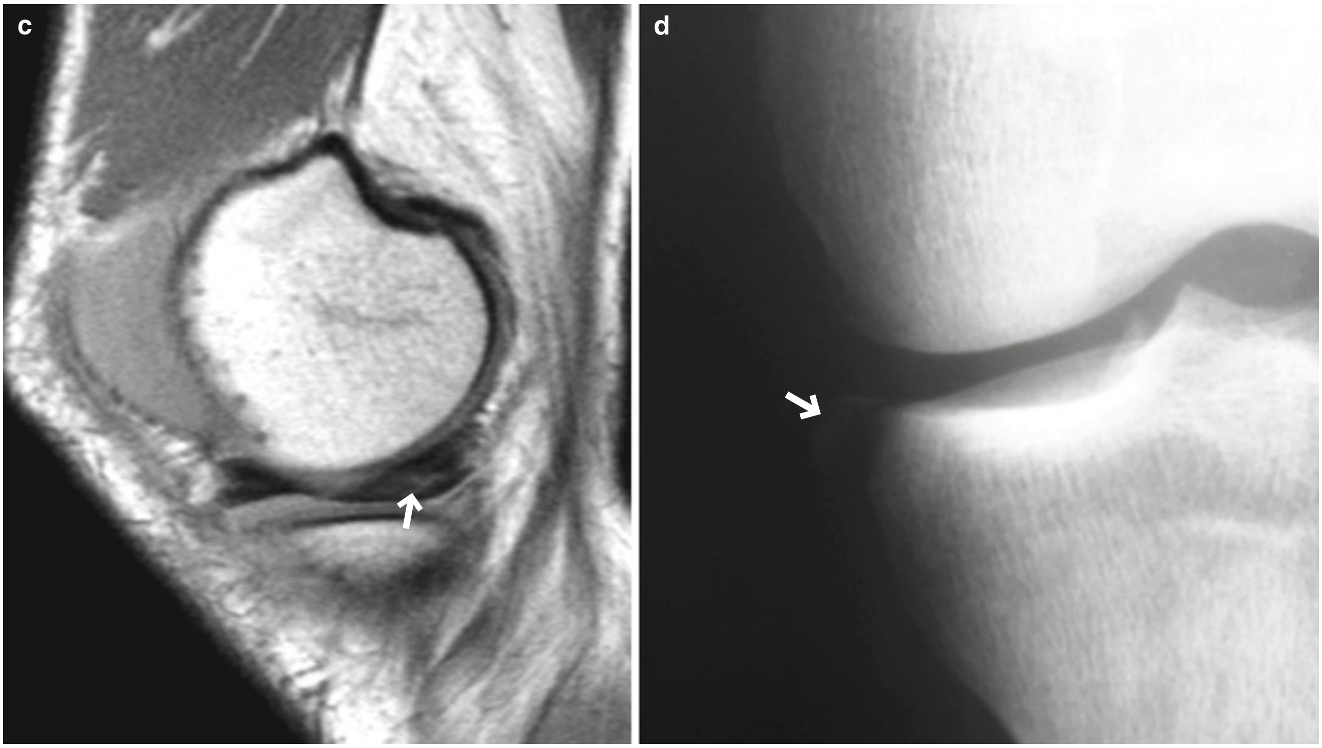

Fig. 4.12 (continued)

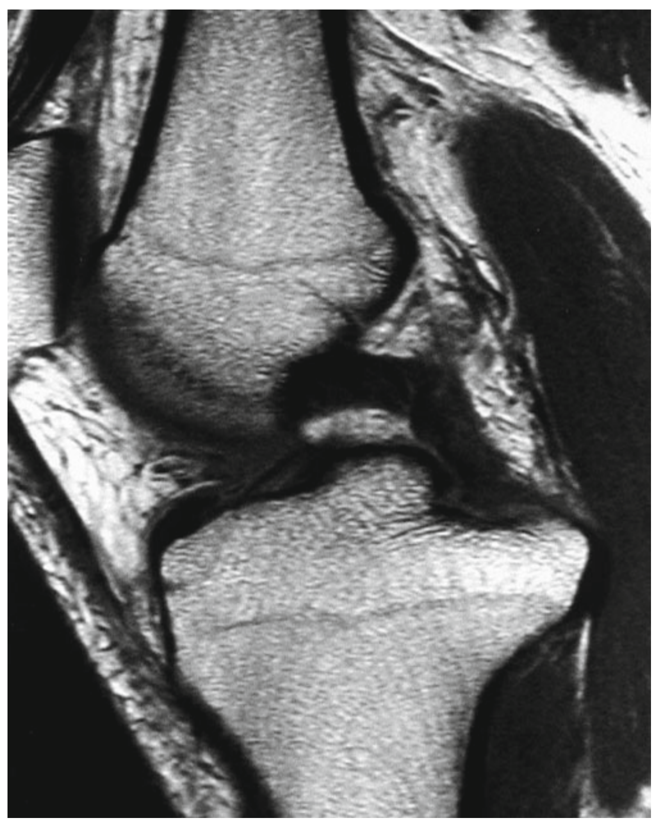

Fig. 4.13 **Long-term follow-up after PCL tear**. PDWI of a man in his 30s. The image was acquired 1 year after the time of injury. MRI appearance of the PCL is normal, but clinical examination reveals persistence of the signs suggestive of PCL instability

Long-term MRI follow-up after PCL tear

- After a long period of follow-up, intrasubstance hyperintensity seen within the PCL may become normalized (Fig. 4.13). In this instance, clinical examination may still reveal signs of PCL instability, and thus radiologists should be careful not to diagnose such PCL as "healed" without due consideration. PCL buckling, which can be seen as a secondary finding of ACL tear, can also be observed in PCL tear.
- Repair process of intrasubstance injury of PCL will take place within the entire length of PCL, and thus it is rare for the ligament to become thinner (unlike in the case of ACL tear). This is said to be due to the abundance of vascular supply to the PCL (Fig. 4.14).

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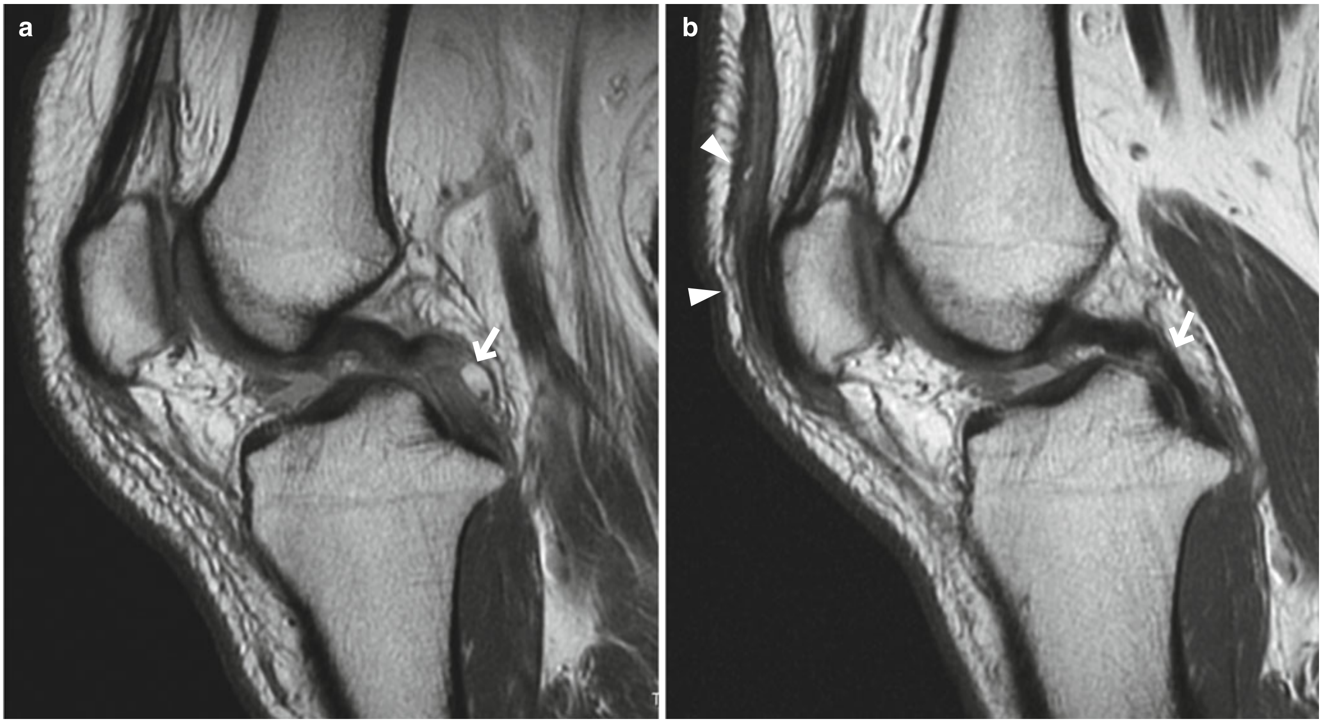

Fig. 4.14 Atrophy of PCL following tear. PDWI of a man in his 30s, acquired (**a**) immediately after injury and (**b**) 1.5 years afterward. At an acute stage, PCL is swollen distally and shows intrasubstance hyperintensity and a cystic change in a distal portion (*arrow*, **a**); 1.5 years later, the portion of PCL with the cystic change in (**a**) is now atrophied (*arrow*, **b**). Also, note the scar tissue formation following prepatellar bursitis (*arrowheads*, **b**)

5 Medial Collateral Ligament (MCL)

5.1 Anatomy

- MCL generally consists of three layers (Figs. 5.1 and 5.2), but the naming and classification of the layers that comprise MCL may vary according to different authors:
- Layer I: Thin sheet that overlies the two heads of the gastrocnemius and the structures of the popliteal fossa.
- Layer II: Superficial layer of the MCL (alternatively called tibial collateral ligament). Anteriorly, Layer II blends with Layer I through the split to form the medial patellar retinaculum. Posteriorly, it blends with Layer III via the posterior oblique ligament.
- Layer III: Deepest layer of the MCL called medial capsular ligament, which is continuous with the medial joint capsule.
- Fibrofatty tissue fills the space between Layer I and II, and the tendons of semitendonisus and gracilis run through this space.
- Small bursae are located within fibrofatty tissue between Layer II and II (Fig. 5.3).
- Superficial layer of MCL runs vertically and has a width of 15 mm, length of 8–12 cm, and thickness of 2–3 mm.
- The posterior oblique portion of the MCL (posterior oblique ligament) is fused with layer III and closely attached to the medial meniscus and also the tibia (Fig. 5.4).

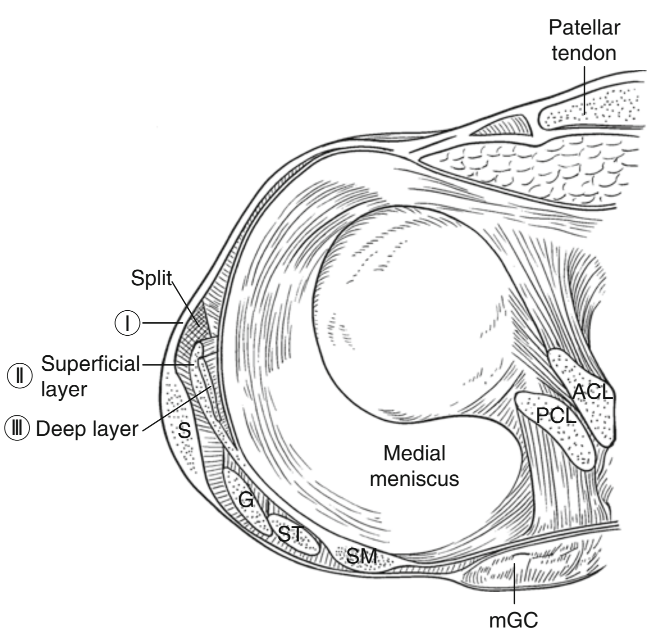

Fig. 5.1 Three layers of the MCL. *Layer I*: thin sheet that overlies the two heads of the gastrocnemius and the structures of the popliteal fossa. *Layer II*: superficial layer of MCL. *Layer III*: medial joint capsule including the deep layer of MCL. *S* sartorius, *G* gracilis, *ST* semitendinosus, *SM* semimembranosus, *mGC* medial head of gastrocnemius (Illustration adapted from Warren and Marshall)

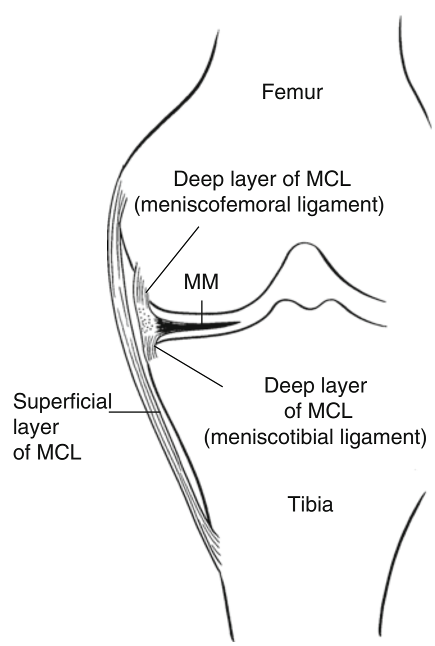

Fig. 5.2 Schematic illustration of the MCL. The superficial layer (also known as the tibial collateral ligament) and the deep layer (also known as medial capsular ligament). Superficial layer of MCL attaches to the tibia at 7–8 cm below the joint space (note the significant distance). The deep layer firmly attaches to the medial meniscus and is also known as meniscofemoral and meniscotibial ligament

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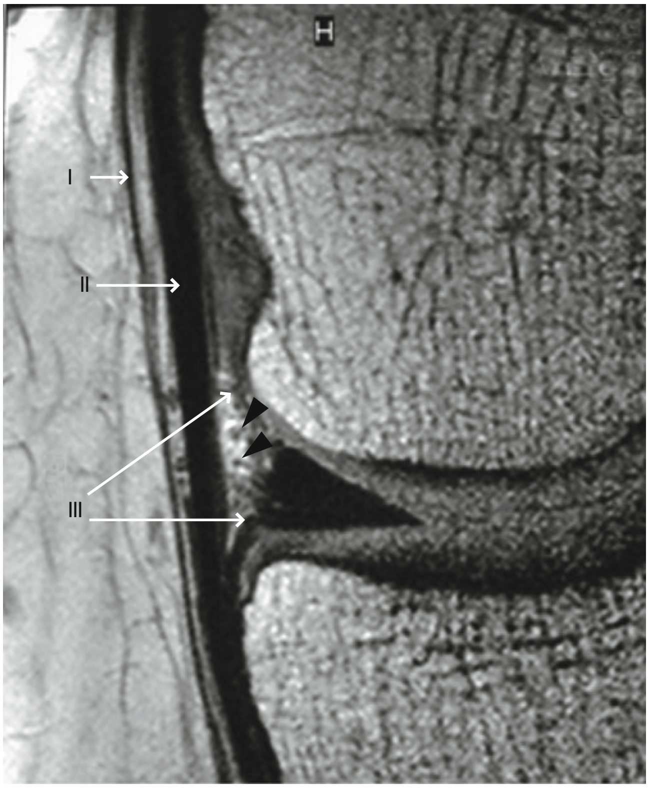

Fig. 5.3 High-resolution image of the medial compartment of the knee joint acquired using a microscopy coil (FOV 50 mm, slice thickness 1.5 mm). As shown in Fig. 5.1, *layer I*: thin sheet of fascia, *layer II*: superficial layer of the medial collateral ligament (MCL), *layer III*: deep layer of MCL, and a small bursa and small blood vessels (*arrowheads*)

- Superficial layer of MCL proximally attaches to the medial femoral condyle 5 cm above the joint space and distally attaches to the metaphyseal region of the tibia 6–7 cm below the joint space. For this reason, on MR imaging, care must be taken to include the inferior edge of the distal MCL within the FOV. The distal attachment lies beneath the pes anserinus.
- Deep to the vertical component of the superficial MCL, the capsule becomes thicker, forming the deep layer of MCL. This layer inserts directly into the edge of femur and tibial plateau and firmly attaches to the medial meniscus and thus divided into meniscofemoral and meniscotibial ligaments, respectively. However, in normal knees without joint effusion, these ligaments may not be delineated on MRI (Figs. 5.5).
- There is no direct connection between the superficial layer of MCL and the medial meniscus.
- MCL prevents resistance to valgus stress and external rotation of the distal lower limb.

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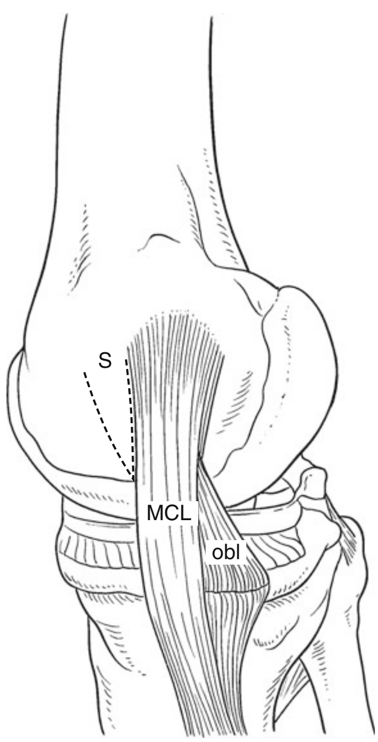

Fig. 5.4 Superficial layer of the medial collateral ligament (MCL) and posterior oblique ligament (obl). There is a split (S) anterior to the superficial layer of the MCL (see also Fig. 5.1)

Fig. 5.5 Visualization of the deep layer of MCL (*arrow*) due to the presence of joint effusion. Damage to MCL or the medial meniscus led to accumulation of joint fluid between the superficial and deep layers of the MCL (*), enabling the delineation of the deep layer

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Hamstrings and the Pes Anserinus (Fig. 5.6)

Hamstrings refer to the posterior thigh muscles that arise from the ischial tuberosity. (A commonly accepted origin of the name is that legs of ham used to be hung using the tendons behind the knee.) Medially, it comprises semitendinosus and semimembranosus, while laterally, it comprises biceps femoris. Pes anserinus ("goose's foot") is the insertion of the conjoined tendons of sartorius (arising from the anterior superior iliac spine), gracilis (arises from the anterior margin of the lower half of the symphysis pubis), and semitendinosus (arises from the tuberosity of the ischium). Semimembranosus attaches behind these three tendons.

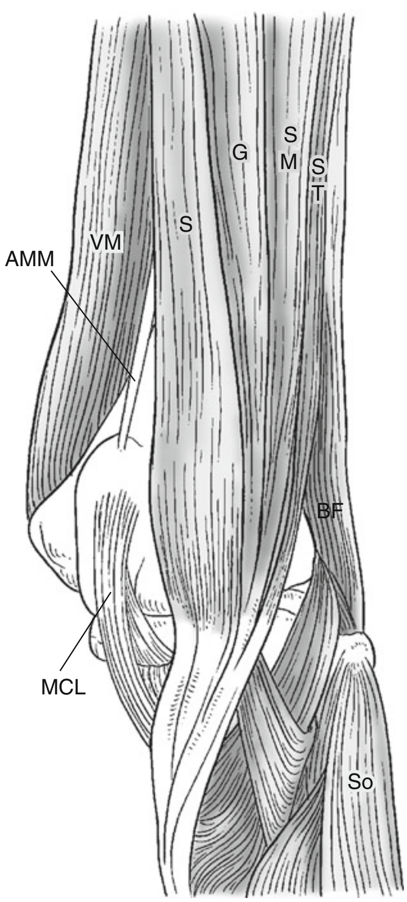

Fig. 5.6 Postero-oblique view of the medial compartment of the knee. *S* sartorius, *G* gracilis, *SM* semimembranosus, *ST* semitendinosus. Semimembranosus and semitendinosus form the medial component of the hamstrings, while sartorius, gracilis, and semitendinosus form the pes anserinus. (Only semimembranosus does not reach pes anserinus because it ends at the posterior aspect of the tibia.) *VM* vastus medialis, *BF* biceps femoris, *AMM* adductor magnus musle, *MCL* medial collateral ligament, *SO* soleus

5.2 MCL Tear

- MCL injury is the most common ligamentous injury in the knee.
- Injury of the MCL alone is likely to occur following valgus stress to the distal lower limb.
- MCL tear can be classified as the following three grades:
- Grade 1: sprain or strain, mainly consisting of elongation of the ligament without any functional loss. Treated conservatively.
- Grade 2: partial tear.
- Grade 3: complete tear.
- Differentiating between grade 2 and 3 may be impossible, even on MRI, and often written as "grade 2–3 tear."
- In grade 1 MCL tear, linear hyperintensity representing edema along the ligament's fibers due to sprain or strain can be seen (Fig. 5.7). However, this imaging finding can also be found in medial meniscal tear and knee osteoarthritis.
- In grade 2–3 MCL tear, discontinuity of the fibers and signal abnormalities due to edema and hematoma will be seen (Figs. 5.8 and 5.9).
- Edematous changes may not be limited to the MCL itself but can extend into the surrounding medial retinaculum and vastus medialis (Fig. 5.8).
- More than half of MCL tear occurs at the proximal (femoral) portion, but it can less commonly occur in the distal (tibial) portion (Fig. 5.10).

Fig. 5.7 Grade 1 tear (strain) of the MCL. A man in his 20s who had a ski injury the day before presentation. Coronal FS PDWI shows linear hyperintensity along the superficial layer of the MCL, representing edema due to strain (*arrows*)

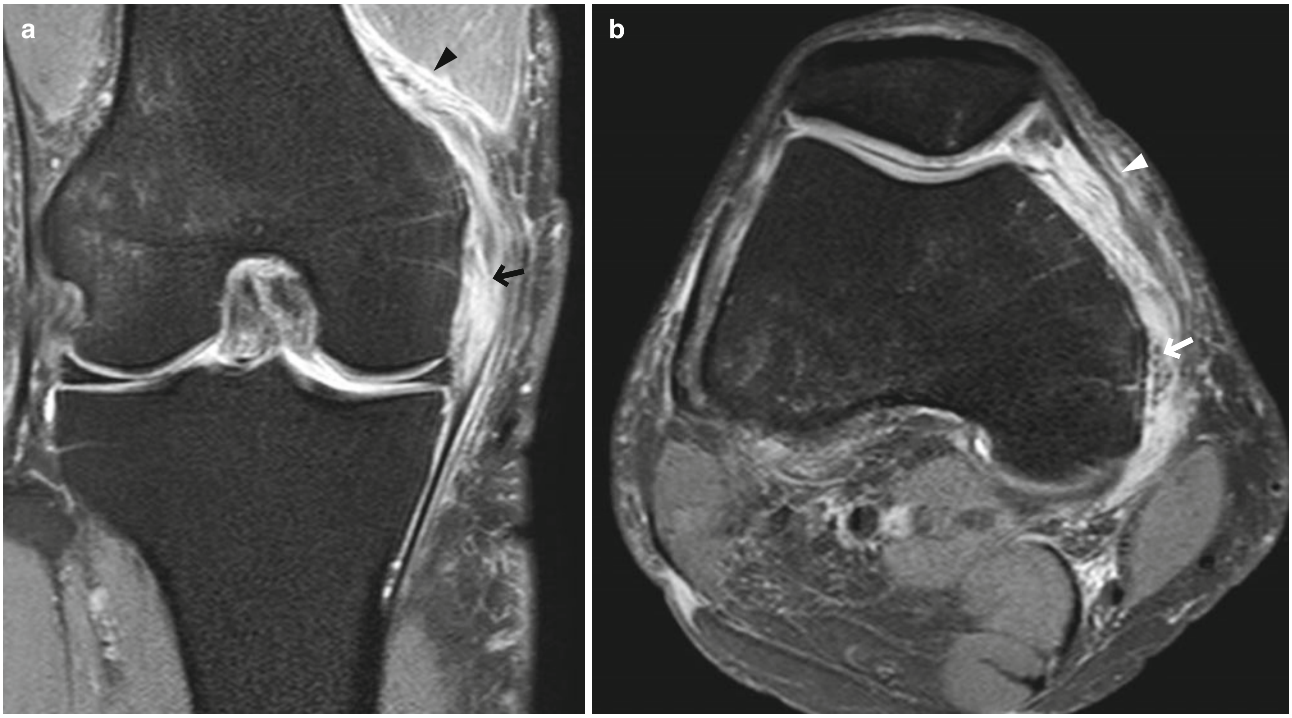

Fig. 5.8 **Grade 2 tear (partial tear) of the MCL**. A man in his 40s. (**a**) Coronal and (**b**) axial FS PDWI show edematous swelling and discontinuity of the superficial layer of the MCL (*arrows*). Edematous changes can also been seen around the medial retinaculum (*arrowhead*, **b**) and vastus medialis (*arrowhead*, **a**)

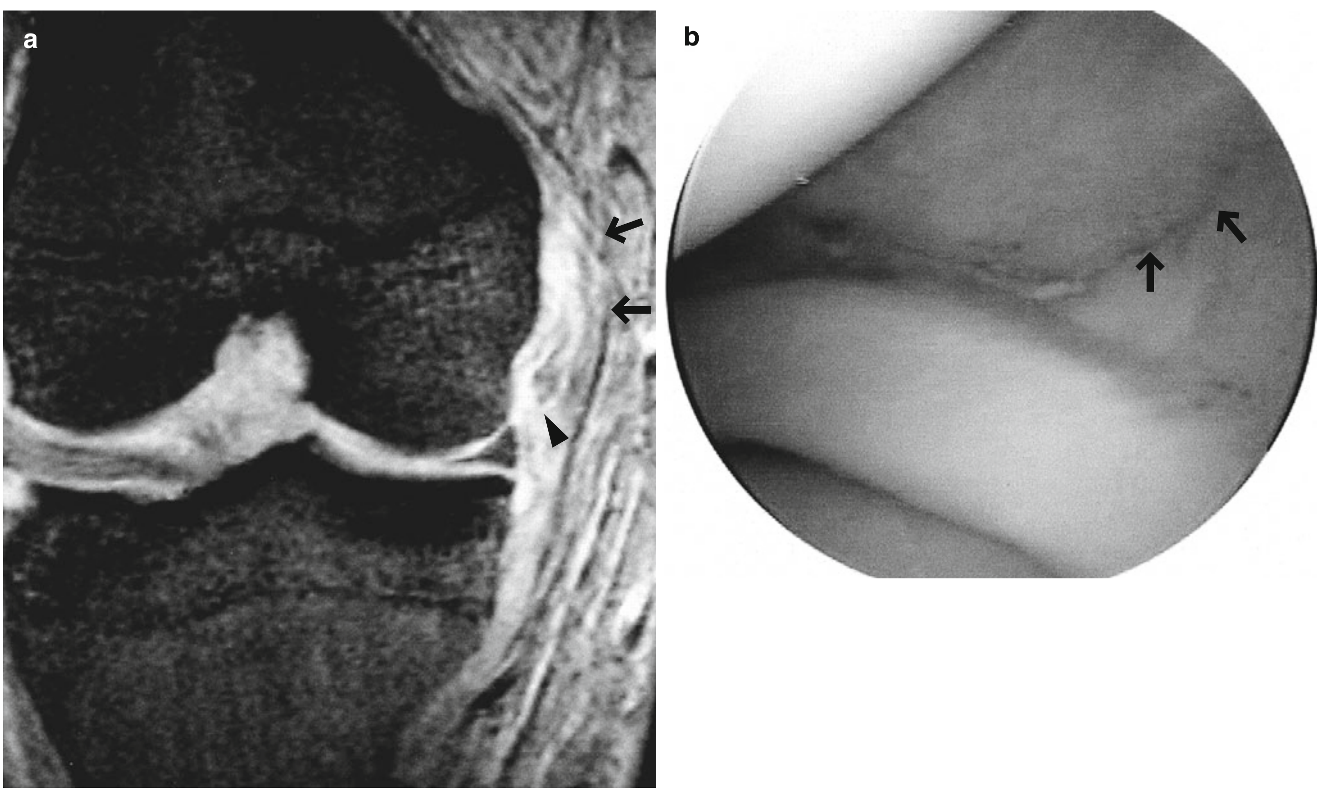

Fig. 5.9 **Grade 3 tear (complete tear) of the MCL**. A man in his late teens. (**a**) Coronal T2*WI and (**b**) arthroscopic image show complete tear of the proximal portion of the MCL (*arrows*), with surrounding edematous changes. In (**b**), rupture of the joint capsule (deep layer of the MCL, *arrows*) is seen. Note the torn meniscofemoral ligament (deep layer of MCL, *arrowhead* in **a**)

Fig. 5.10 Partial tear of the distal (tibial) portion of the MCL. A woman in her 20s. Coronal T2*WI shows torn superficial layer of the MCL (*arrow*) at the close proximity to its tibial attachment site

- IF MCL tear is accompanied by ACL tear and medial meniscal tear, this compound injury is called the classic 'O'Donoghue's unhappy triad'. It is known to occur while playing contact sports such as American football, but in daily clinical practice it is not so commonly encountered. However, more recent definition of 'unhappy triad' includes the ACL tear, MCL tear and lateral meniscal tear. This newer 'unhappy triad' is frequently seen in clinical practice.
- MCL injury is said to commonly accompany the peripheral longitudinal tear of the medial meniscus.
- MCL is an extra-articular structure, and its injury alone does not lead to joint effusion.
- Unless the deep layer of MCL is disrupted, arthroscopy will not reveal any pathological findings (Fig. 5.9b).
- Torn ligament will eventually be replaced by scar tissue. On MRI, the scar tissue may give the appearance of the normal MCL, but the functional loss is present on clinical examination (Figs. 5.11, and 5.13). However, in the varus knee in patients with knee osteoarthritis, MCL may appear thickened due to reduced tension because of the malalignment of the knee.

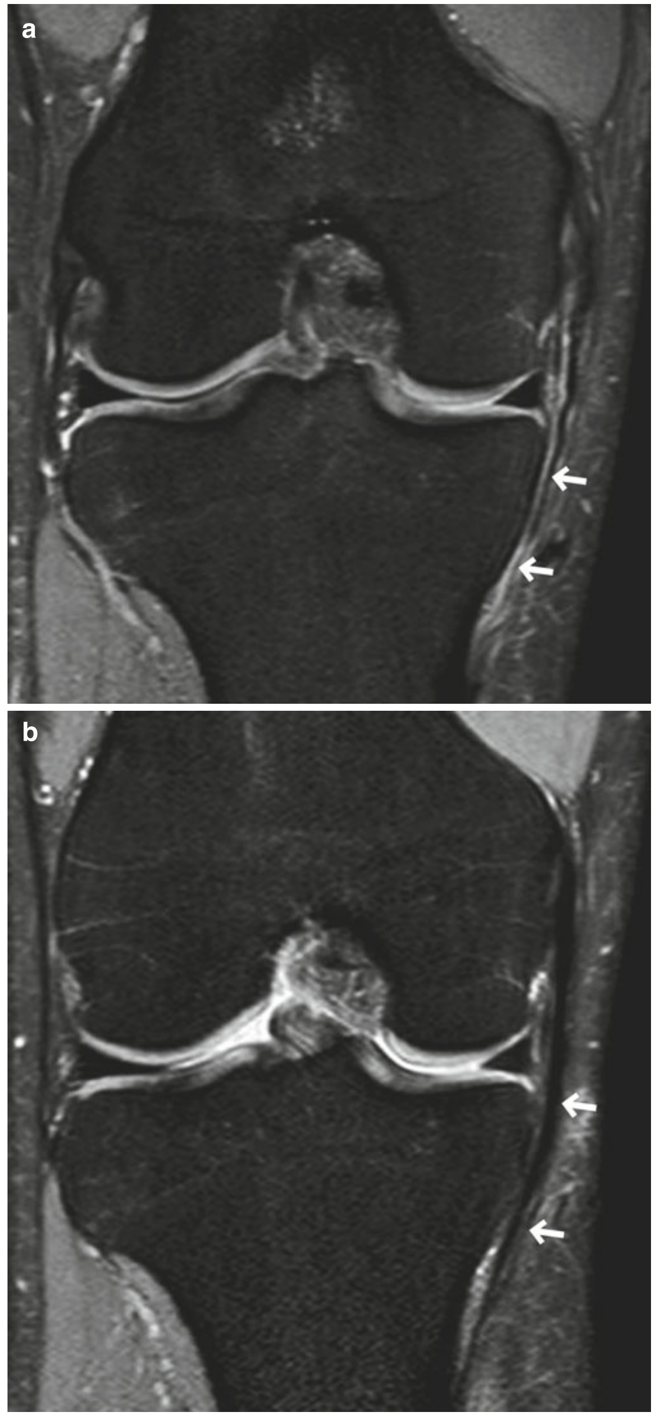

Fig. 5.11 Longitudinal follow-up of partially torn MCL. A woman in her 20s. Coronal FS PDWI acquired (**a**) immediately after the injury and (**b**) 7 months later. In (**a**), grade 1 tear of the superficial layer of the MCL is noted (*arrows*). In (**b**), the torn portion of the MCL demonstrates fibrous thickening (*arrows*)

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Fig. 5.12 **Avulsion fracture of the MCL attachment site of the femur**. A man in his 30s. Coronal FS PDWI shows a small bone fragment (*arrow*) that has separated from the femur, corresponding to the avulsion fracture of the MCL attachment site

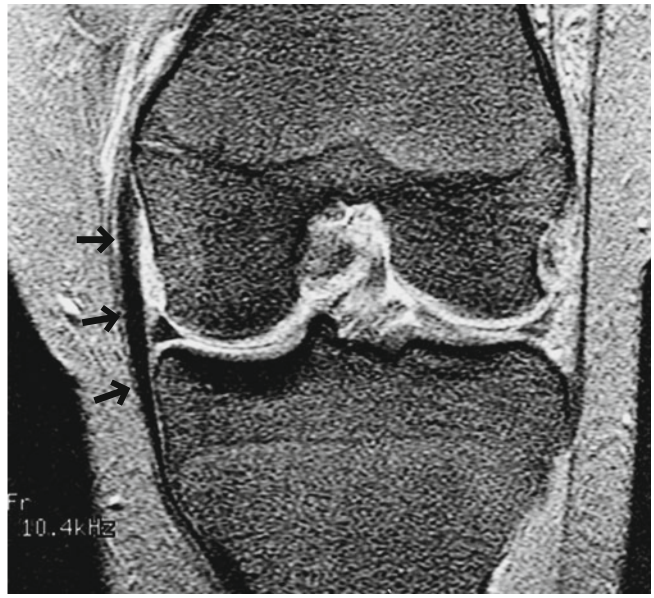

Fig. 5.13 **Chronic tear of the MCL**. A woman in her 30s. Coronal T2*WI shows torn MCL being replaced by fibrous scar tissue and thickened (*arrows*). It appears as if it is a normal MCL. Caution is needed when interpreting this type of cases

5.3 Pellegrini-Stieda Syndrome

- In patients with chronic MCL tear, the ossification of the proximal part of the MCL may occur, and it is called Pellegrini-Stieda syndrome.
- It can also be found in patients without history of knee trauma (incidental finding).
- It is commonly seen near the femoral MCL attachment site. Sometimes it may need to be differentiated from avulsion fracture of the MCL attachment site of the femur.
- Large calcification may contain ossified component with fatty marrow (Fig. 5.14).

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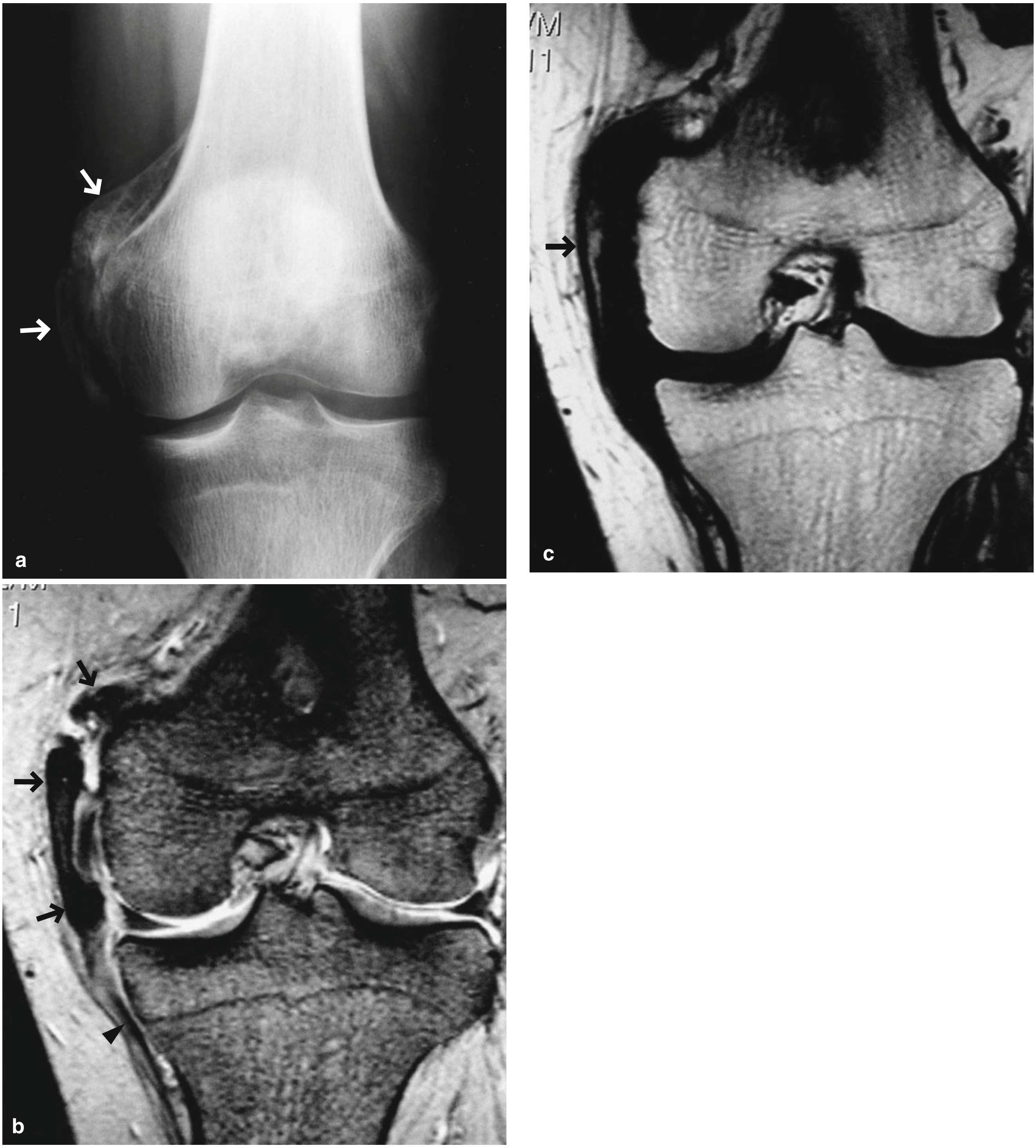

Fig. 5.14 Pellegrini-Stieda syndrome. A man in his 20s who had a knee injury due to a traffic accident 11 months prior presented with swelling of the medial side of the knee, pain during the knee motion, and mild stiffness. (**a**) Anteroposterior knee radiograph shows macrocalcification along the medial femoral condyle (*arrows*). (**b**) Coronal T2*WI shows signal void (*arrows*, **b**) corresponding to the calcification seen in (**a**) and discontinuity of the proximal portion of the superficial layer of the MCL. Note the distal portion of the superficial MCL is preserved (*arrowhead*, **b**). (**c**) T1WI shows hyperintensity (representing fatty marrow) within the calcified lesion (*arrow*, **c**)

6 Lateral Supporting Structures Including Lateral Collateral Ligament (LCL)

6.1 Anatomy

- The lateral supporting structure of the knee is a compound of several ligaments and tendons and thus is more complex than the medial supporting structure.
- It consists of three layers:
  Layer I: Has two parts: the iliotibial band (ITB) and its expansion anteriorly and the superficial portion of the biceps femoris tendon (BFT) and its expansion posteriorly.
  Layer II: Anteriorly it is formed by the lateral patellar retinaculum, and laterally by the lateral collateral ligament (LCL, also known as fibular collateral ligament).
  Layer III: This is the deepest layer which is the lateral part of the joint capsule and includes fabellofibular ligament and arcuate ligament.
- Three most prominent structures are, from anteriorly, ITB, LCL, and BFT (Fig. 6.1).
- LCL runs down to form a conjoint tendon with BFT near the attachment site of the fibular head, where it forms a V-shape. However, BFT belongs to the Layer I and the LCL belongs to the Layer II, anatomically and it is uncommon to be able to visualize this V-shape in a single sagittal image(Fig. 6.2).
- LCL resists the varus stress and prevents overextension of the knee. It is under the highest tension when the knee is extended.
- Popliteus tendon runs in a slightly different route than the aforementioned three ligaments (Fig. 6.3).
- Popliteus tendon arises from the popliteal sulcus (Fig. 6.4) located just below the LCL attachment site of the lateral femoral condyle. It runs deep to the LCL, passes diagonally through the meniscocapsular junction of the lateral meniscus to become the popliteus muscle, and then attaches to the posterior surface of the tibia. Thus, the upper half of the popliteal tendon is intra-articular and can be observed by arthroscopy (Fig. 6.5). One should be cautious not to misdiagnose the normal popliteal tendon sheath which runs close to the periphery of the lateral meniscus as a meniscal tear (Figs. 6.6 and 6.7).
- MRI may reveal a thin band-like structure called popliteofibular ligament which arises from the popliteus tendon and inserts to the fibular head (Figs. 6.8 and 6.9).
- Musculotendinous junction of the popliteus muscle is covered by the arcuate ligament (Fig. 6.10).
- Popliteus tendon and the arcuate ligament form the posterolateral supporting structure. ACL tear is commonly accompanied by damage to this posterolateral supporting structures (Fig. 6.11).

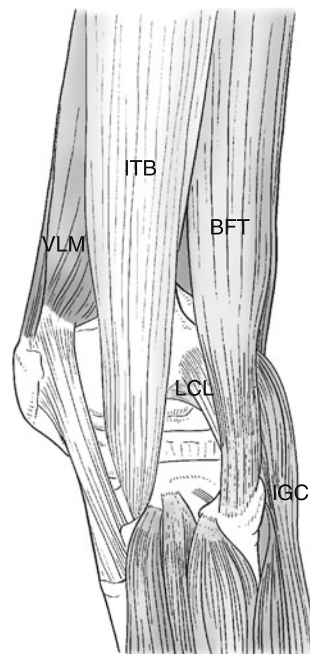

Fig. 6.1 Schematic illustration of the lateral supporting structures. From anteriorly, iliotibial band (*ITB*), lateral collateral ligament (*LCL*), and biceps femoris tendon (*BFT*). *VLM* Vastus lateralis, *IGCM* Lateral head of gastrocnemius

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Fig. 6.2 Conjoint tendon. This PDWI shows LCL (*L*) and BFT (*B*) form the conjoint tendon. Anatomically it forms a V-shape. However, it is uncommon to be able to visualize this V-shape in a single sagittal image

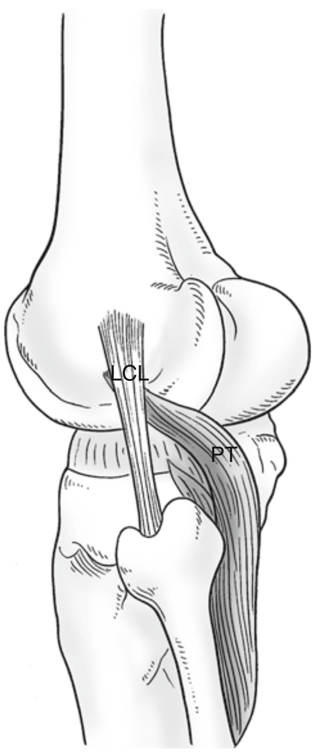

Fig. 6.3 Schematic illustration of the lateral collateral ligament and the popliteus tendon. Popliteus tendon (*PT*) arises from the lateral femoral condyle and runs deep to the LCL through the popliteal hiatus to reach the extra-articular space

Fig. 6.4 Popliteal sulcus of the lateral femoral condyle. Coronal T2*WI shows the popliteus tendon (*arrow*) arising from the popliteal sulcus (*arrowheads*), running deep to the LCL (*L*)

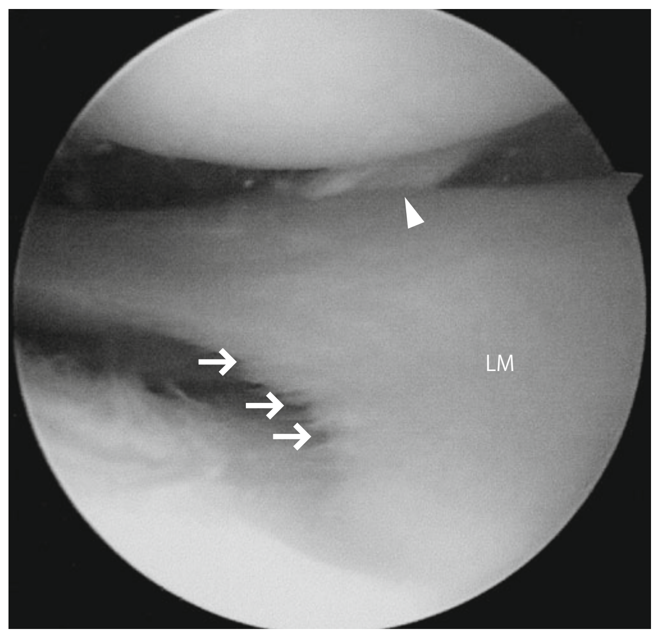

Fig. 6.5 Popliteus tendon as seen by arthroscopy. Popliteus tendon is seen running diagonally beyond the lateral meniscus (*LM*). Free border of the meniscus shows fibrillation as a result of degenerative process

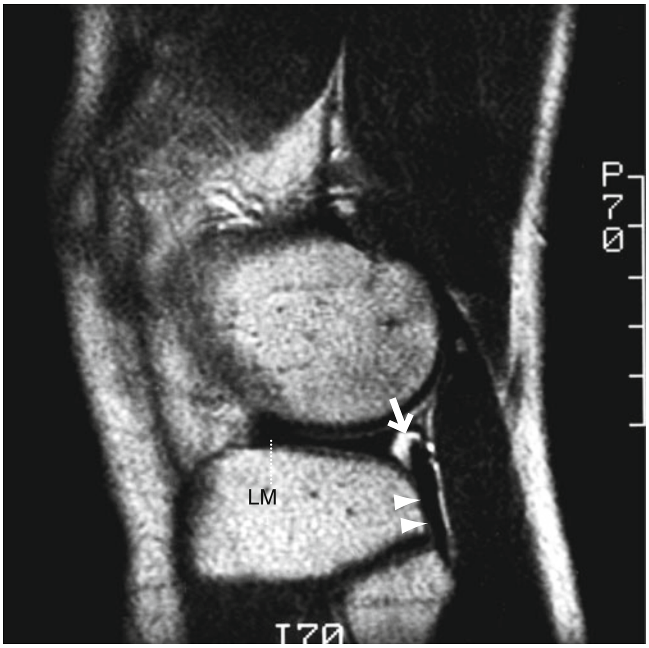

Fig. 6.6 Popliteus tendon. T2WI through the lateral meniscus (*LM*). Popliteus tendon (*arrowheads*) forms tendon sheath and runs through the meniscocapsular junction of the lateral meniscus. It is physiologic to see some fluid accumulation (*arrow*) at this location, and this should not be mistaken as meniscal damage

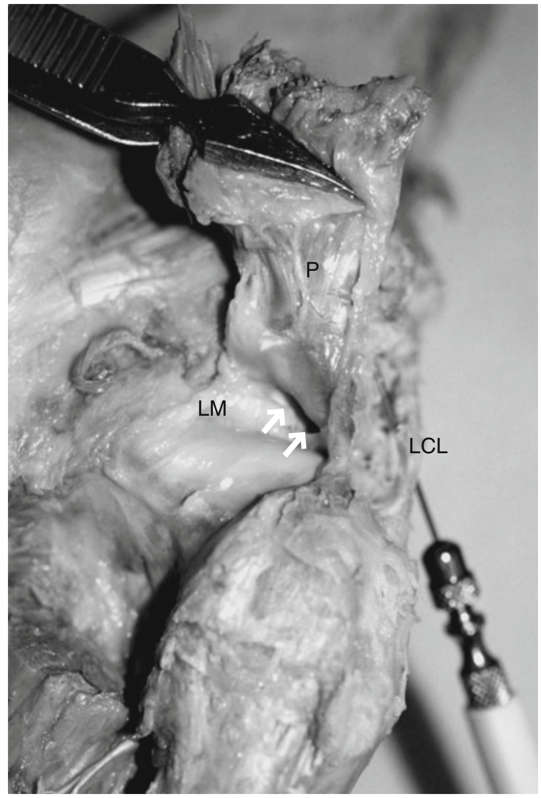

Fig. 6.7 Cadaveric specimen of popliteus tendon, LCL and lateral meniscus. Popliteus tendon (*P*) is cut through the musculotendinous junction and folded over to reveal the space (*arrows*) between it and the lateral meniscus (*LM*). The needle is placed deep to the LCL

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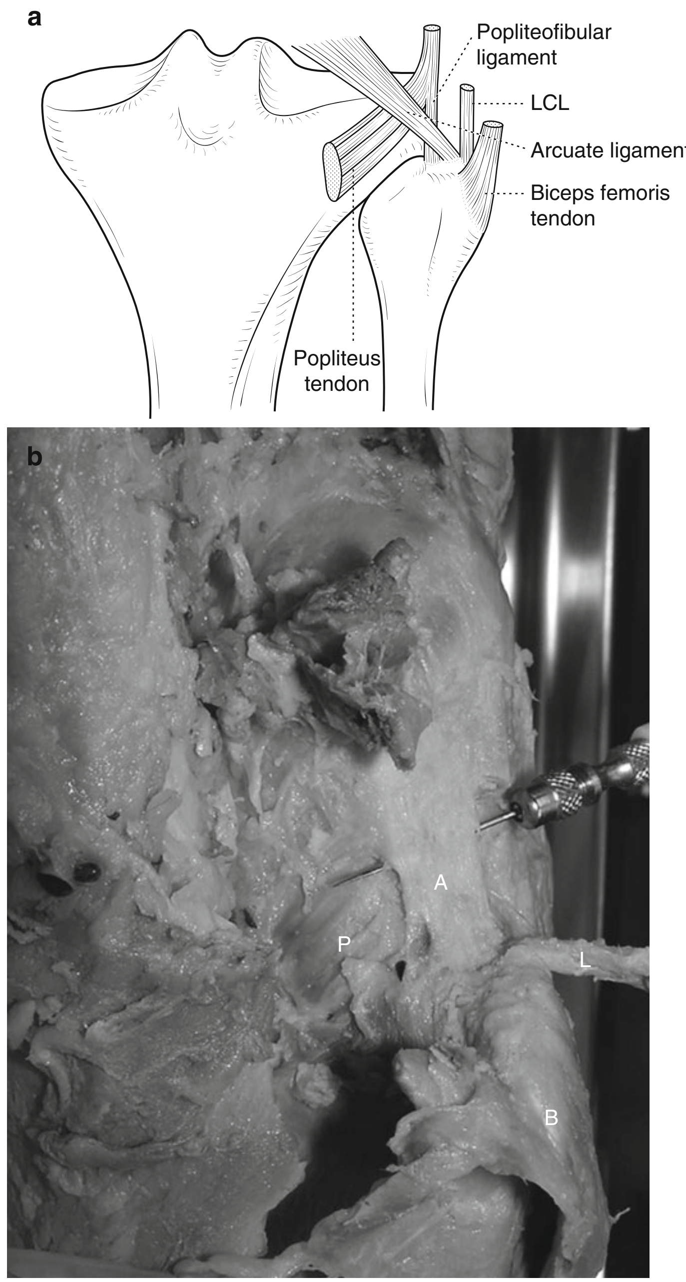

Fig. 6.8 Schematic illustration (a) and cadaveric specimen (b) of the posterolateral corner of the knee. Popliteus tendon (P), which gives off a small branch called popliteofibular ligament that attaches to the fibular head. The musculotendinous junction of the popliteus muscle runs deep to the arcuate ligament (A) and reaches the popliteal fossa. L: LCL, B: BFT

Communication Between Radiologists and Orthopedic Surgeons Through the Knee MRI Report

For radiologists, writing a knee MRI report can be analogous to playing catch with orthopedic surgeons. Our diagnostic skills cannot improve if we keep writing reports without receiving any feedback from them. If we get it "completely wrong," surgeons who requested the MRI, as well as the patients, will inevitably be very unhappy. It is thus important for us to communicate with the orthopedic surgeons by obtaining additional information pertinent to the imaging diagnosis, such as arthroscopy, radiography, history, and clinical findings, and what they think of the report from us. We should keep in mind to write reports that are consistent with the purpose of the examination (i.e., we should do our best to throw a "strike" ball). Also, the language and contents of our reports should be tailored to who the requesting physician is (i.e., is it an orthopedic surgeon specializing in the knee or a primary care physician without in-depth knowledge of orthopedics?). So that we can receive a ball back from them, we should try to keep a good relationship with them. To achieve this, we may need to apologize honestly if we get the diagnosis completely wrong. We should work together with them to find why we got it wrong and how we can prevent the same mistakes in the future.

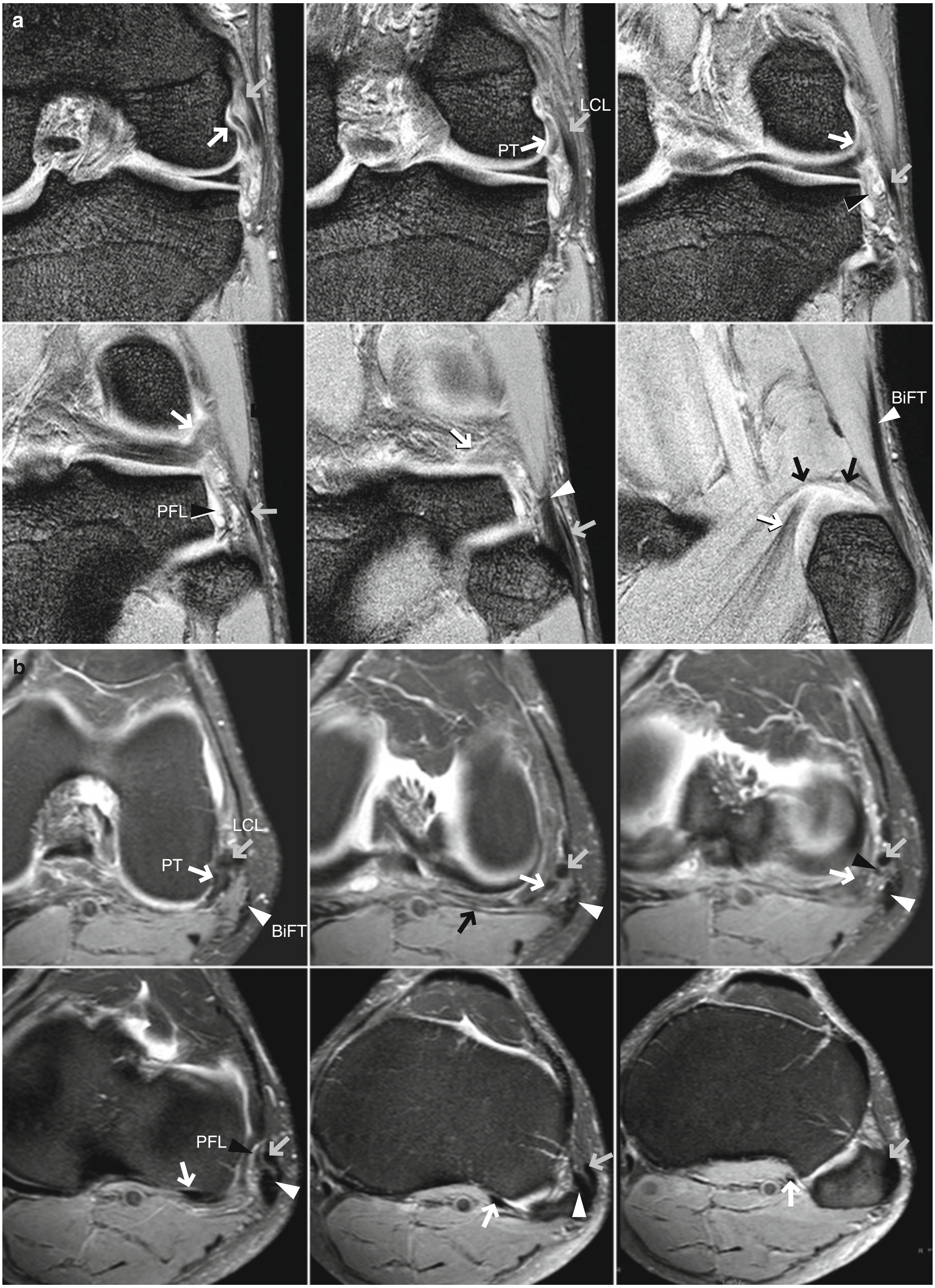

Fig. 6.9 **MRI of the posterior structures of the knee**. (**a**) Coronal T2*WI and (**b**) axial FS PDWI. Popliteus tendon (*PT*, *white arrows*) originates from just below the LCL (*gray arrows*) attachment site of the lateral femoral condyle, runs inferiorly, and gives off a branch called popliteofibular ligament (PFL, *black arrowheads*). The popliteus musculotendinous junction runs beneath the arcuate ligament (*black arrows*) and reaches the popliteal fossa. Attached to the fibular head are several ligaments and tendons including PFL, LCL, biceps femoris tendon (*BiFT*, *white arrowheads*)

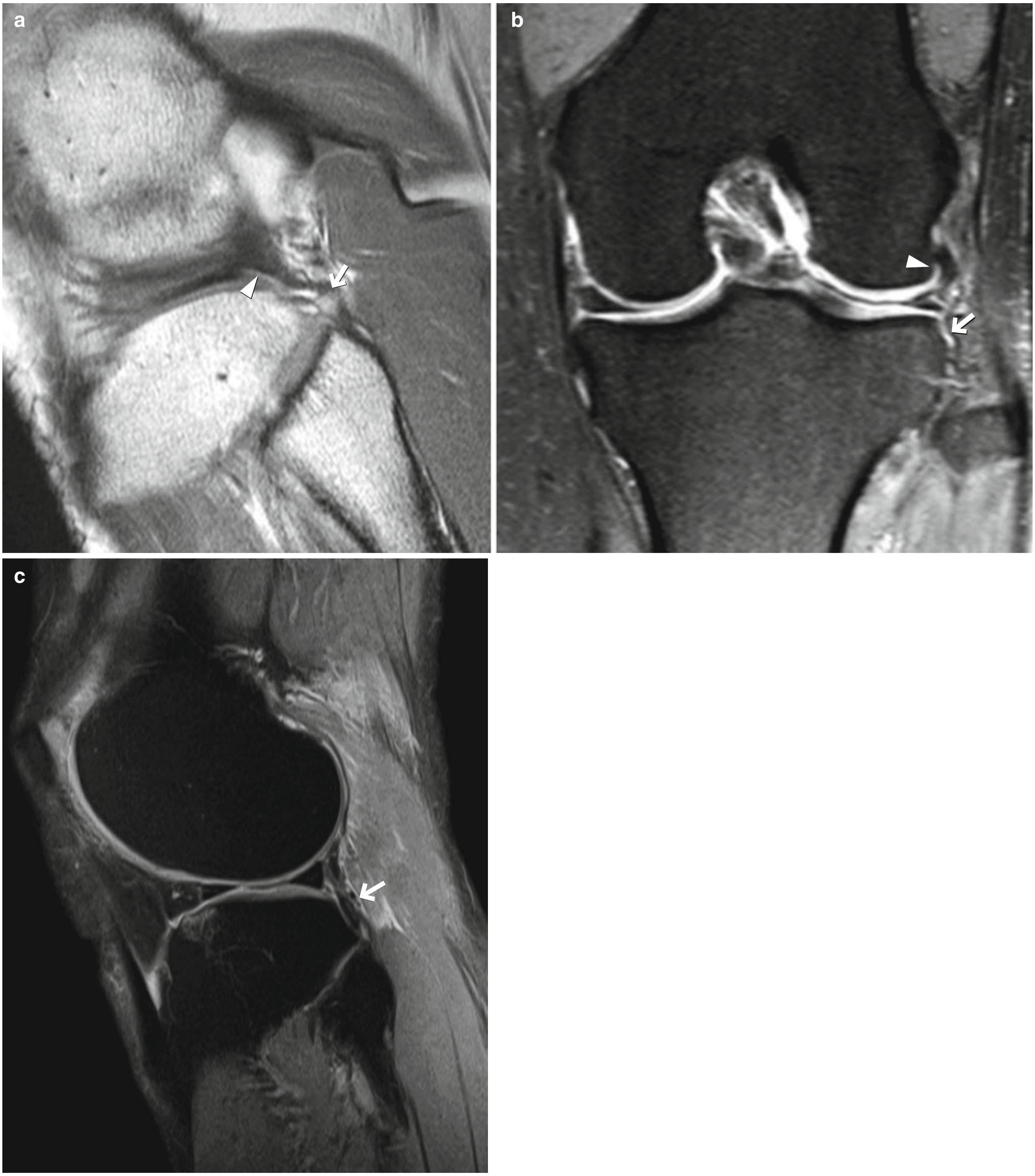

Fig. 6.10 **Damage to the popliteofibular ligament**. (**a**) PDWI and (**b**) coronal FS PDWI of a woman in her 30s. Partial tear and abnormal kinking of the popliteofibular ligament is seen (*arrows*). Note the popliteus tendon (*arrowheads*). (**c**) FS PDWI of a man in his twenties (Image courtesy of Dr. Yuko Kobashi, Department of Radiology, Jikei University School of Medicine). Localized intrasubstance hyperintensity (*arrow* in C) is seen within the popliteofibular ligament

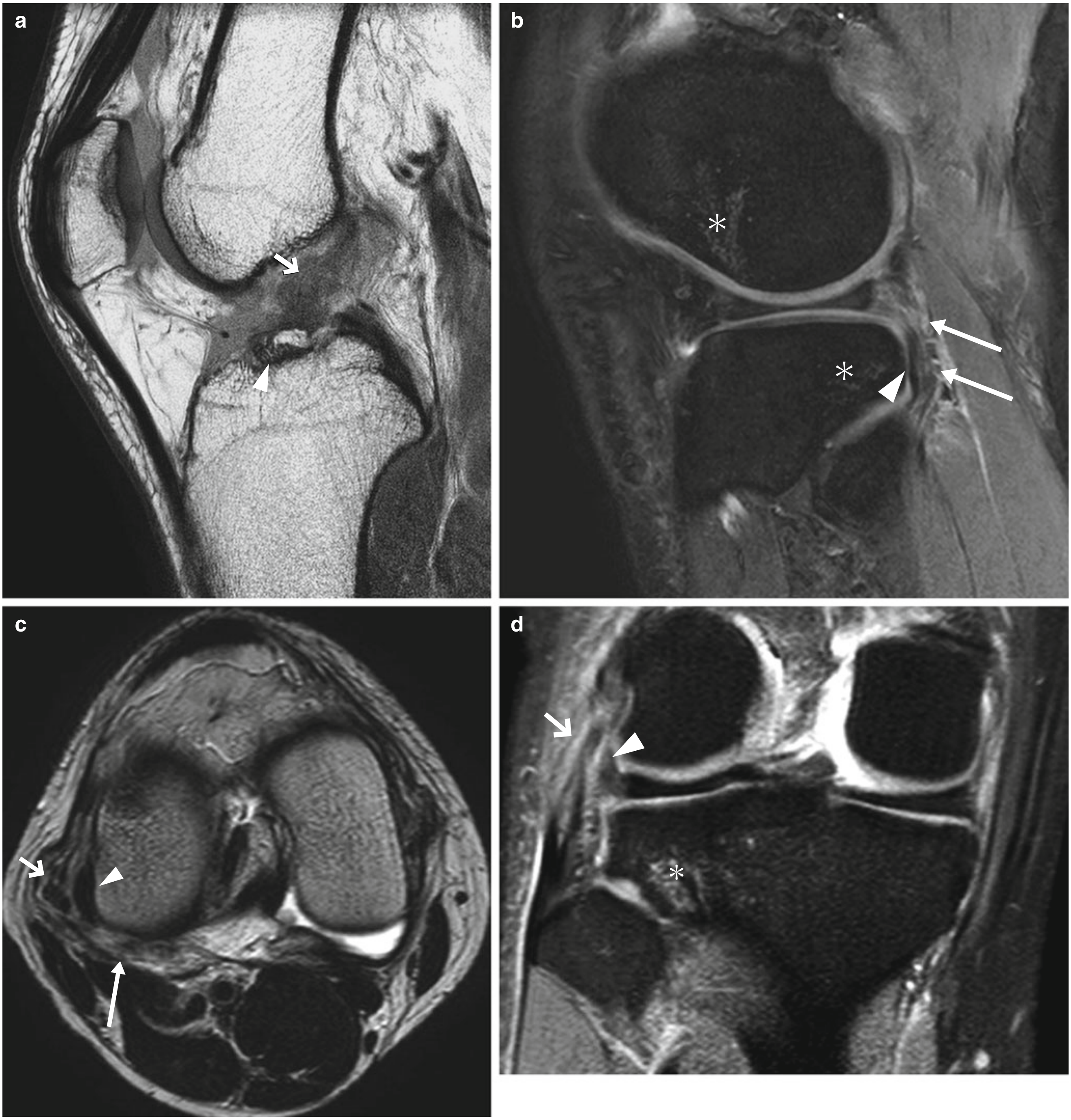

Fig. 6.11 **Injury to the posterolateral supporting structures accompanying ACL tear**. A man in his 30s. (**a**) PDWI, (**b**) FS T2*WI, (**c**) axial T2WI, and (**d**) coronal FS PDWI. ACL complete tear (*arrow*, **a**) with intercondyloid eminence fracture (*arrowhead*, **a**) and associated bone bruise (*, **b, d**). Continuity of the popliteus tendon (*arrowhead*) and LCL (*arrow*) are preserved, but there is partial intrasubstance hyperintensity (*arrow*, **d**). Partial discontinuity of the arcuate ligament is seen alongside with the surrounding edematous swelling (*long arrows*, **b, c**)

Key points for MRI interpretation

- Normal LCL is depicted as a hypointense band.
- LCL is best visualized on coronal images, but since it is tilted slightly in the anterior direction, it is commonly seen in several coronal slices.
- Popliteus tendon runs in the diagonal direction and thus increased signal due to the magic angle effect (see Chaps. 2, 3 and 4) can be present if a short TE sequence is used to acquire the image.

6.2 LCL Tear

- Tear of LCL is the least common of the four major ligaments of the knee (i.e., ACL, PCL, MCL, and LCL).
- LCL is torn when an excessive amount of external force is applied (e.g., by traffic accidents) and may accompany dislocation of the knee joint and tear of multiple ligaments (Figs. 6.11 and 6.12). Peroneal nerve damage may also occur.
- Injury of LCL alone is rare and is commonly accompanied by damages to the lateral supporting structures (especially rupture of the lateral joint capsule) (Fig. 6.13).
- LCL is an extra-articular structure, and therefore its tear does not result in joint effusion.
- Acute stage of LCL tear is depicted as a loss or discontinuity of fibers alongside with edema and hemorrhagic changes.
- If LCL is torn, the common site of injury is the middle portion of the LCL or the avulsion fracture of its attachment site at the fibular head (see next section).
- Chronic stage of LCL tear may be depicted as thickened or slack band-like structure.

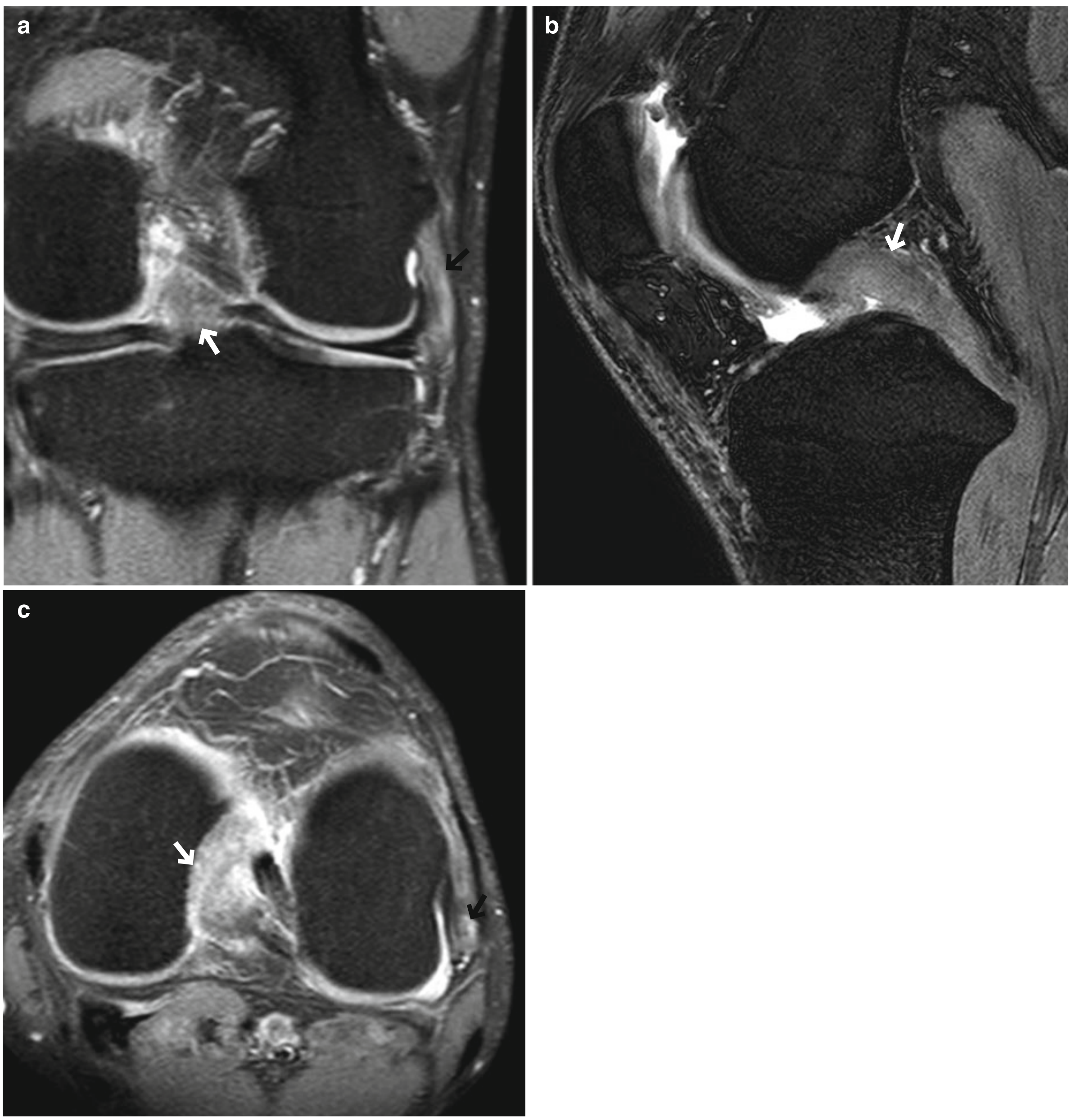

Fig. 6.12 LCL tear with PCL tear. A man in his 30s who had a traffic accident. (**a**) Coronal FS PDWI, (**b**) T2*WI, and (**c**) axial FS PDWI. There is partial tear of the proximal LCL (*black arrows*) and the intrasubstance injury of the PCL (*white arrows*), both of which are represented by intrasubstance hyperintensity

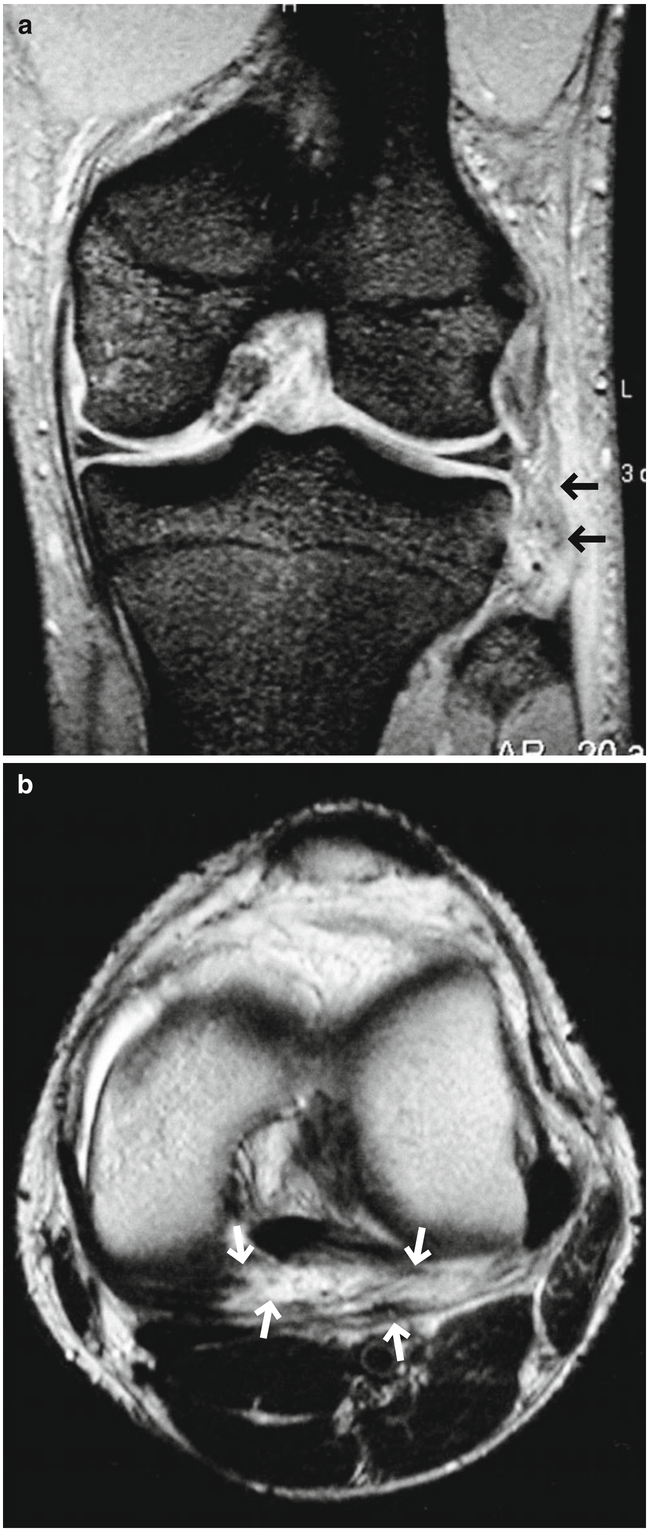

Fig. 6.13 LCL tear with rupture of the posterolateral joint capsule. A teenage man who had a traffic accident. (**a**) Coronal T2*WI and (**b**) axial T2WI. Discontinuity of LCL fibers (*arrows*, **a**) as well as swelling and discontinuity of the posterolateral joint capsule (*arrows*, **b**) are observed

6.3 Avulsion Fracture of the Fibular Head

- Avulsion fracture of the fibular head may occur if a strong varus stress is applied to the extended knee (Fig. 6.14).
- Avulsed bone fragments are displaced in the cephalic direction. The long axis of the bone fragment may be horizontal (moves in parallel).
- It is important to clinically diagnose peroneal nerve damage as a complication.
- PCL tear often coexists.
- Disruption of LCL, arcuate ligament, and the joint capsule (and other posterolateral supporting structures) are common ("arcuate" sign).

Key points for MRI interpretation

- It is important to detect the avulsed bone fragment which was displaced in the cephalic direction and to assess the extent of damage to the attached LCL and biceps femoris tendon.

Reference

Huang GS, Yu JS, Munshi M, Chan WP, Lee CH, Chen CY, Resnick D. Avulsion fracture of the head of the fibula (the "arcuate" sign): MR imaging findings predictive of injuries to the posterolateral ligaments and posterior cruciate ligament. AJR. 2003;180:381–7.

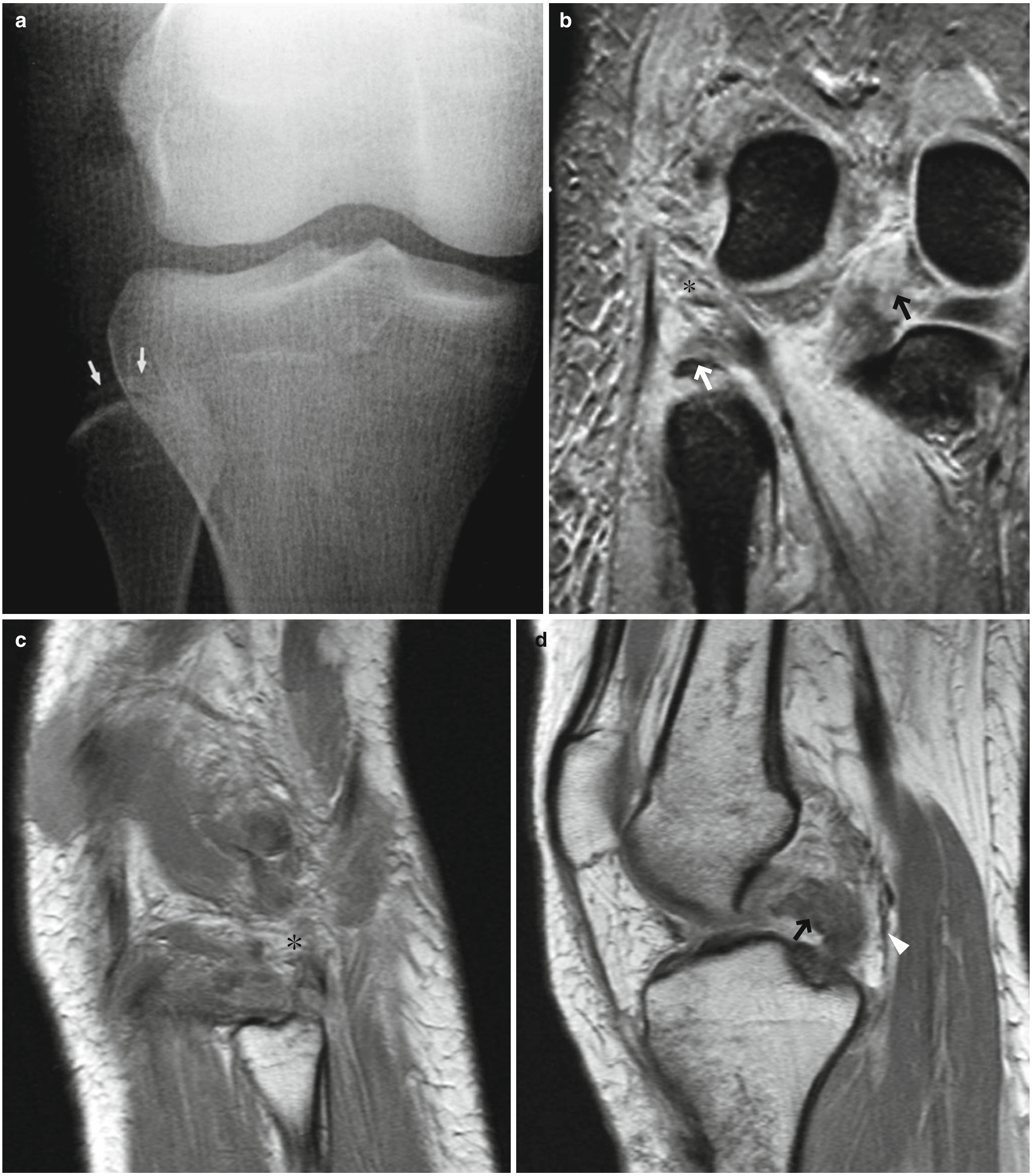

Fig. 6.14 **Avulsion fracture of the fibular head**. A woman in her late teen after a traffic accident. (**a**) Anteroposterior radiograph, (**b**) coronal T2*WI, and (**c**, **d**) sagittal PDWI. There is a small bone fragment just cephalic to the fibular head (*small arrows*, **a**). The fragment shows no MR signal (*arrow*, **b**), and LCL which should be attached to the fragment cannot be visualized (*). PCL tear (*black arrows*) and disruption of the posterior joint capsule (*arrowheads*) are also present

6.4 Segond Fracture

- Segond fracture is a type of avulsion fracture (Fig. 6.15) that occurs at the lateral edge of the tibial condyle (see also reverse Segond fracture, Chap. 4).
- Most commonly occurs following a strong pulling force to the lateral joint capsule ligaments (posterior fibers of ITB and anterior diagonal fibers of LCL) due to varus stress and internal rotation of the distal lower limb.
- ITB is also said to be associated with this injury.
- ACL tear coexists in almost all cases.
- Treatment should be focused around the ACL tear, and the Segond fracture itself will not be a focus of treatment.

Key points for MRI interpretation

- A small avulsed bone fragment may not be visualized on MRI.
- Assessment of damage to the joint capsule is best done using coronal and axial images.
- If Segond fracture is suspected clinically, integrity of ACL should first be investigated.

References

Dietz GW, Wilcox DM, et al. Segond tibial condyle fracture: lateral capsular ligament avulsion. Radiology. 1986;159:467–9.

Campos JC, Chung CB, Lektrakul N, et al. Pathogenesis of Segond ftacture: anatomic and MR imaging evidence of an iliotibial tract or anterior oblique tract or anterior oblique band avulsion. Radiology. 2001;219:381–6.

Refer to Radiographs as Much as Possible

Radiologists are usually asked to read MRI alone on the day of examination. However, radiography offers valuable and sometimes critical information for imaging diagnosis of orthopedic disorders, including musculoskeletal tumors. Today, most hospitals have a PACS system, but sometimes radiographic films from the past are not digitalized and stored in the online server. In this scenario, we need to obtain old films from the storage. For disorders such as intercondyloid eminence fracture and Segond fracture, radiographic findings can be of critical importance. We should therefore not "cut corners" even if it is a hassle to obtain such films.

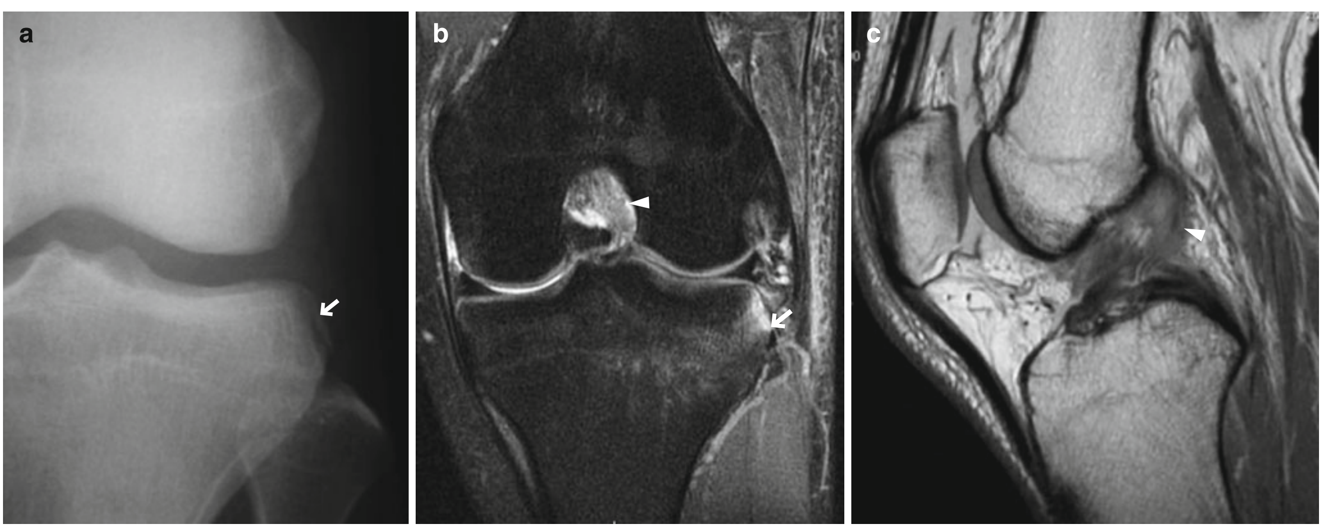

Fig. 6.15 **Segond fracture**. A man in his late teens. (**a**) Anteroposterior radiograph, (**b**) coronal FS PDWI, and (**c**) PDWI. There is a small bone fragment (*arrows*) at the periphery of the lateral tibial condyle. ACL is completely torn (*arrowheads*)

6.5 Avulsion Fracture of the Gerdy's Tubercle

- Avulsion fracture of the Gerdy's tubercle, which is the attachment site of the iliotibial band (ITB), is rare (Fig. 6.16).
- Lone injury is extremely rare and commonly associated with ACL tear and complex damage to the lateral supporting structures.
- In the absence of the avulsion fracture, inflammation of the ITB attachment site (= Gerdy's tubercle) may occur following chronic irritation (Fig. 6.17).

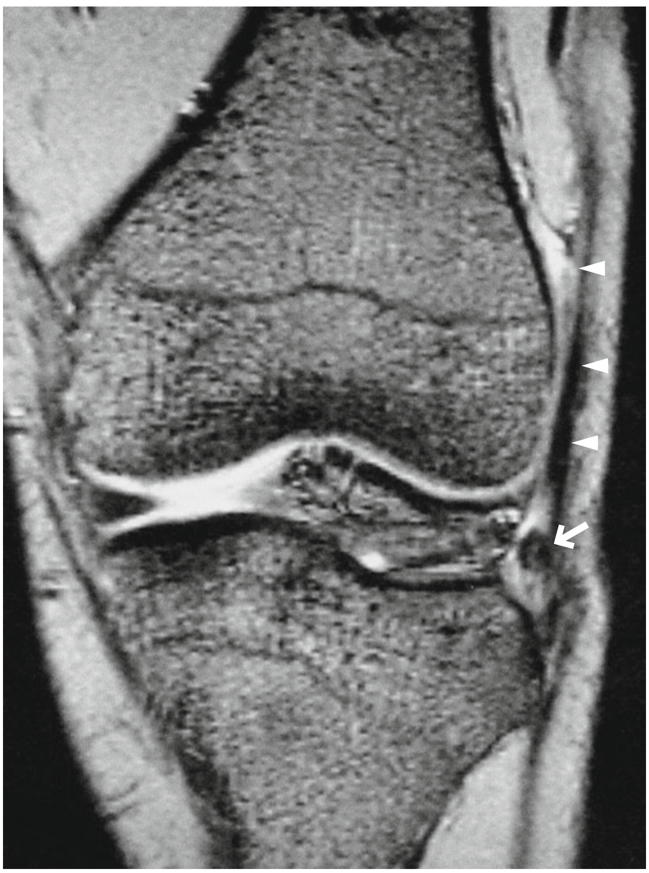

Fig. 6.16 Avulsion fracture of the Gerdy's tubercle. A man in his 30s. Coronal T2*WI shows a small bone fragment (*arrow*) at the end of the iliotibial band (*arrowheads*)

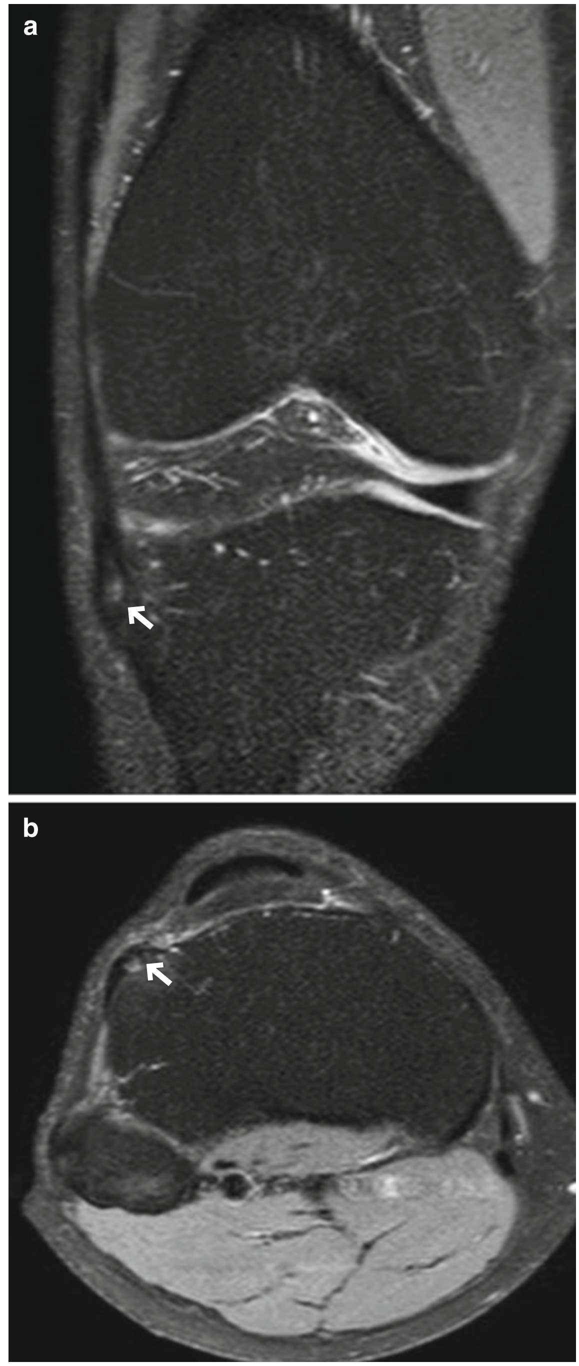

Fig. 6.17 Inflammation of the iliotibial band attachment site (Gerdy's tubercle). A man in his 40s. (**a**) Coronal and (**b**) axial FS PDWI. Localized edematous changes are seen at the Gerdy's tubercle (iliotibial band attachment site)

6.6 Iliotibial Band Friction Syndrome

- Localized edematous changes may be seen surrounding the femoral portion of the iliotibial band (Fig. 6.18).
- This is called iliotibial band syndrome and occurs as a result of repeated frictional rub of the iliotibial band against the lateral femoral condyle as the knee is flexed and extended (Fig. 6.19).
- The aforementioned localized edematous changes may be the only MRI finding.
- It is commonly seen in long-distance runners ("runner's knee"), and the symptoms worsens when running downhill.
- It is one of "overuse" syndromes. Similar pathologic mechanism at the medial side of the knee will lead to anserine bursitis (=inflammation between the pes anserinus and the tibial attachment site, see Chap. 12).

Reference

Murphy BJ, Hechtman KS, Uribe JW, et al. Iliotibial band friction syndrome: MR imaging findings. Radiology. 1992;185:569–71.

Fig. 6.18 Iliotibial band friction syndrome. A man in his twenties. Coronal FS T2WI shows localized hyperintensity surrounding the femoral portion of the iliotibial band (*arrowheads*), consistent with edematous changes (*arrows*)

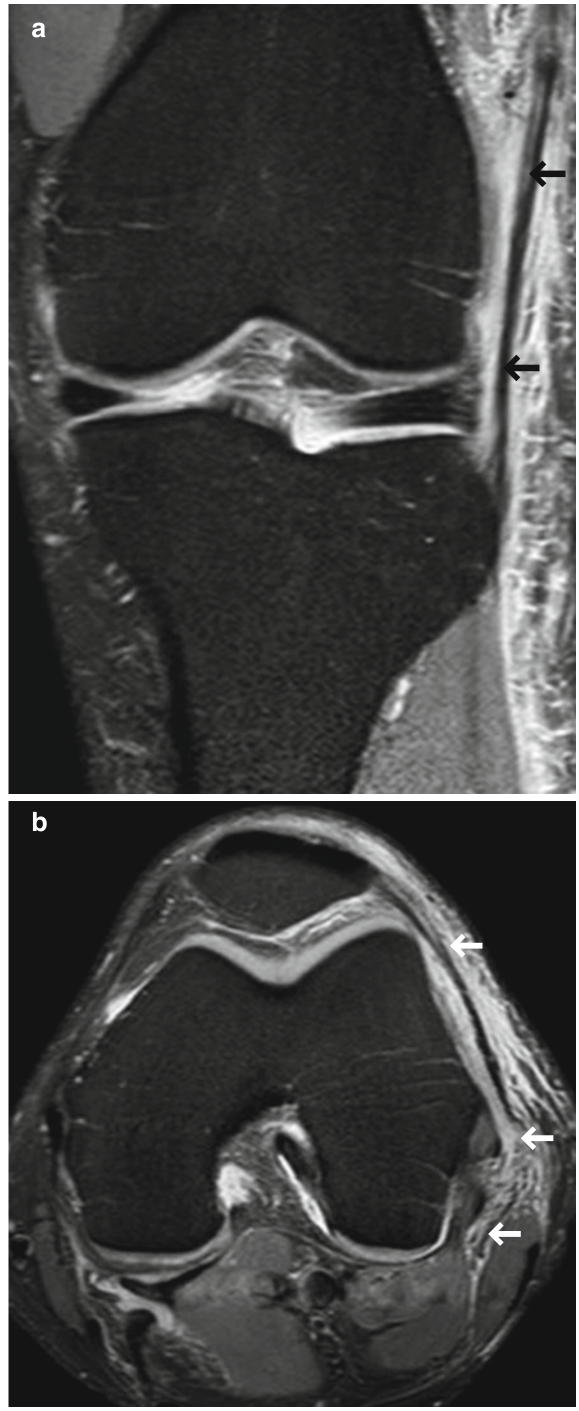

Fig. 6.19 Iliotibial band friction syndrome and extension of inflammation to the surrounding tissue. A man in his 30s. (**a**) Coronal and (**b**) axial FS PDWI show extension of the edematous changes including the femoral portion of the iliotibial band (*black arrows*, **a**), along the medial retinaculum anteriorly, and also posteriorly (*white arrows*, **b**)

6.7 Popliteus Musculotendinous Injury

- Popliteus musculotendinous injury commonly occurs at the musculotendinous junction and the muscle belly. Injury to the attachment site to the lateral femoral condyle is rare.
- Damage to the intra-articular portion (see Fig. 6.5) can be assessed by arthroscopy, but the extra-articular portion can only be assessed by MRI.
- Partial tear is more common than complete tear.
- It may accompany ACL tear. In that case, damage to the posterior joint capsule is commonly present.
- MRI findings include swelling, kinking, and intrasubstance hyperintensity (Fig. 6.20).

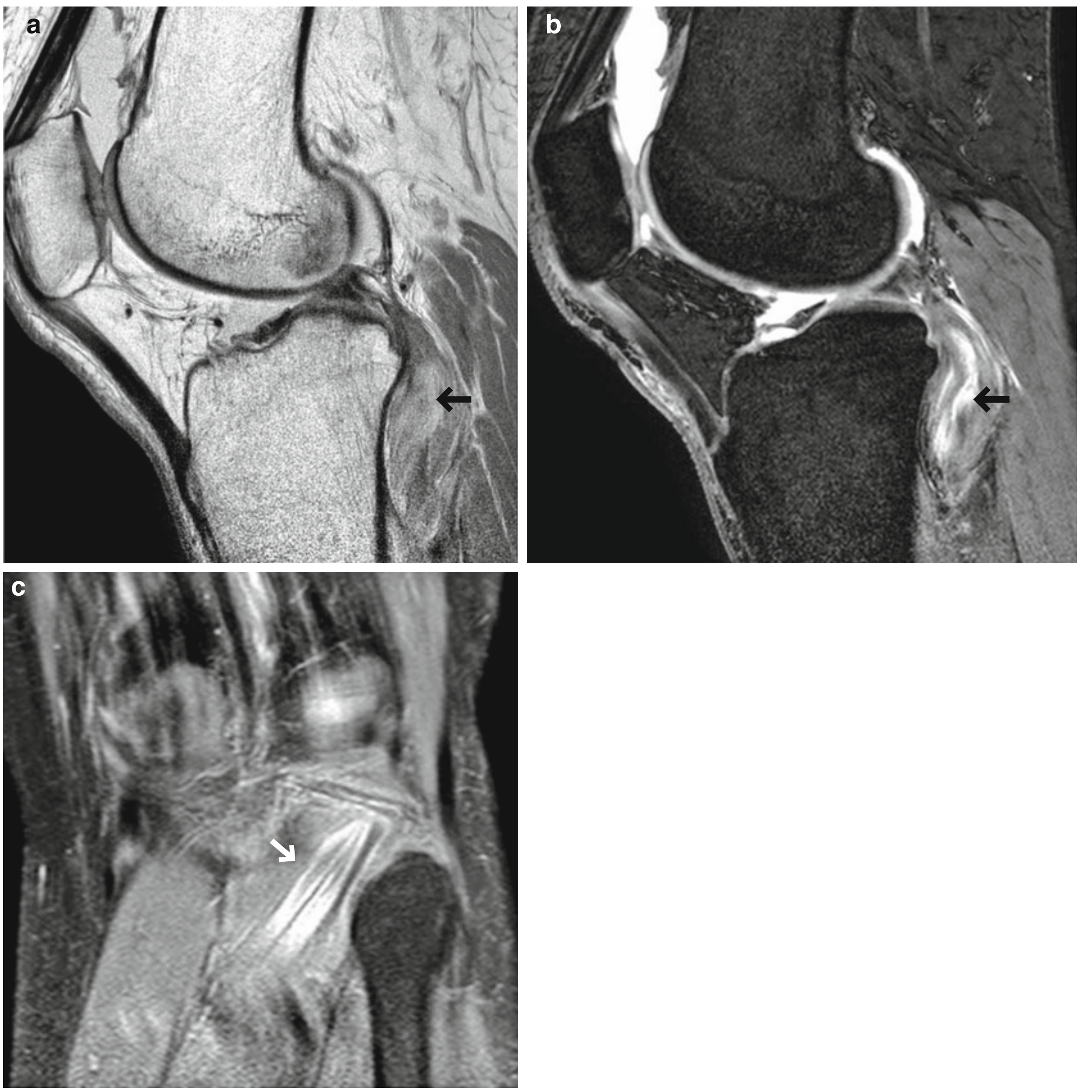

Fig. 6.20 **Partial tear of the popliteus muscle**. A woman in her 50s. (**a**) PDWI, (**b**) sagittal, and (**c**) coronal FS PDWI. There is swelling and intrasubstance hyperintensity at the muscle belly and the musculotendinous junction of the popliteus muscle (*arrows*)

7 Meniscus

7.1 Anatomy

- Menisci are thought to play a role in maintaining the stability of the tibiofemoral joint, spreading the mechanical weight, shock absorption, and protection of cartilage. It is thought that menisci transmit 60–70% of mechanical weight to the femur and tibia.
- Menisci are comprised of fibrous cartilage, mainly composed of type I collagen. The inner two third contains fibers running in the longitudinal and circumferential fashion. The outer one third is mainly composed of fibers running in the circumferential fashion. In the central (deep) portion of the meniscus, fibers run in a random manner.
- The outer one third has vascular supplies and is called the red zone. If a small tear occurs here, natural healing may occur. However, the inner portion has no vascular supply and is called the white zone (Fig. 7.1).

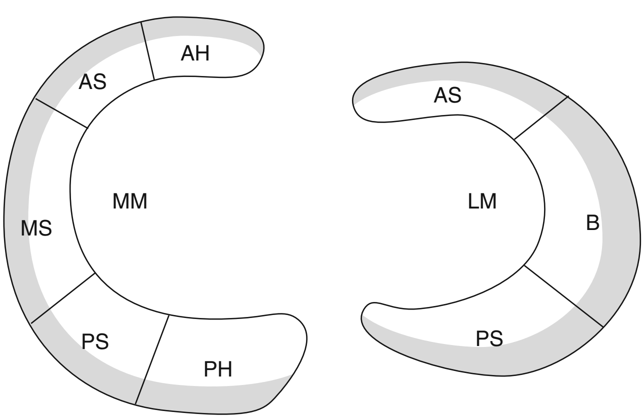

Fig. 7.1 Schematic illustration of the menisci. Medial meniscus (*MM*) and lateral meniscus (*LM*), which looks more like a C-shape. *AH* anterior horn, *AS* anterior segment, *MS* middle segment, *PS* posterior segment, *PH* posterior horn. The outer one third (*shaded gray area*) has vascular supplies and is called the red zone

- There are two ways of classifying meniscal segments.
- It can be divided into three segments: anterior segment, body, and posterior segment (or anterior horn, body, and posterior horn).
- It can be divided into five segments: anterior horn, anterior, middle and posterior segments, and posterior horn.

7.2 Medial and Lateral Menisci

- Medial meniscus is larger than the lateral meniscus and is more "open" (=less C-like) and less wide.
- Peripheral part of the medial meniscus is thick, especially the posterior segment is the thickest at 5 mm approximately.
- Posterior horn of the medial meniscus is always wider than the anterior horn and can be as wide as 12 mm (which is twice as wide as the anterior horn). The width of the posterior horn is greater than its thickness (Fig. 7.2).
- Lateral meniscus has a smaller radius than the medial meniscus, and it has a more C-like shape.
- Width of the lateral meniscus is consistently 10 mm approximately (Fig. 7.2).
- Posterior horn of the lateral meniscus lies obliquely in the coronal MRI due to the slope of the tibial plateau. For this

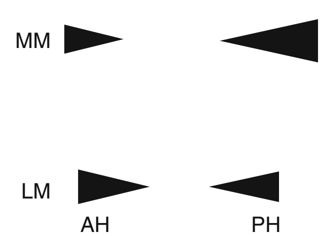

Fig. 7.2 Appearance of the medial (*MM*) and the lateral (*LM*) menisci in sagittal MRI. The posterior horn of the medial meniscus is wider and thicker than the anterior horn. This discrepancy is not seen in the lateral meniscus

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reason, it may be affected by the magic angle effect (see Chap. 2).

- The tip of the anterior and posterior horns of the menisci are called “meniscal root.” They firmly attach to the tibia (Figs. 7.3 and 7.4). Posteriorly, the posterior root covers the surface of the tibial plateau.
- Anterior root of the medial meniscus attaches immediately anterior to the tibial ACL attachment site, while that

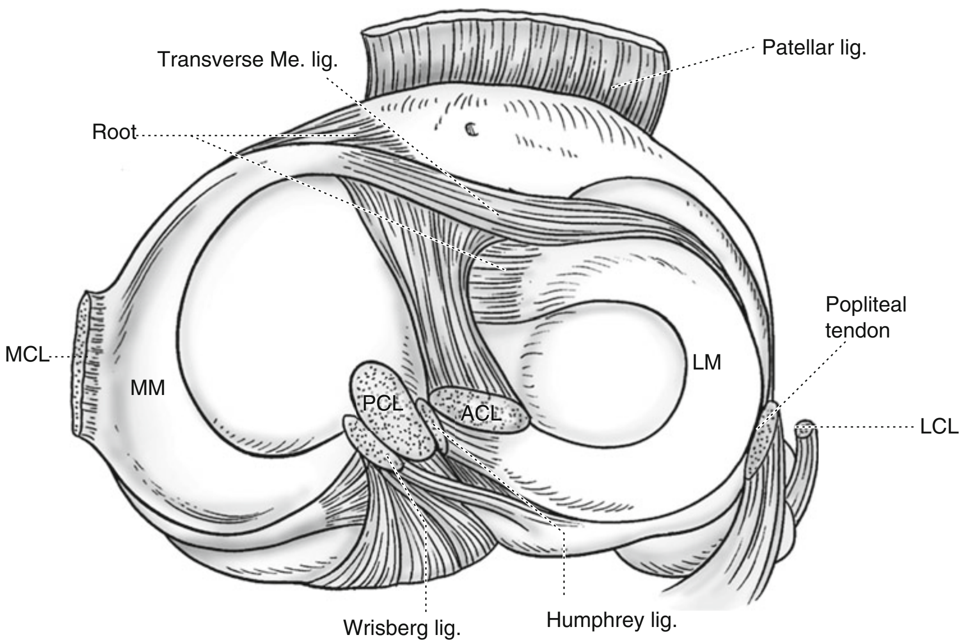

Fig. 7.3 Schematic illustration of the menisci and the surrounding structures sitting on the tibial plateau, as seen from above

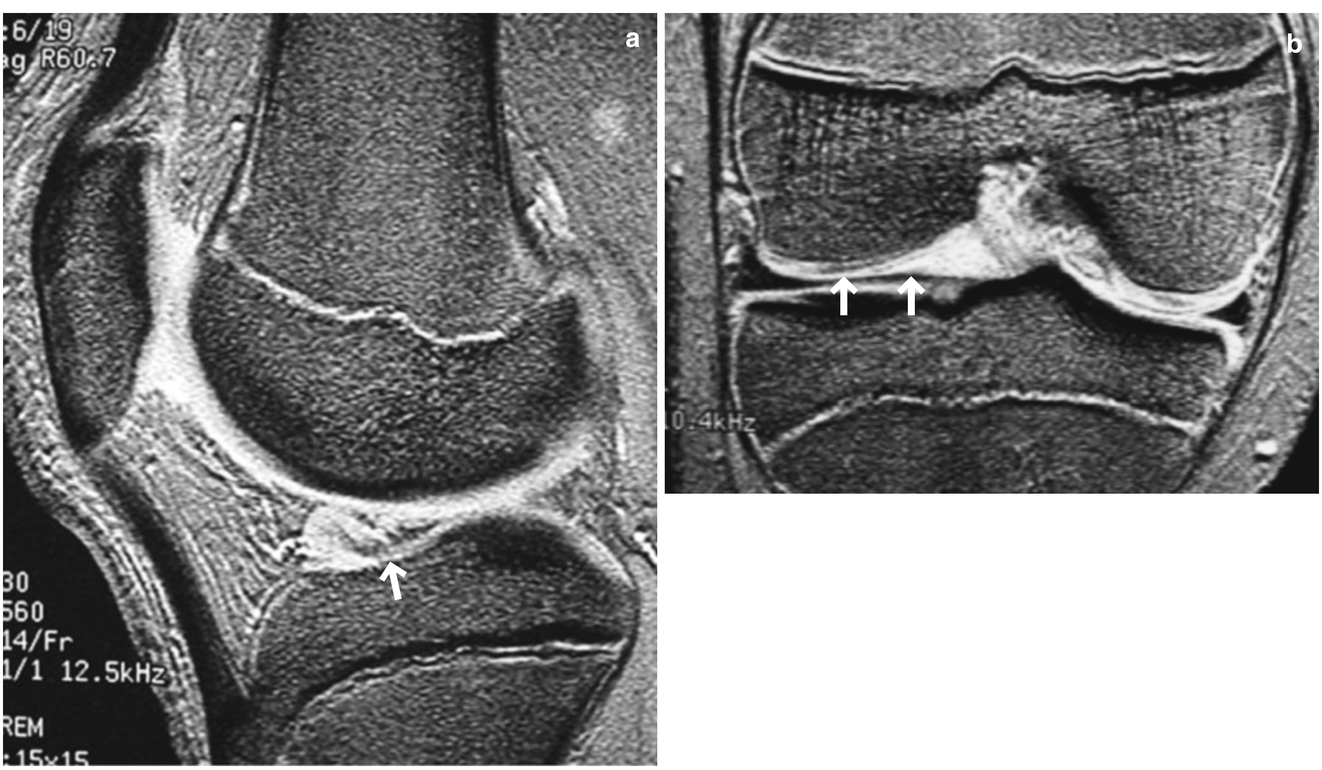

Fig. 7.4 **Anterior meniscal root of the lateral meniscus**. (**a**) Sagittal and (**b**) coronal T2*WI shows normal anterior meniscal root (*arrows*). It can be mistaken as a meniscal tear in a single sagittal slice, but the coronal image confirms it is a normal root

of the lateral meniscus attaches immediately posterior to the tibial ACL attachment site.

- Transverse ligament of Winslow connects between the medial and lateral menisci, both anteriorly (between anterior horns) and posteriorly (between posterior horns).
- Posterior component of the anterior root of the medial meniscus joins the transverse meniscal ligament.
- Peripheral part of the medial meniscus firmly attaches to the deep layer of the MCL and the joint capsule.
- Lateral meniscus has a weak bond with the joint capsule, and posteriorly it is only supported by the limited amount of fascicles of the joint capsule. Thus, its range of motion is much greater than that of the medial meniscus as the knee is flexed and extended.

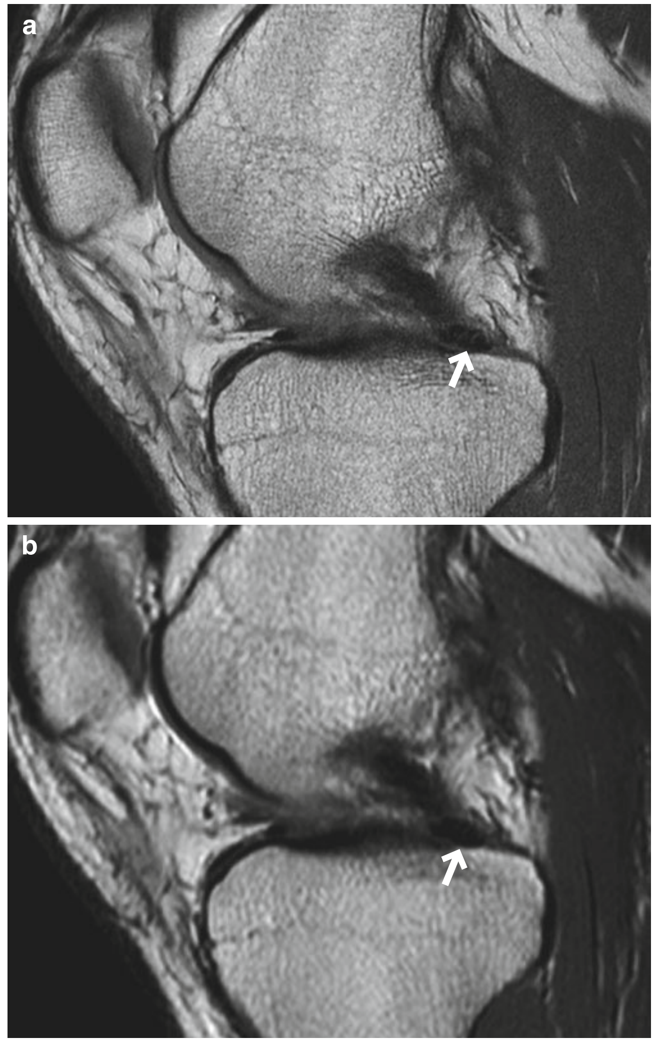

Fig. 7.5 Posterior meniscal root of the medial meniscus. PDWI showing the posterior root of the medial meniscus. (**a**) 512 sampling and 1024 matrix and (**b**) 256 sampling and 256 matrix. High-resolution image (**a**) enables visualization of the fibers of the posterior root of the medial meniscus (*arrows*)

7.3 Delineation of Meniscal Lesions by MRI

- High-resolution MRI is essential for delineation of a small meniscal tear.

Meniscal window

- Delineation of meniscal lesions requires the use of "meniscal window," in which the window width is kept narrow and the window level low (Fig. 7.6). Therefore, if the images need to be printed onto a film, two sets of films with different window levels (one for visualization of meniscal lesions and the other for other structures of the knee) may be needed.

FSE vs. conventional SE

- When the fast spin-echo (FSE) sequence initially became available, its ability to delineate meniscal lesions was reported to be inferior to that of conventional SE sequence (Rubin et al. 1994).
- However, later reports emphasized the usefulness of proton-density-weighted and T2-weighted FSE sequences (Escobedo et al. 1996).
- FSE sequence with echo train length of 5–6 produces images without blurring, and its short scan time allows for higher spatial resolution and increased NEX.

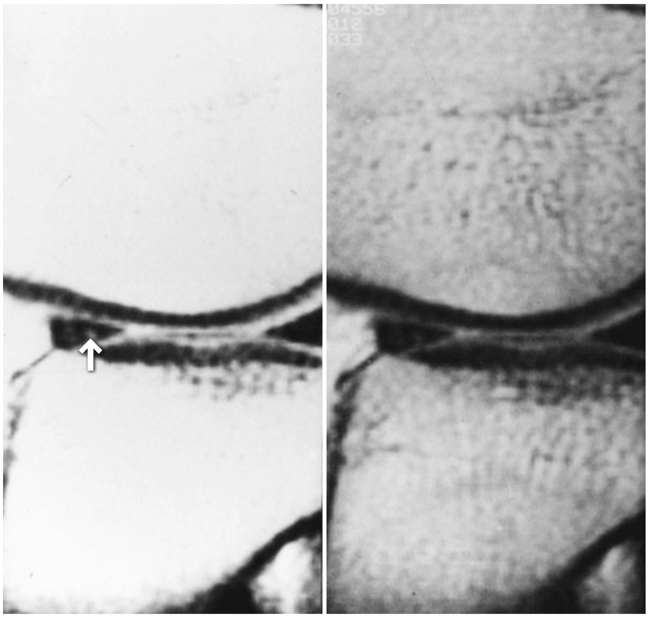

Fig. 7.6 **Meniscal window**. "Meniscal window" (*left*) with a narrow window width and a low window level, and (*right*) normal window width/level. PDWI. A small lesion in the anterior segment of the lateral meniscus (*arrow*) can only be detected in the "meniscal window" image. Note, however, it is impossible to see anything within the bone if the "meniscal window" is used

References

Rubin DA, Kneeland JB, Listerud J, Underberg-Davis SJ, Dalinka MK. MR diagnosis of meniscal tears of the knee: value of fast spin-echo vs conventional spin-echo sequences. AJR. 1994;162:1131–5.

Escobedo EM, Hunter JC, Zink-Brody GC, Wilson AJ, Harrison SD, Fisher DJ. Usefulness of turbo spin-echo MR imaging in the evaluation of meniscal tears: comparison with a conventional spin echo sequence. AJR. 1996;167:1223–7.

Meniscal Intrasubstance Hyperintensity

- Tear
- Mucoid (myxoid) degeneration
- Magic angle effect
- Chondrocalcinosis
- Partial volume effect

Grading of Meniscal Intrasubstance Hyperintensity

One of the grading schemes that has been proposed is:

Grade 1: Presence of dotted hyperintensity within the meniscus (Fig. 7.8a)

Grade 2: Presence of linear hyperintensity within the meniscus (Fig. 7.8b)

Grade 3: Presence of linear hyperintensity that reaches the meniscal surface

The problem with this classification system is that the grades 1 and 2 lesions do not truly represent the meniscal tear, and it may be confusing to readers of the report. Radiologists should be cautious when reporting the grade of lesions with numerical values because it may be completely meaningless to referring physicians who are not aware of the classification system itself. It is the author's personal opinion that we should not create more grading systems which do not have much clinical significance.

7.4 Meniscal Tear

Definition of meniscal tear

1. Intrasubstance hyperintensity that reaches the surface of the meniscus
2. Deformation of the meniscus

- The posterior segment of the medial meniscus is the thickest portion of the medial meniscus, and light intrasubstance hyperintensity is often observed. However, unless the hyperintensity reaches the meniscal surface, it is more likely to be physiologic changes (mucoid or myxoid degeneration) (Figs. 7.7 and 7.8).
- There is no evidence to suggest that intrasubstance hyperintensity within the meniscus seen in young persons will develop into a meniscal tear at later life.
- If signal changes suggestive of a meniscal tear are seen in more than one slices, or both in sagittal and coronal slices, the signal change is likely to represent a true meniscal tear (sensitivity >90%).
- If such signal changes are seen in only one slice, the sensitivity is 55% for the medial meniscus and 30% in the lateral meniscus.

Reference

De Smet AA, Norris MA, Yandow DR, et al. MR diagnosis of meniscal tears of the knee: importance of high signal in the meniscus that extends to the surfact. AJR. 1993;161:101–7.

- If the tear reaches both the superior and the inferior meniscal surface, it is called a complete tear (or a full-thickness tear). If the tear reaches only one surface, it is called a partial tear.

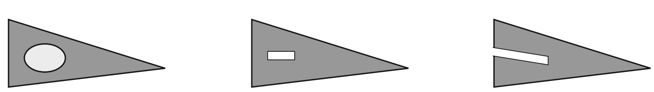

Fig. 7.7 **Meniscal intrasubstance hyperintensity (degeneration)**

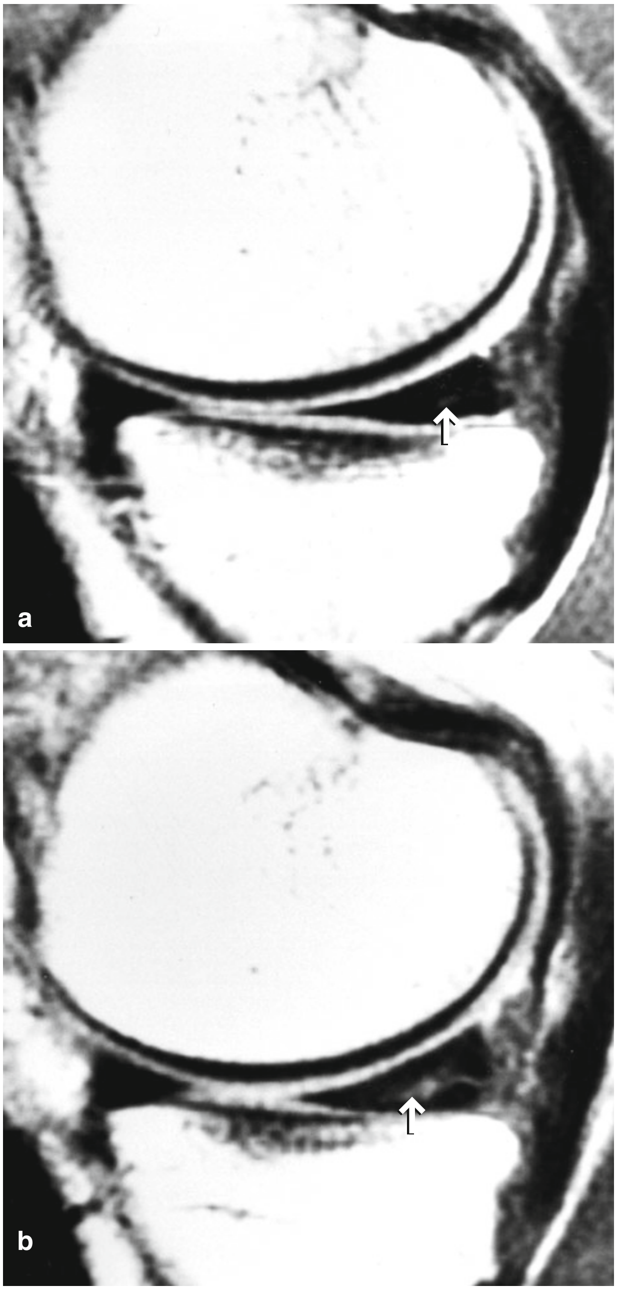

Fig. 7.8 Intrasubstance hyperintensity within the posterior segment of the medial meniscus. PDWI. Within the posterior segment of the medial meniscus, there is dotted (**a**) and linear (**b**) hyperintensity (*arrows*). If such signal changes do not reach the meniscal surface, it is more likely to be physiologic degenerative changes rather than a tear

Classification of the meniscal tear

1. Vertical tear
   (a) Longitudinal tear
       Bucket-handle tear
   (b) Radial tear
   (c) Oblique tear (parrot-beak tear)
2. Horizontal tear
3. Complex tear

(A) Complete tear (full-thickness tear)
(B) Partial tear

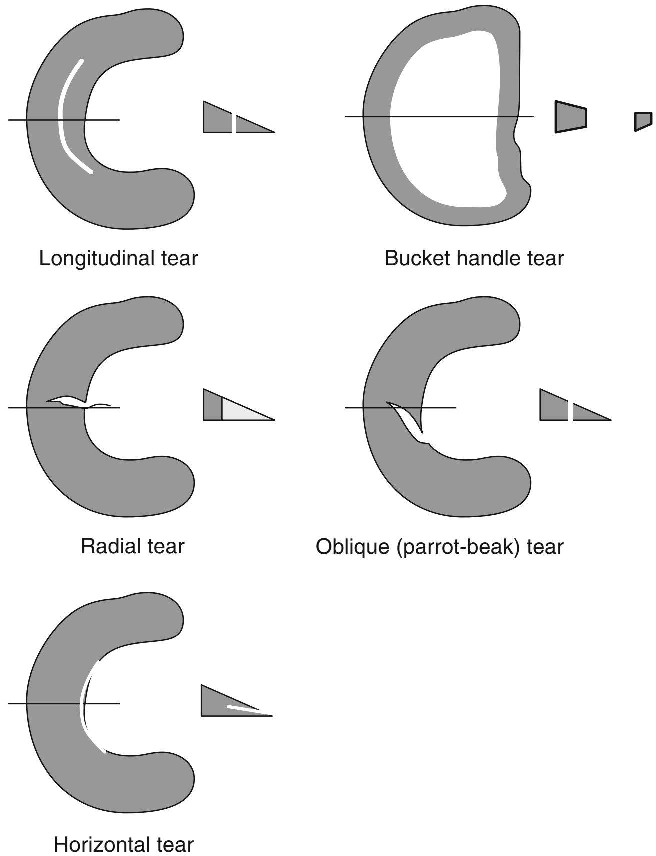

Fig. 7.9 Classification of meniscal tear (1)

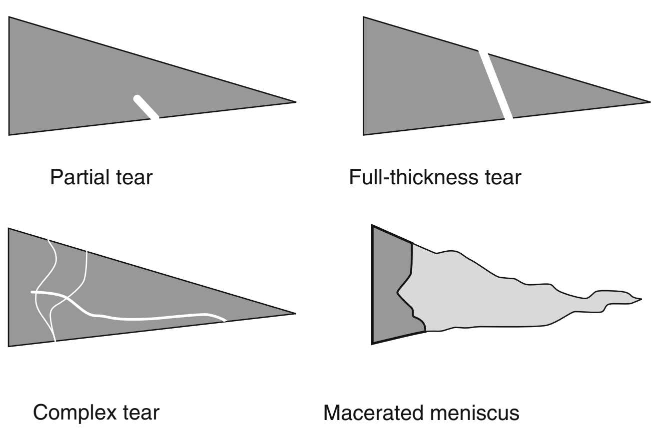

Fig. 7.10 Classification of meniscal tear (2)

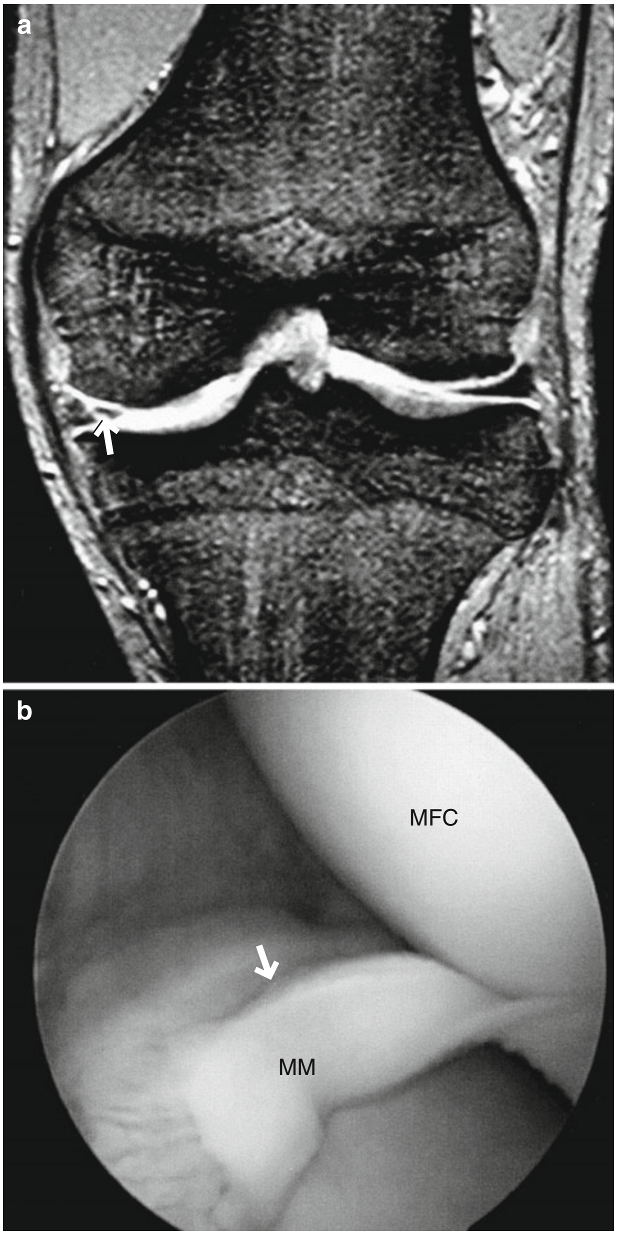

Fig. 7.11 Longitudinal tear of the posterior horn. A man in his 20s. (**a**) Coronal T2*WI and (**b**) arthroscopic image. There is a full-thickness longitudinal tear extending from the posterior horn to the middle segment of the medial meniscus (*MM*) (*arrows*). *MFC* medial femoral condyle

Vertical tear

- Vertical tear is commonly seen in young persons.
- Longitudinal tear commonly begins in the posterior horn and extends into the middle segment (Fig. 7.11).
- In sagittal image, vertical tear may be partially unclear due to partial volume effect.

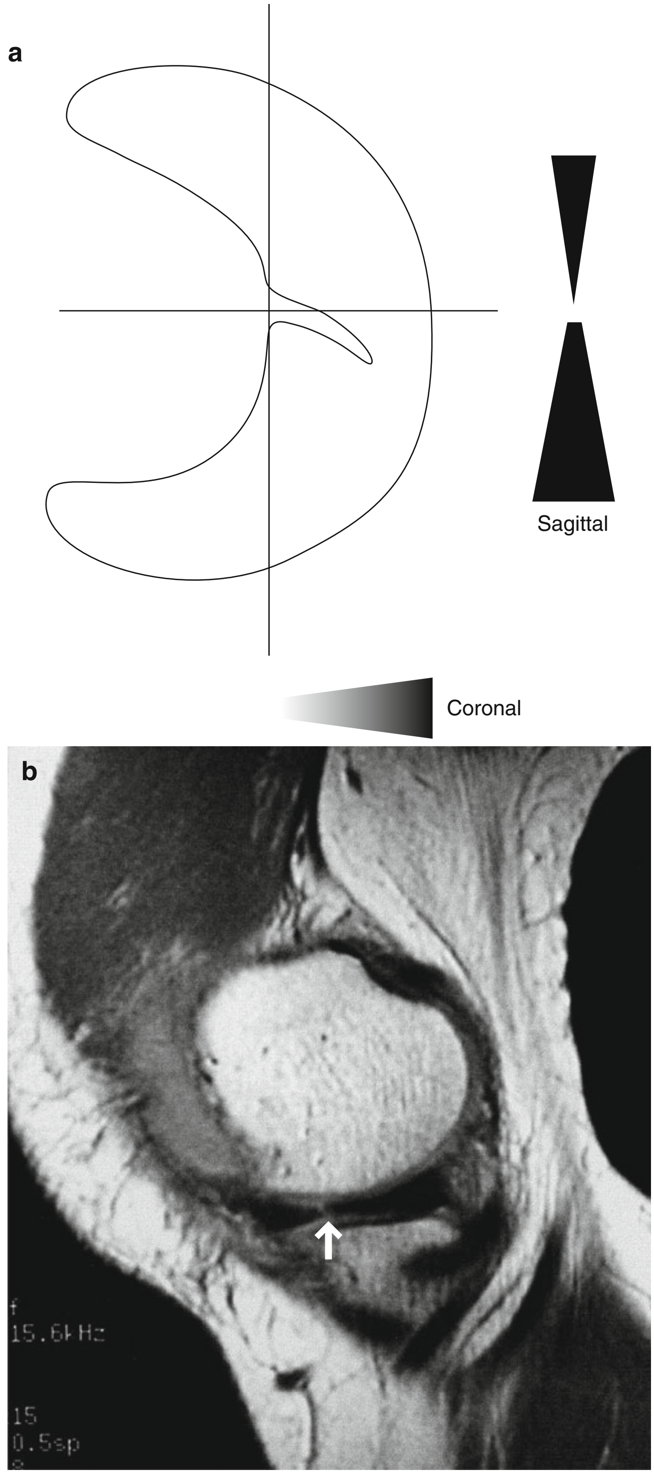

Fig. 7.12 Radial tear. A woman in her 50s. (**a**) Schematic illustration, (**b**) PDWI, (**c**) coronal T2*WI, and (**d**) axial T2WI. There is a full-thickness tear extending from the free border of the middle segment to the peripheral direction (*arrow*, **b**). In the coronal slice which cuts through the radial tear, the meniscus partially disappears (*arrows*, **c**). It is rare for a radial tear to be entirely visualized in axial images (*arrow*, **d**)

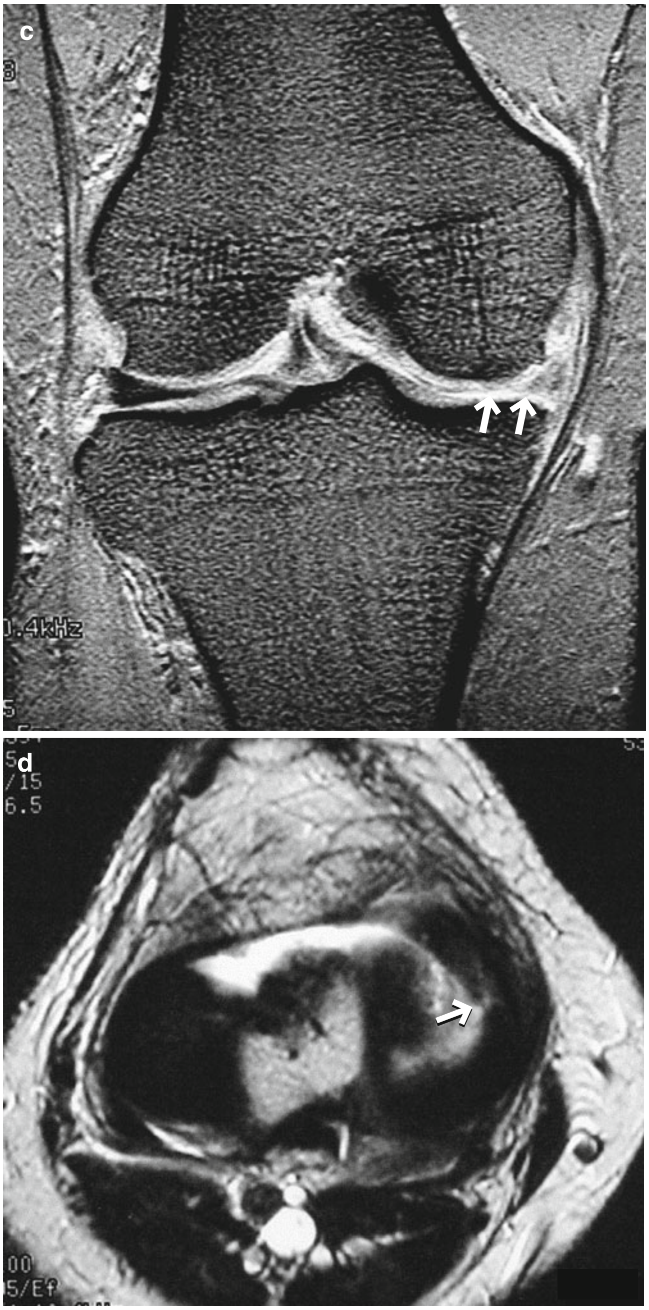

Fig. 7.12 (continued)

- Radial tear usually begins from the free border of the meniscus and extends into the peripheral portion.
- Radial tear may be difficult to visualize, especially in the axial slice.
- Radial tear sometimes produces a meniscal gap, depending on the slice (Fig. 7.12).
- Radial tear of the meniscal root is particularly difficult to diagnose.
- If radial tear progresses, a portion on the side of free border becomes detached from the meniscal body and creates a flap (Fig. 7.13).
- A fragment from the flap tear may drop into the coronary recess of the joint space (Fig. 7.14).
- If a fragment is displaced to the intercondylar space (especially the lateral meniscus), it will be positioned just inferoposterior to the ACL, leading to the "double-ACL" sign (there appears to be the "second ACL" under the true ACL) (Fig. 7.15).

References

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Vande Berg BC, Malghem J, Pilvache P, maldague B, Lecouvet FE. Meniscal tears with fragments displaced in notch and recesses of knee: MR imaging with arthroscopic comparison. Radiology. 2005;234:842–50.

Bui-Mansfield LT, Dewitt RM. Magnetic resonance imaging appearance of a double anterior cruciate ligament associated with a displaced tear of the lateral meniscus. J Comput Assist Tomogr. 2006;30:327–32.

Horizontal tear

- Horizontal tear is commonly seen in elderly persons and frequently coexists with intrasubstance signal abnormalities (Fig. 7.16). It is also called "fish mouth" or "cleavage."
- Horizontal tear begins just below the meniscal surface and extends peripherally.
- If the tear reaches the peripheral border, joint fluid will enter through it to form a meniscal cyst (see Chap. 12).

Complex tear

- Complex tear is the most severe form of tear and involves both vertical and horizontal tears. It can develop into meniscal segmentation and displacement of the entire meniscus from its original position (Fig. 7.17).
- Complex tear and severe degenerative changes will lead to macerated meniscus, which is the end stage of the meniscal damage (Fig. 7.18).

Meniscal contusion

- Localized intrasubstance hyperintensity following acute meniscal trauma (Fig. 7.19).
- The intrasubstance hyperintensity does not reach the meniscal surface and therefore does not fulfill the criteria for the meniscal tear.

Fig. 7.13 **Radial tear which progressed to a flap tear**. A woman in her 50s. (**a**, **b**) Taken at the time of initial presentation. (**c**, **d**) Taken at 40-day follow-up. (**a**, **c**) Axial FS PDWI. Initially, there was only a radial tear of the middle segment of the medial meniscus (**a**, **b**, *arrows*) but at follow-up, the torn fragment is anteriorly displaced to form a flap (**c**, **d**, *arrows*)

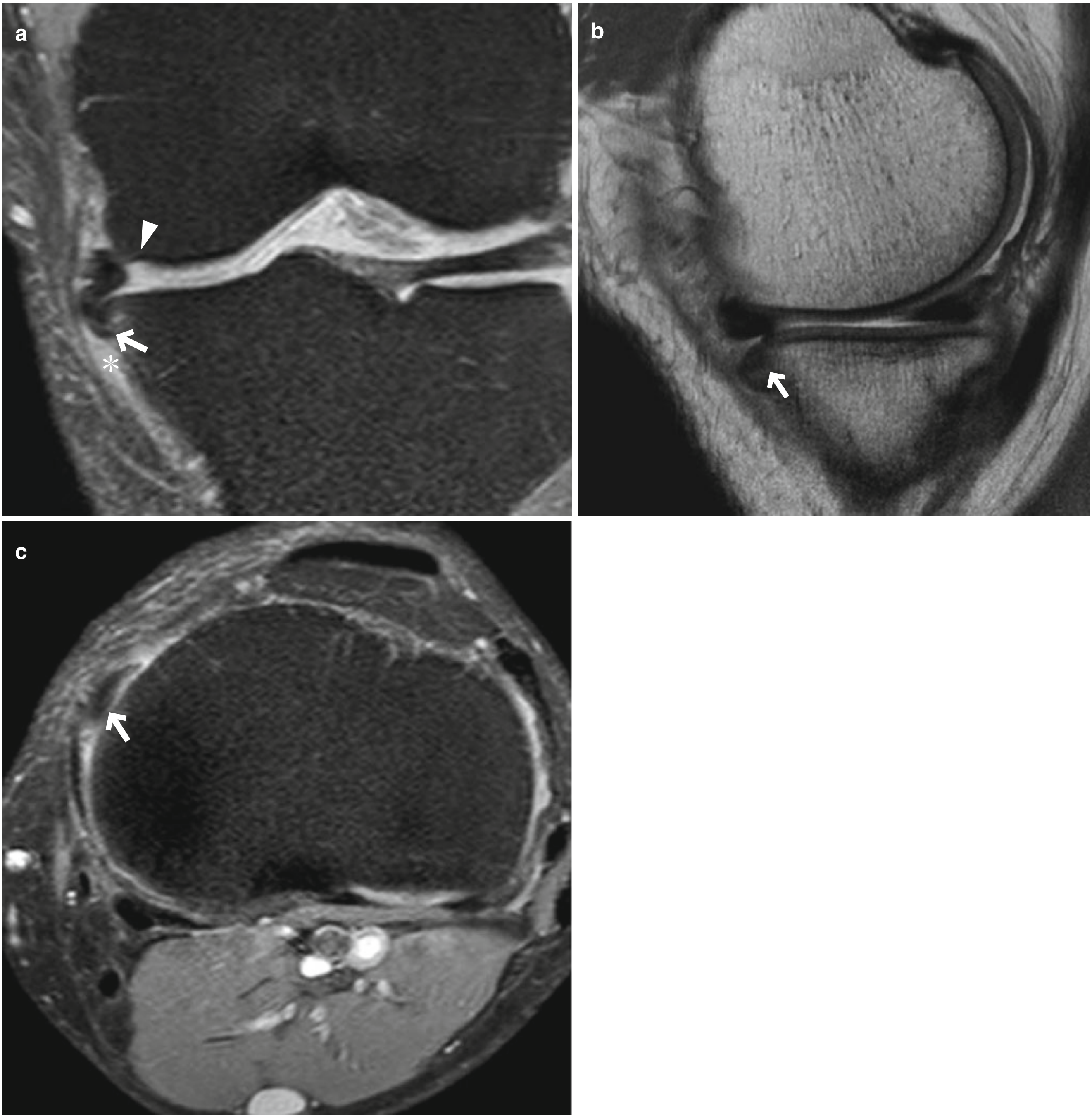

Fig. 7.14 **Fragment of a flap tear that fell into the coronary recess**. A man in his 30s. (**a**) Coronal FS PDWI, (**b**) PDWI, and (**c**) axial FS PDWI. A fragment (*arrow*) of a flap tear (*arrowhead*, **a**) is seen falling into the coronary recess (*, **a**) of the joint space

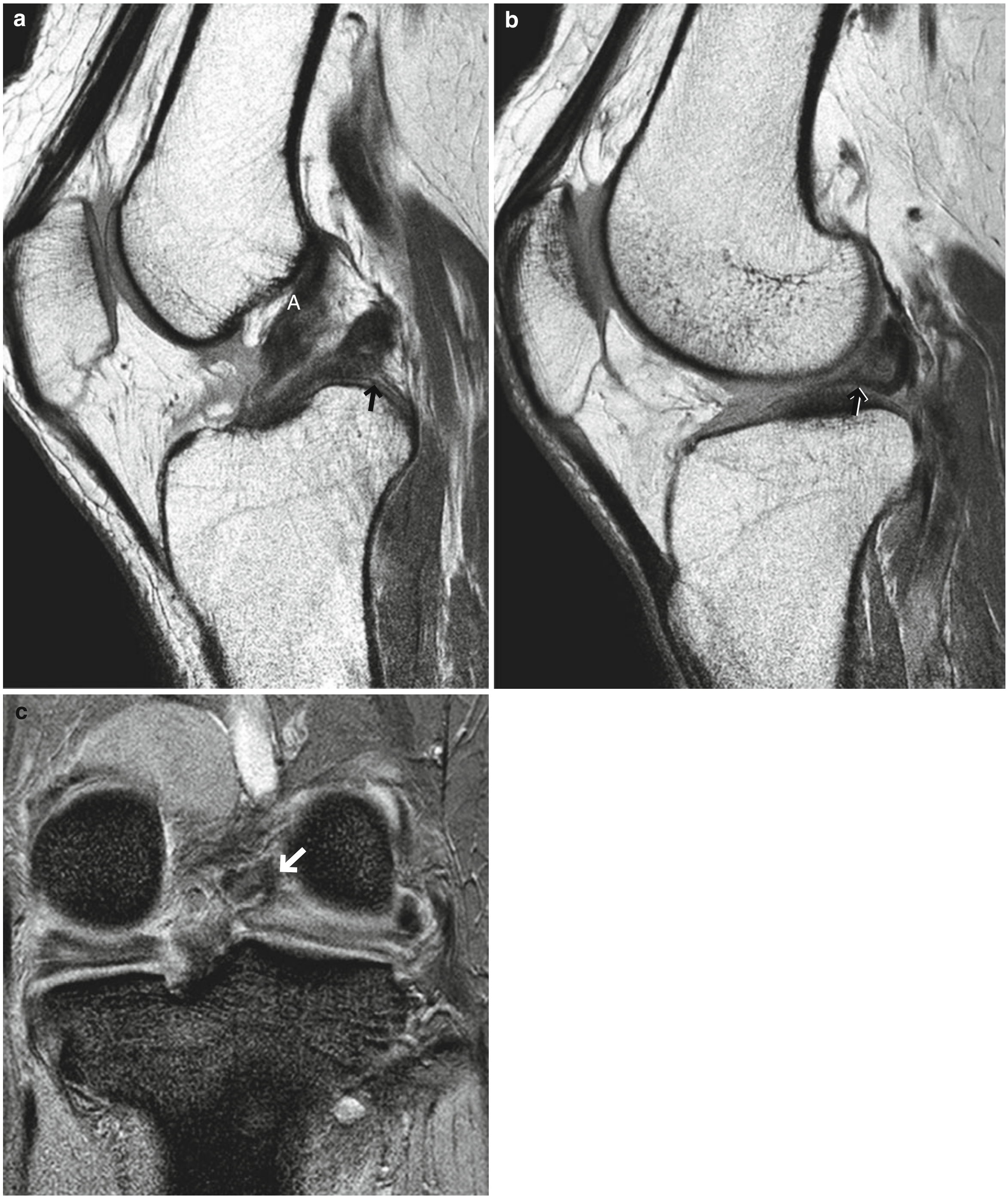

Fig. 7.15 Double ACL sign created by a fragment of the lateral meniscal flap tear. A woman in her 50s. (**a**, **b**) PDWI and (**c**) coronal T2*WI. Slice (**b**) is more lateral to the slice (**a**). A fragment of the flap tear (*arrows*) is displaced to the intercondylar space, and there appears to be the "second ACL" just inferoposterior to the true ACL (A)

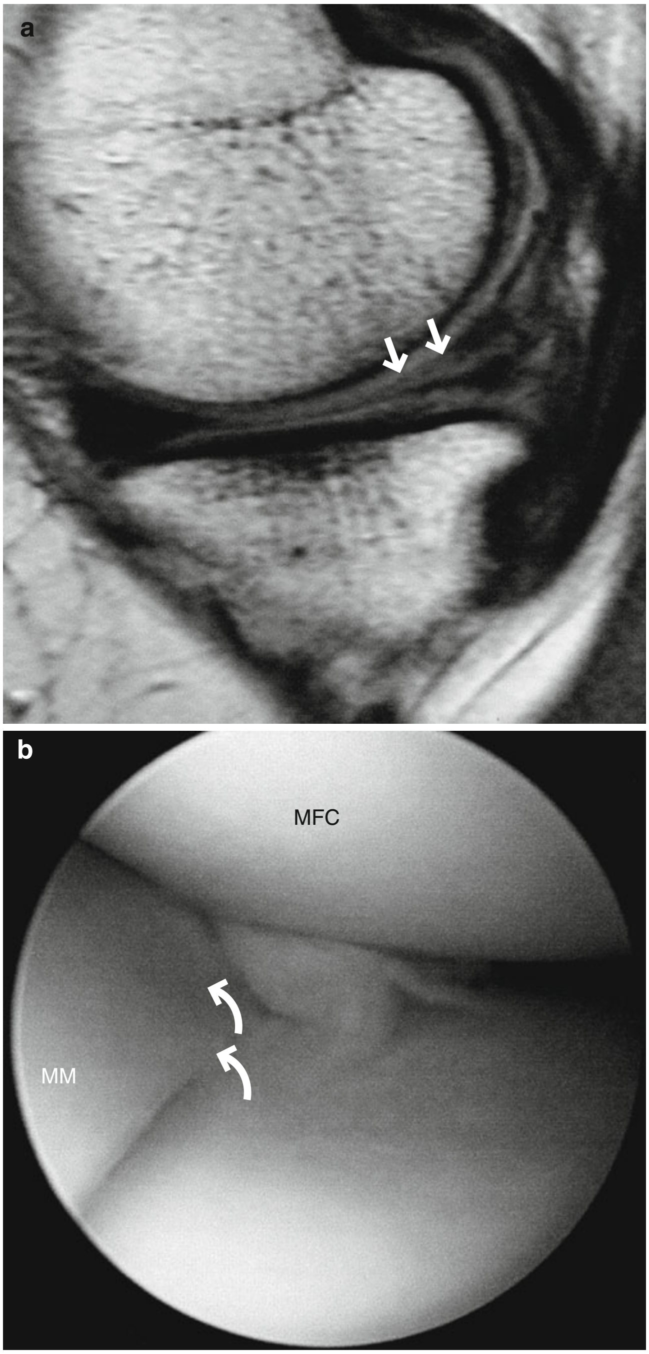

Fig. 7.16 **Horizontal tear**. A woman in her 50s. (**a**) PDWI and (**b**) arthroscopic image. There is a horizontal tear extending from the free border of the meniscus within the posterior segment of the medial meniscus (*arrows*, **a**). Arthroscopy revealed a horizontal tear (*curved arrows*, **b**) in the middle and posterior segments of the medial meniscus

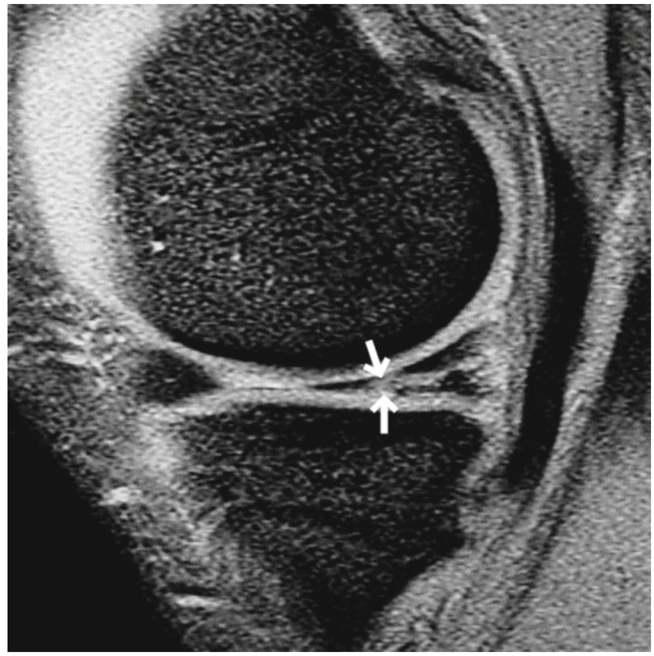

Fig. 7.17 **Complex tear**. A man in his 20s. Sagittal T2*WI. There are several tears (*arrows*) in addition to a horizontal tear within the posterior segment of the medial meniscus

Fig. 7.18 **Macerated meniscus**. A man in her 60s. Sagittal T2*WI. The anterior segment of the medial meniscus has lost its original shape and appears swollen (*arrows*) due to complex tear and severe degenerative changes

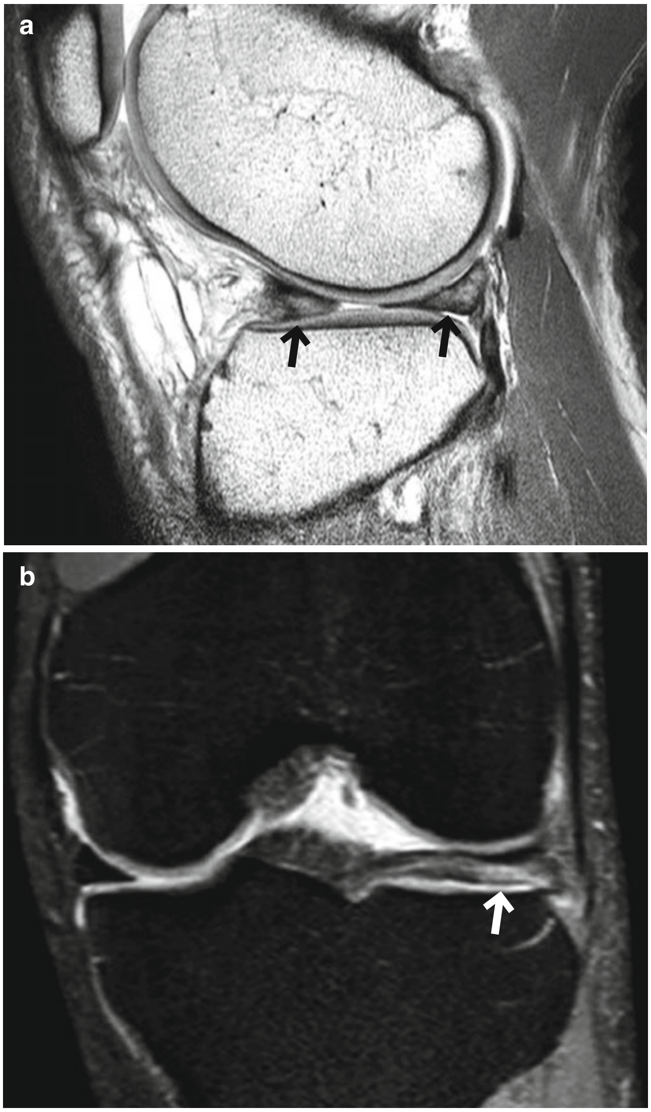

Fig. 7.19 **Meniscal contusion**. A man in his 20s who had a fall from a height 1 month prior to presentation. (**a**) PDWI and (**b**) coronal FS PDWI demonstrate intrasubstance hyperintensity extending from the anterior to the posterior segment of the lateral meniscus (*arrows*)

- Unlike physiologic hyperintensity (see Sect. 7.4), it exists just below the meniscal surface.
- Unlike age-related degenerative changes, the signal abnormality often disappears at follow-up examinations.
- Often accompanied by femoral and tibial bone contusion.
- Also commonly associated with ACL or PCL tear.

Reference

Cothran RL Jr, Major NM, Helms CA, Higgins LD. MR imaging of meniscal contusion in the knee. AJR. 2001;177:1189–92.

Very small tears

- Very small meniscal tears may be depicted as a minute step-like abnormality of the meniscal surface (Figs. 7.20, 7.21, and 7.22). Fibrillation is a very small localized irregularity of the meniscal surface which can be directly visualized by arthroscopy. A small longitudinal or an oblique tear causes blunting of the free edge.
- The posterior horn of the lateral meniscus (near the hiatus of the popliteus tendon) is prone to a longitudinal tear, but commonly it is asymptomatic without a need for specific treatment.
- Peripheral tear should be treated by meniscal suture or conservative treatment.
- Lone meniscal tear (without any ligamentous tear) is more common in the medial than the lateral meniscus.
- Meniscal tear associated with ACL tear is more common in the lateral than the medial meniscus. In fact, bone bruise, which occurs secondary to the ACL tear, is seen in the lateral compartment of the femur and tibia, and correspondingly a tear is commonly seen in the posterior segment/horn of the lateral meniscus (Fig. 7.23).
- A combination of the medial meniscal tear, ACL tear, and the MCL tear is known as "O'Donoghue's unhappy triad." However, what is more commonly seen is the lateral meniscal tear in combination with ACL tear and MCL tear.
- Meniscal tear associated with ligamentous tears is commonly a longitudinal tear in the posterior segment/horn of the medial or lateral meniscus.
- If ACL tear is left untreated, medial rather than lateral meniscal tear is likely to occur at a later stage, most commonly degenerative complex tear.

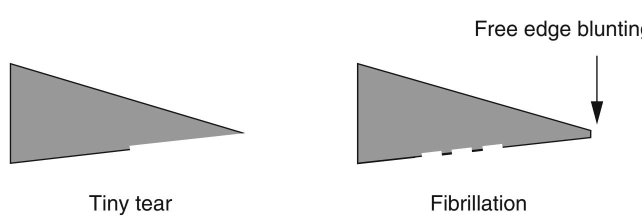

Fig. 7.20 **Schematic illustration of a very small meniscal tear**

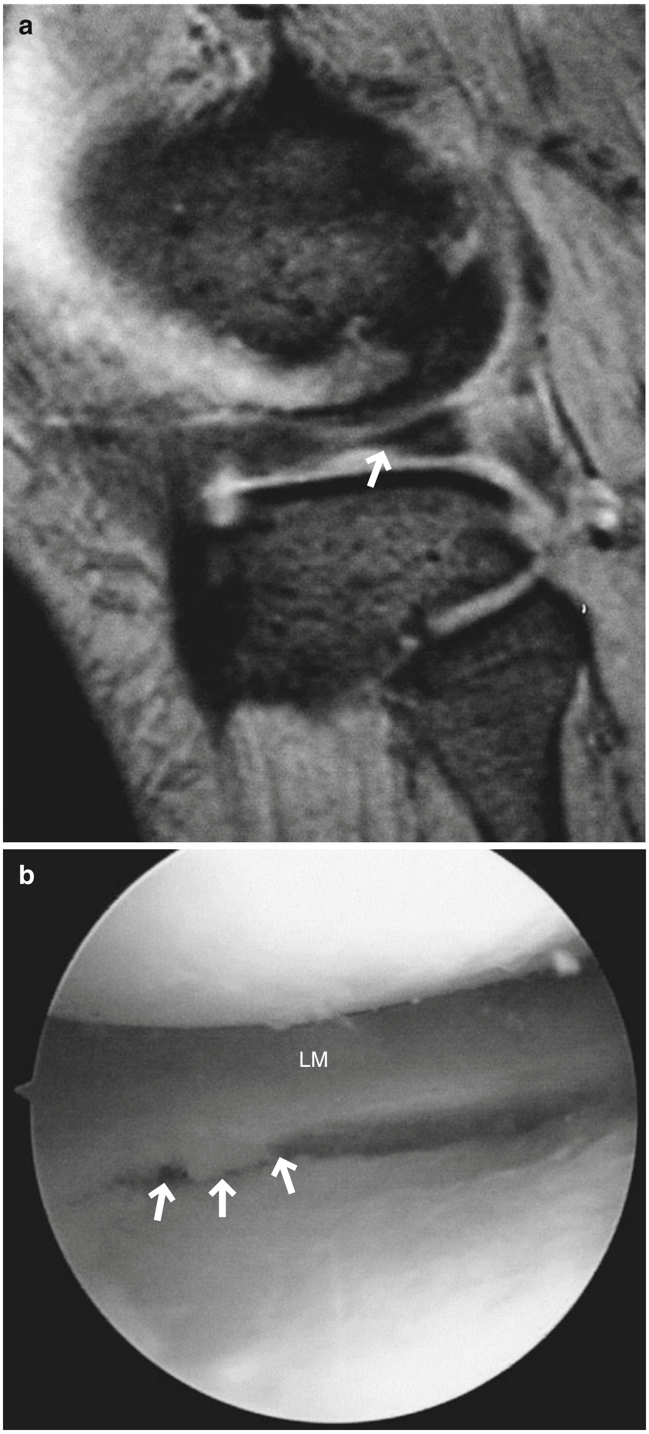

Fig. 7.21 **Very small meniscal tear**. A woman in her 60s. (**a**) T2*WI and (**b**) arthroscopic image. There is a small step-like appearance at the inferior surface of the lateral meniscus (*LM*) (*arrow*, **a**). Irregularity of the meniscal free edge and fibrillation of the inferior surface are seen by arthroscopy (*arrows*, **b**)

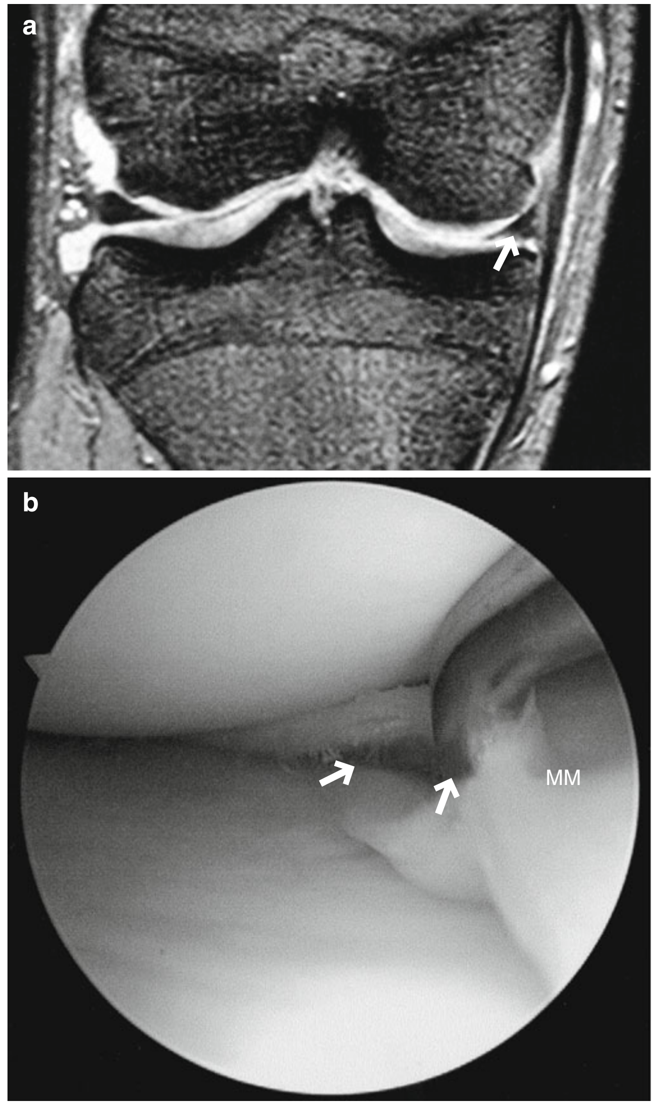

Fig. 7.22 **Small horizontal tear**. A man in his 50s. (**a**) Coronal T2*WI and (**b**) arthroscopic image. MRI depicts a small lesion suspicious of a tear of the medical meniscal free edge (*arrow*, **a**). Arthroscopy revealed a horizontal tear in the middle/posterior segment of the medial meniscus (*arrows*, **b**)

- The sensitivity of clinical examination for the diagnosis of meniscal tear is around 75%, but that of MRI is 90% or higher.
- Approximately 40% of cases in which MRI could not correctly diagnose meniscal tear is said to be “inevitable.”

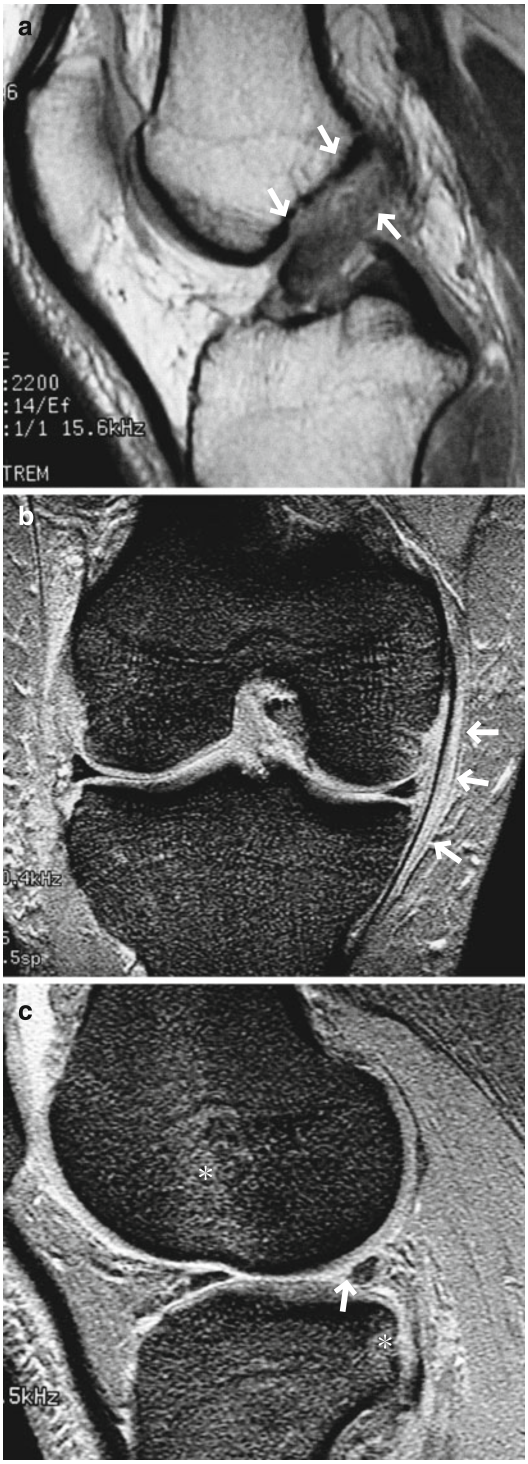

Fig. 7.23 Lateral meniscal tear in combination with ACL tear and MCL tear. A 26-year-old man. (**a**) PDWI, (**b**) coronal T2*WI, and (**c**) T2*WI. Acute ACL tear (*arrows*, **a**) and grade 1 MCL injury (*arrows*, **b**) are observed. Meniscal injury that occur in combination with these injuries are more commonly lateral than medial. Longitudinal tears of the posterior horn of the lateral meniscus are particularly common (*arrow*, **c**). Bone bruise is present in the lateral femoral condyle and the posterior aspect of the tibial plateau (*, **c**)

- False-negative finding is most commonly seen in the posterior horn of the lateral meniscus, especially a small longitudinal tear. In particular, diagnosis of a tear of the posterior horn of the lateral meniscus is frequently missed when ACL tear coexists.
- However, approximately half of meniscal tears that are missed by MRI do not require treatment anyway. Especially, missing a small tear of the lateral meniscus does not seem to produce any long-term consequences.
- Commonly, the posterior segment/horn of the medial meniscus is the arthroscopic blind spot, and arthroscopy may fail to detect a tear that was detected by MRI in that region of the medial meniscus. Thus, it is important for radiologists to inform physicians who are performing the arthroscopy beforehand about the MRI diagnosis.

References

Barber FA. What is the terrible triad? Arthroscopy. 1992; 8:19–22.

De Smet AA, Graf BK. Meniscal tears missed on MR imaging: relationship to meniscal tear patterns and anterior cruciate ligament tears. AJR. 1994;162:905–11.

De Smet AA, Mukherjee R. Clinical, MRI and arthroscopic findings: associated with failure to diagnose a lateral meniscal tear on knee MRI. AJR. 2008;190:22–6.

Be Actively Involved in Clinical Assessment of Patients
Most radiologists are busy working in the reporting room or in the control room, instructing technologists, and writing reports. However, sometimes, it is worthwhile seeing the patient ourselves, especially if the referring physician fails to give sufficient clinical history or to indicate which meniscus (lateral or medial) they are particularly concerned about. In such cases, it is actually quickest to ask the patient themselves to find out the answer. Asking about the mechanism of injury is of particular importance in narrowing differential diagnoses. A quick and simple clinical examination of the knee (e.g., inspection and palpation) will yield a tremendous amount of information, which will certainly help us to reach the correct diagnosis.

7.5 Bucket-Handle Tear of the Meniscus

- Extensive complete longitudinal tear may progress to a bucket-handle tear (Fig. 7.24).
- Much more common in the medial meniscus (Fig. 7.25).
- A torn portion is displaced from its original location at the periphery to the central location (close to cruciate ligaments) to form the “bucket-handle” appearance, and the meniscus shows a ring-like appearance. This may cause symptoms such as the “locking” of the knee, requiring surgical treatment.
- The “bucket-handle” portion of the torn meniscus can be found in the intercondylar space adjacent to the ACL anteriorly. Intact ACL prevents further central displacement of the “bucket handle.”

Reference

Wright DH, De Smet AA, Noris M. Bucket-handle tears of the medial and lateral menisci of the knee: value of MR imaging in detecting displaced fragments. AJR. 1995;165:621–5.

Absent bow tie sign

- In sagittal images, the body of normal menisci have a shape of a bow tie in many slices. However, if a bucket-handle tear occurs, this bow tie appearance is seen in a reduced number of sagittal slices

Reference

Helms CA, Laorr A, Cannon WD Jr. The absent bow tie sign in bucket-handle tears of the menisci in the knee. AJR. 1998; 170:57–61.

Double PCL sign

- Torn “bucket-handle” portion of a torn meniscus may be displaced just inferior to the PCL, giving impression that there are two PCLs in sagittal images (Fig. 7.25). Coronal images reveal the bucket-handle tear.

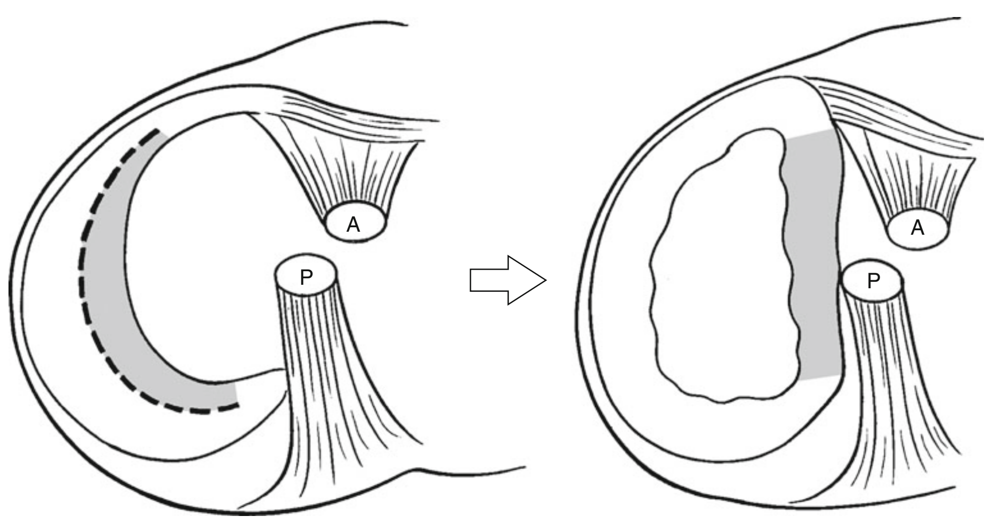

Fig. 7.24 Schematic illustration of a bucket-handle tear. A torn portion is displaced from its original location at the periphery to the central location (close to cruciate ligaments) to form the “bucket-handle” appearance, and the meniscus shows a ring-like appearance. *A* ACL, *P* PCL

Fig. 7.25 A bucket-handle tear. A man in his 40s. (**a**) PDWI, (**b**) coronal T2*WI, (**c**) PDWI at the intercondylar space, and (**d**) arthroscopic image. The posterior segment of the medial meniscus is torn and appears smaller than normal (*arrow*, **a**). The “bucket-handle” portion of the meniscus is displaced to the intercondylar space (*arrow*, **b**) and sits beneath the PCL (*P*, *arrows*, **c**) demonstrating the double PCL sign. Arthroscopy shows the bucket handle (**b**) located adjacent to the ACL (**d**)

Flipped meniscus

- If a bucket-handle tear occurs at the posterior segment/horn of the lateral meniscus, the torn portion may be anteriorly displaced to superimpose the anterior horn (Fig. 7.26). In this case, the posterior horn is absent and an abnormally large anterior horn is present in sagittal images. If the torn portion sits immediately posteriorly to the anterior horn, it is called “double peak” (Fig. 7.27), while if the torn portion sits on top of the anterior horn, it is called “double-decker” (Fig. 7.28).

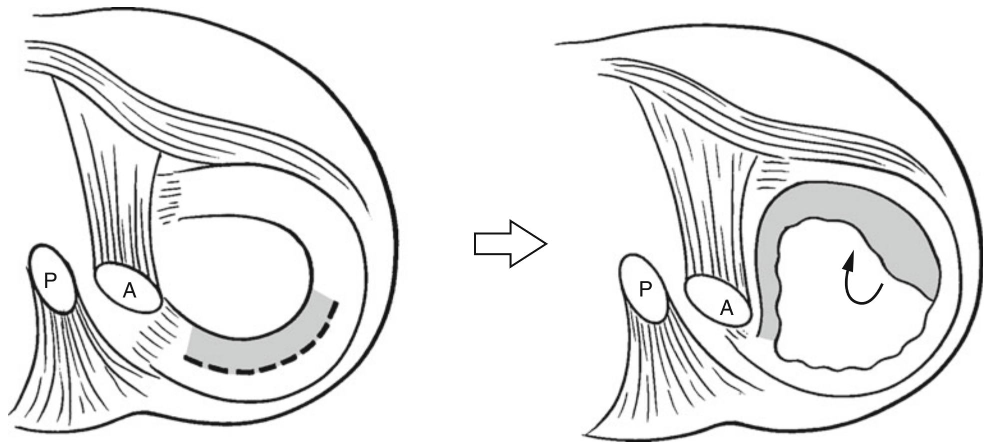

Fig. 7.26 Schematic illustration of a flipped meniscus. This is a type of bucket-handle tear with the bucket handle being displaced anteriorly. It is commonly seen in the lateral meniscus

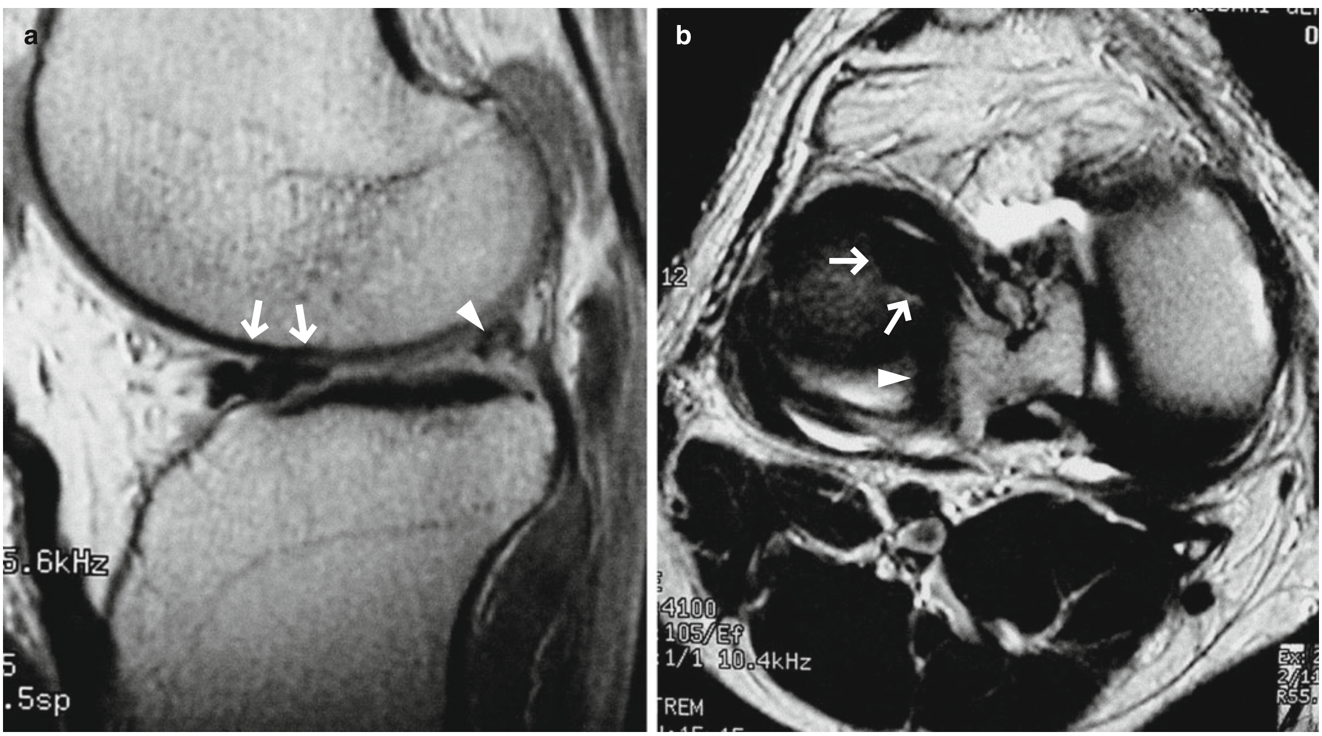

Fig. 7.27 Flipped meniscus showing the double-peak sign. A man in his 40s. (**a**) PDWI and (**b**) axial T2WI. The posterior horn of the lateral meniscus appears abnormally small (*arrowhead*, **a**), and the anterior horn has an abnormal shape (*arrows*, **a**). This appearance of the anterior horn is called "double peak" and represents a bucket-handle tear. In the axial image, the displaced "bucket-handle" (*arrowhead*, **b**) appears as if it is connected to the anterior horn of the meniscus (*arrows*, **b**)

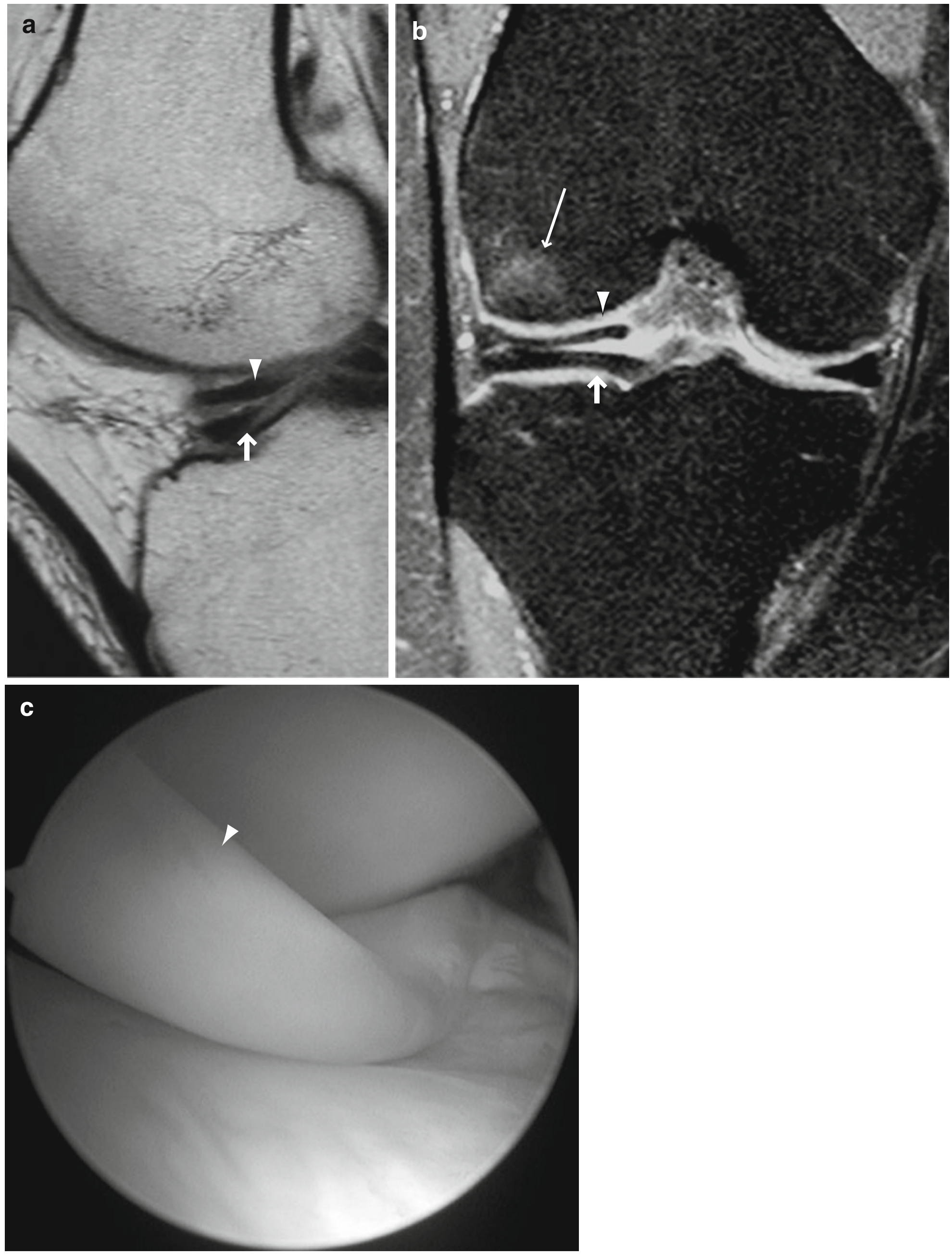

Fig. 7.28 Flipped meniscus showing the double-decker sign. A woman in her 30s. (**a**) PDWI, (**b**) coronal T2*WI, and (**c**) arthroscopic image. The bucket-handle portion of the torn meniscus (*arrowhead*) sits on top of the anterior horn of the lateral meniscus (*arrow*). There is a bone bruise in the lateral femoral condyle (*thin arrow*)

7.6 Meniscal Lesions in the Elderly

Intrasubstance hyperintensity is commonly seen in the elderly. In particular, such signal abnormality of the posterior segment of the medial meniscus is seen in almost all cases. Mostly, these are associated with osteoarthritis of the knee, and bone deformity and cartilage loss frequently coexist. It is not definitively known yet whether meniscal tear occurred as a result of osteoarthritis, or vice versa. In elderly patients, even if the intrasubstance hyperintensity reaches the meniscal surface, it is more likely to be a secondary meniscal tear as a result of degenerative changes.

Reference

Hodler J, Haghighi P, Pathia MN, et al. Meniscal changes in the elderly: correlation of the MR imaging and histologic findings. Radiology. 1992;184:221–5.

Fig. 7.29 **Meniscal extrusion**. A woman in her 40s. Coronal T2*WI. The knee exhibits osteoarthritic changes as represented by some osteophytes (bony spurs). The medial meniscus is extruded (*curved arrows*)

Meniscal extrusion (pseudosubluxation)

- Menisci in the elderly patients are not as elastic as those in young persons, and they may be extruded circumferentially (Fig. 7.29).
- Meniscal extrusion is particularly common in the posterior horn of the medial meniscus as a result of posterior root tear (Fig. 7.30).
- Meniscocapsular separation often coexists.
- Meniscal extrusion results in less effective transmission of the mechanical load through the tibiofemoral joint, as well as loss of shock-absorbing function, leading to progression of osteoarthritis changes.
- Posterior root tear of the lateral meniscus leads to extrusion of the lateral meniscus. It is likely to accompany ACL tear.

References

Lerer DB, Umans HR, Hu MX, Jones MH. The role of meniscal root pathology and radial meniscal tear in medial meniscal extrusion. Skeletal Radiol. 2004;33:569–74.

Brody JM, Lin HM, Hulstyn MJ, Tung GA. Lateral meniscal root tear and meniscus extrusion with anterior cruciate ligament tear. Radiology. 2006;239:805–10.

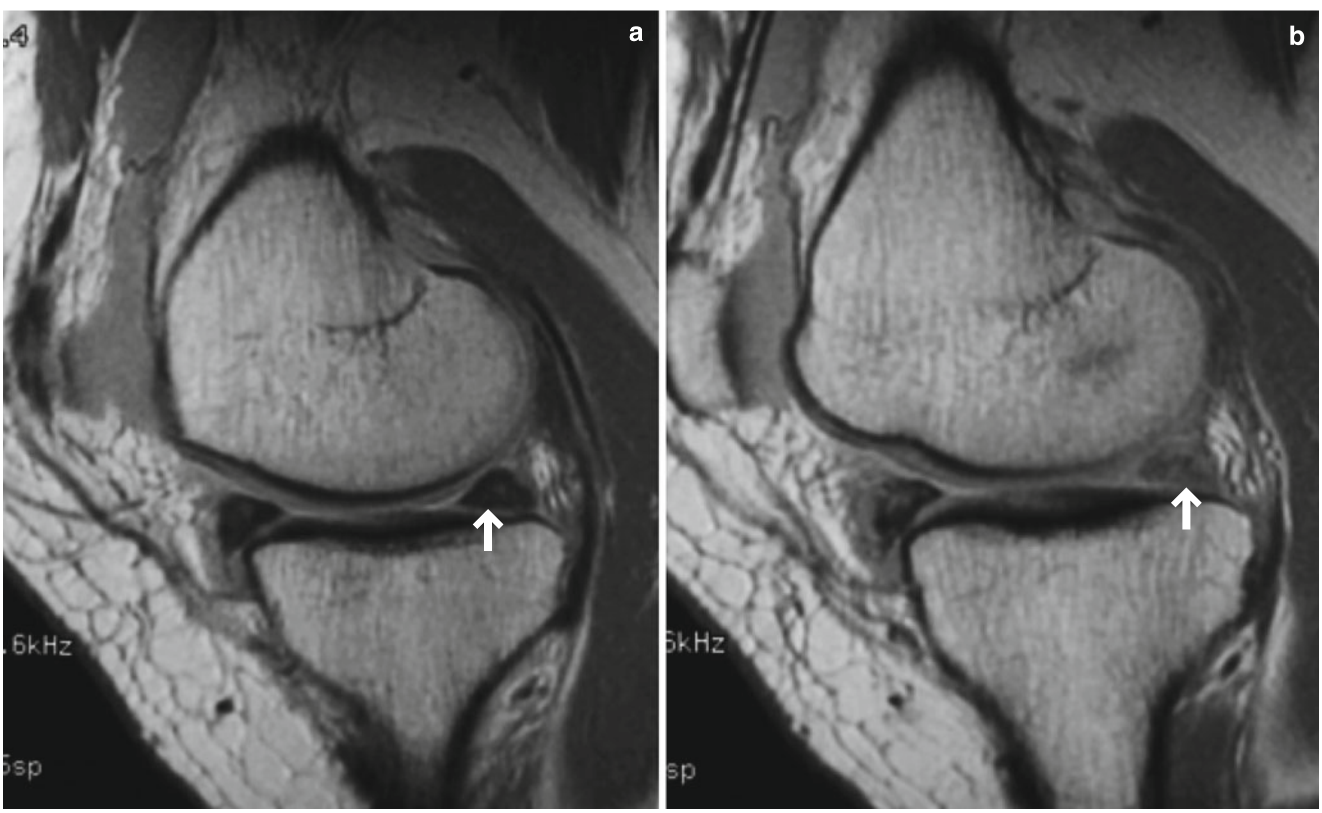

Fig. 7.30 **Posterior root tear of the medial meniscus**. A woman in her 60s. (**a**, **b**) PDWI, (**c**) coronal T2*WI, and (**d**) axial T2WI. In (**a**), the posterior horn of the medial meniscus is seen (*arrow*), but it disappeared in (**b**, *arrow*). Coronal and axial images confirm that there is a posterior root tear (*arrows*, **c**, **d**)

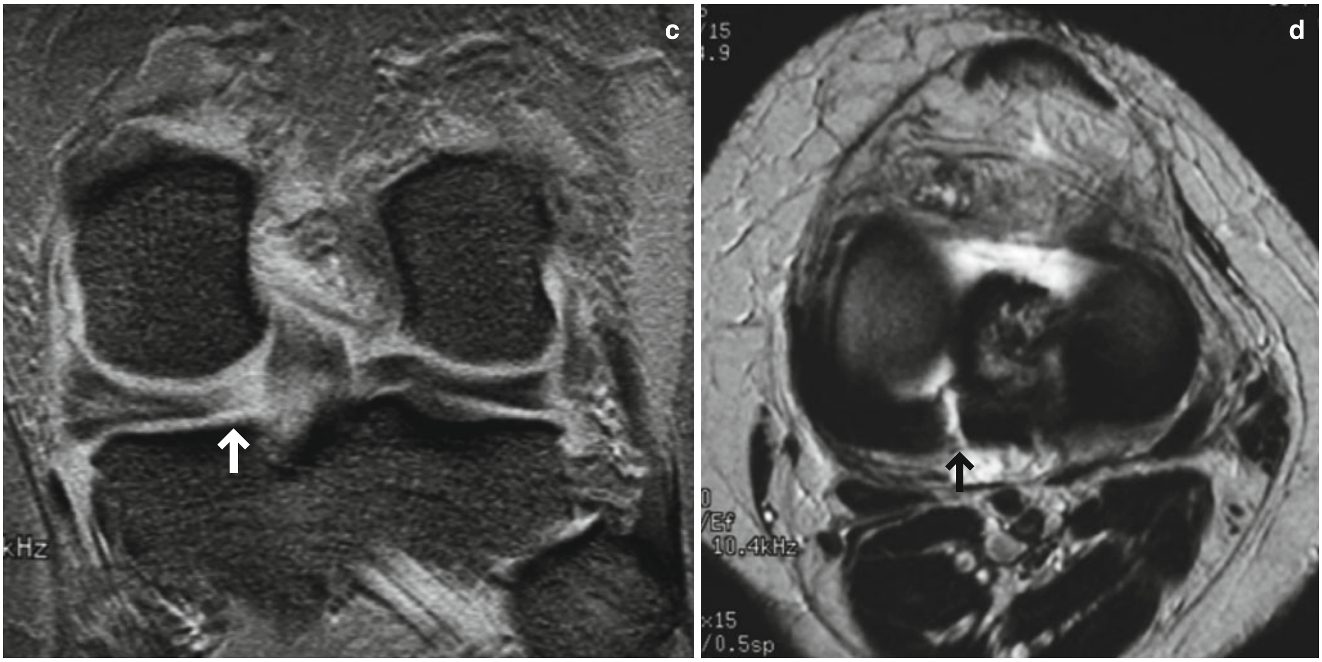

Fig. 7.30 (continued)

7.7 Peripheral Meniscal Tear and Meniscocapsular Separation

- The menisci are peripherally contiguous with the joint capsule (Fig. 7.31).
- Longitudinal vertical tear commonly occurs in the peripheral zone (Fig. 7.32). Such tears may heal naturally because of the abundant vascular supply at the peripheral zone.

Meniscocapsular separation

- Meniscus becomes separated from the joint capsule.
- More common in the medial meniscus and commonly associated with MCL tear.
- MRI shows irregularity of the outer meniscal border and the presence of fluid between the meniscus and the joint capsule.
- It is difficult to differentiate on MRI between the tear of the peripheral zone of the meniscus and the meniscocapsular separation. However, there seems to be little clinical importance for differentiating between the two.

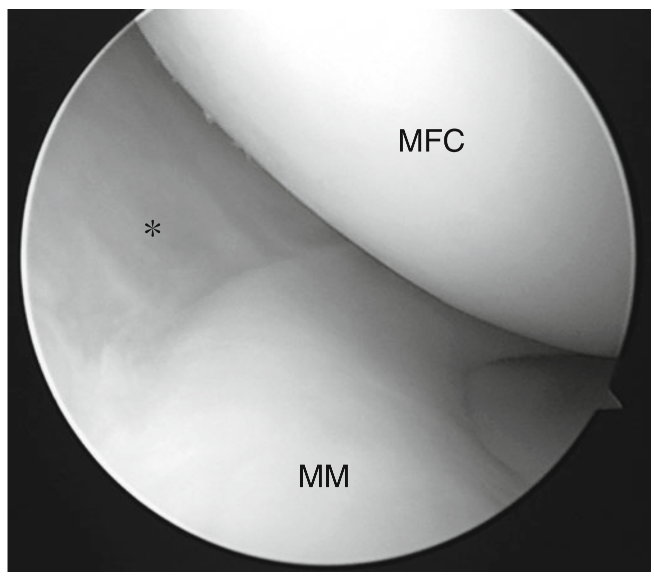

Fig. 7.31 **Arthroscopic image**. Medial meniscus (*MM*) and the contiguous joint capsule (*) is seen. *MFC* medial femoral condyle

Reference

De Maeseneer M, Lenchik L, Starok M, Pedowitz R, Trudell D, Resnick D. Normal and abnormal medial meniscocapsular structures: MR imaging and sonography in cadavers. AJR. 1998; 171:969–76.

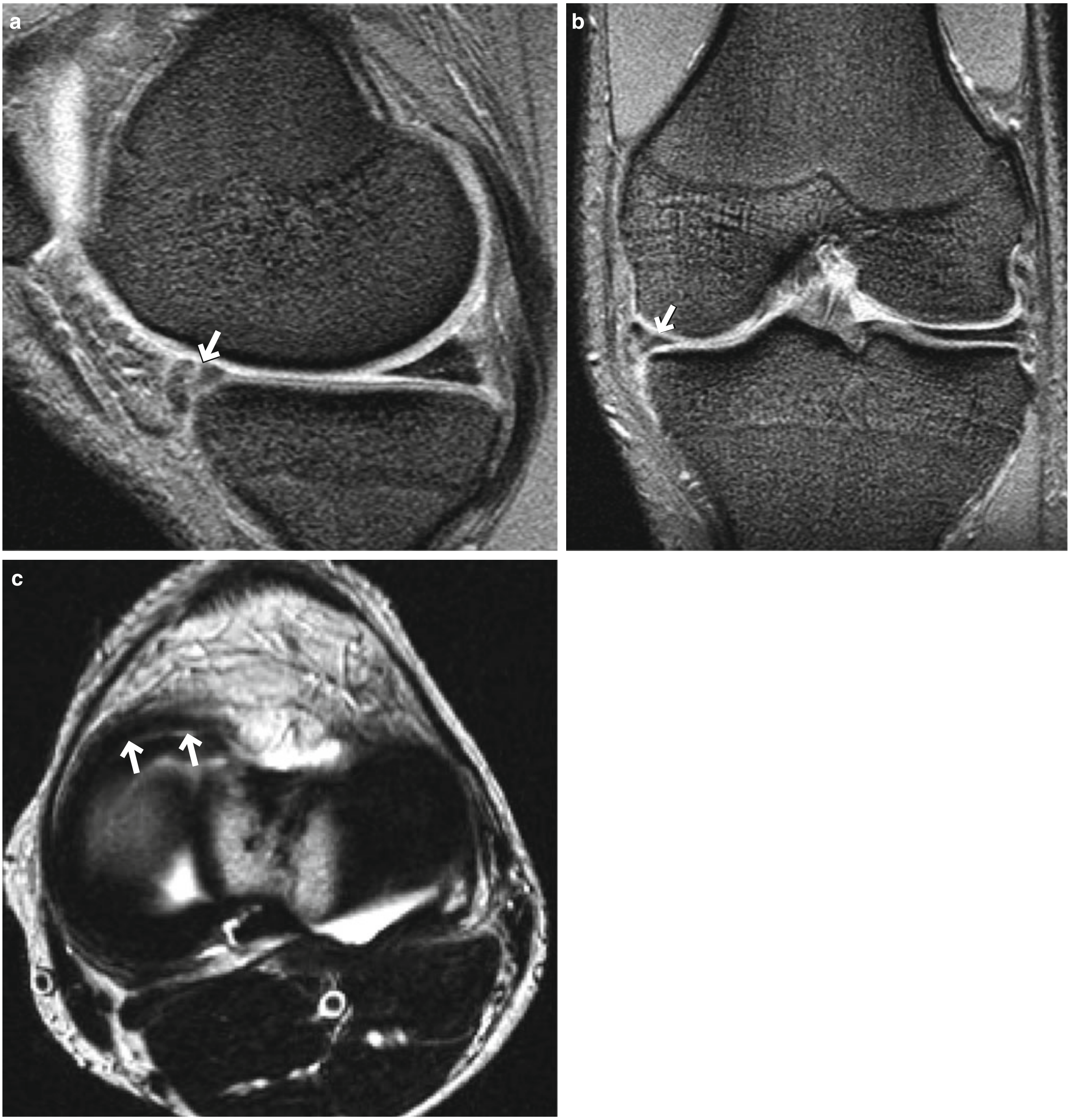

Fig. 7.32 **Meniscal tear in the peripheral zone**. A man in his late teens. (**a**) Sagittal, and (**b**) coronal T2*WI, and (**c**) axial T2WI. There is a vertical tear extending from the anterior horn to the anterior segment in the peripheral zone (*arrow*). Axial image visualizes the tear very clearly (*arrows*)

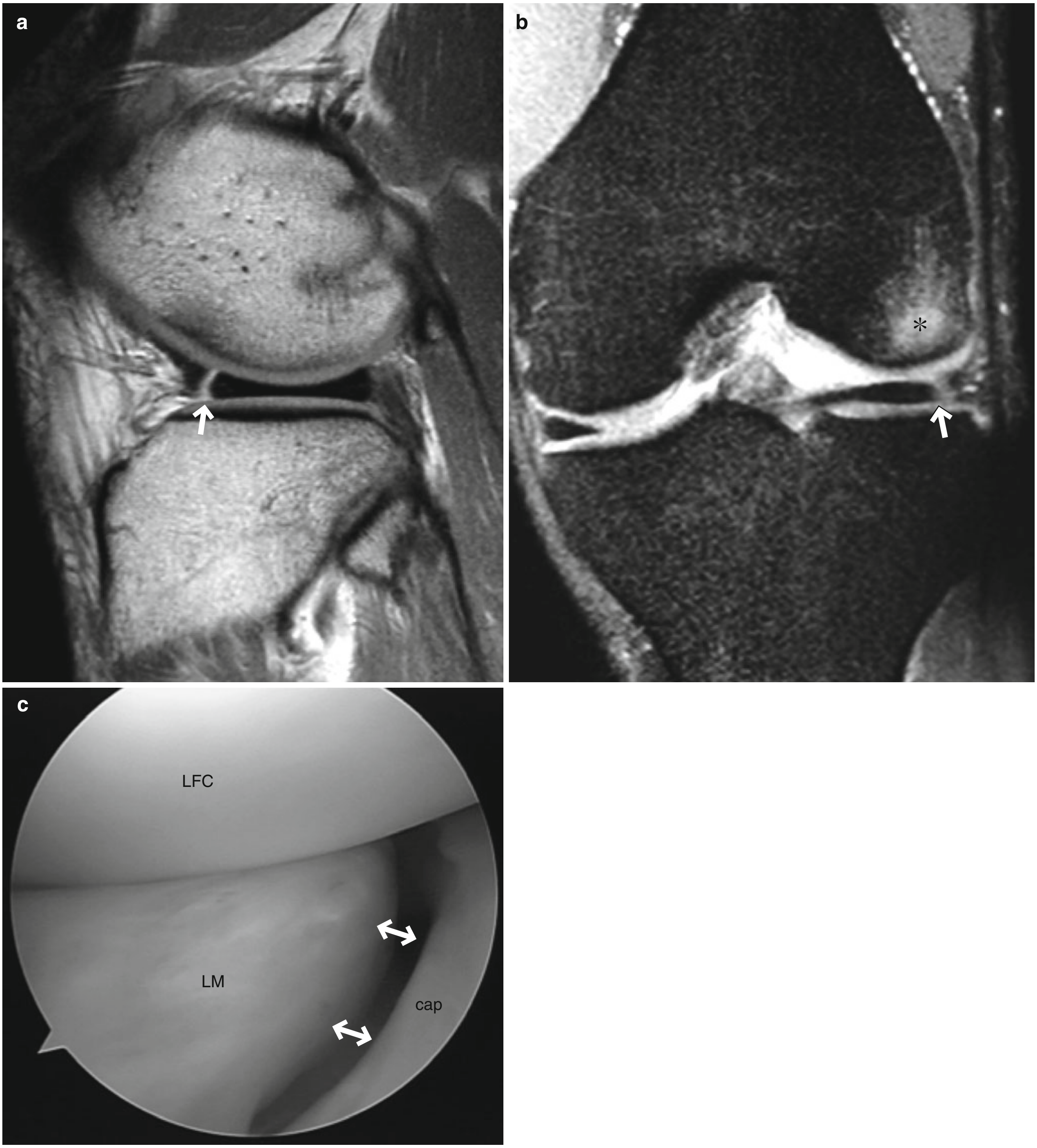

Fig. 7.33 Meniscocapsular separation. A man in his 20s. (**a**) PDWI, (**b**) coronal FS PDWI, and (**c**) arthroscopic image. There is abnormal hyperintensity (*arrow*) extending from the anterior horn to the anterior segment along the periphery of the lateral meniscus. There is bone bruise in the lateral femoral condyle (*, **b**). Arthroscopy showed the separation (*arrows*, **c**) of the lateral meniscus (*LM*) from the joint capsule (cap). *LFC* lateral femoral condyle (Image courtesy of Dr. Akihiro Kanamori, Department of Orthopaedics, Tsukuba University School of Medicine)

Hypermobile meniscus

- There is no damage to the meniscal substance itself, but symptoms resemble those arising from meniscal tear (e.g., locking or pain of the knee on knee flexion).
- More common in the lateral meniscus.
- Discoid meniscus (Wrisberg type) can be a cause for this condition (see Sect. 7.9).
- Range of meniscal motion of becomes abnormally large (especially anterior to the popliteus tendon).
- MRI examination may reveal no obvious pathologic findings (Fig. 7.34).

Floating meniscus

- Traumatic separation of the meniscus from the tibial plateau.
- Occurs due to meniscocapsular ligament tear (e.g., meniscotibial (coronal) ligament).
- More common in the lateral meniscus.
- On MRI, joint fluid is seen between the meniscus and the tibial plateau.

Reference

Bikkina RS, Tujo CA, Schraner AB, Major NM. The "floating" meniscus: MRI in knee trauma and implications for surgery. AJR. 2005;184:200–4.

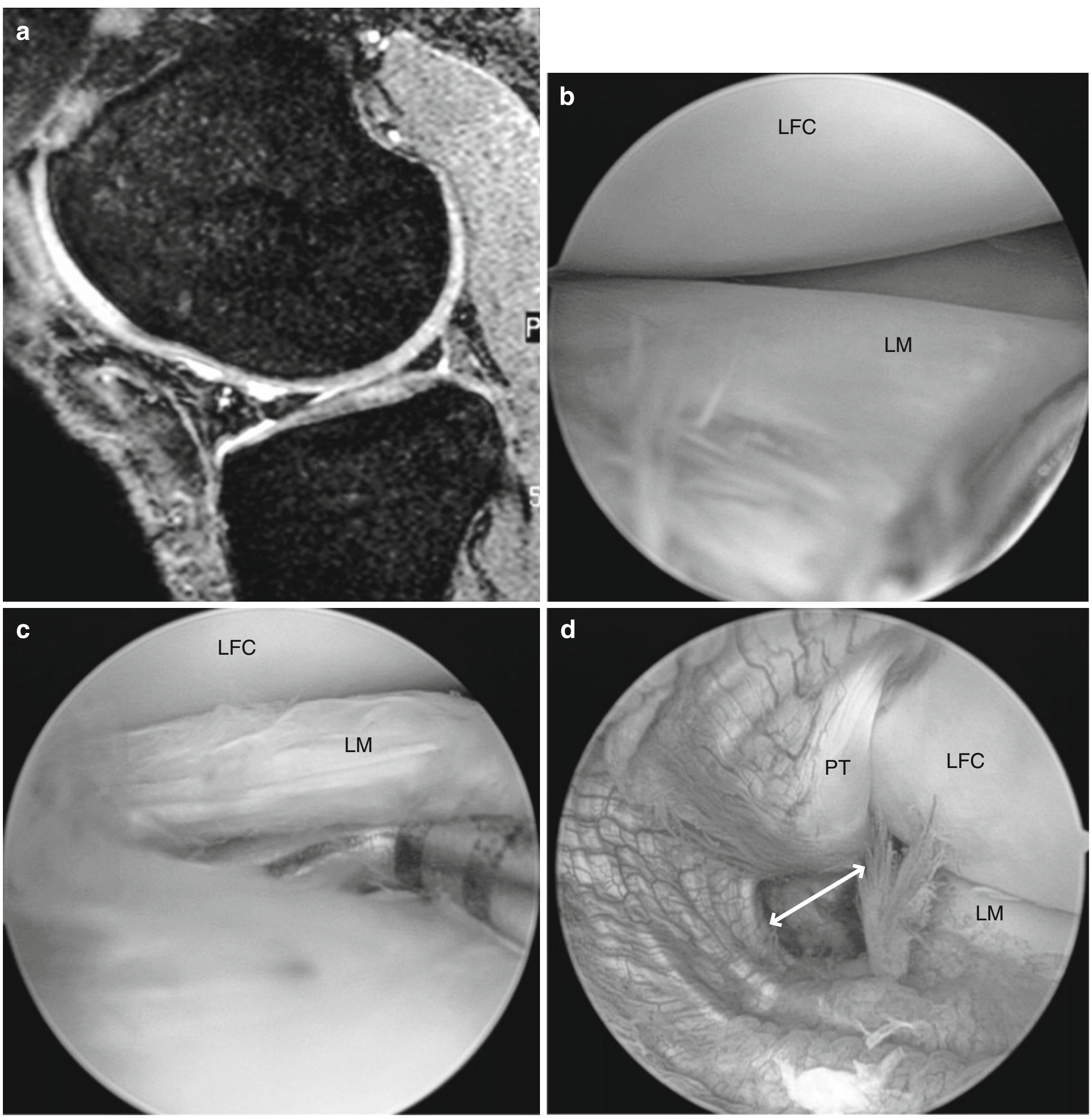

Fig. 7.34 **Hypermobile meniscus**. A man in his 20s presenting with knee pain on flexion. (**a**) T2*WI and (**b**–**d**) arthroscopic images. MRI revealed no pathologic findings. However, arthroscopic examination showed abnormally large mobility of the lateral meniscus (*LM*). There is an enlarged popliteus tendon (*PT*) hiatus (*arrow*, **d**). *LFC*: lateral femoral condyle (Image courtesy of Dr. Akihiro Kanamori, Department of Orthopaedics, Tsukuba University School of Medicine)

7.8 Discoid Meniscus

- During the fetal development, the central part of the C-shaped meniscus fails to be absorbed and forms a meniscus with a disk-like shape (Fig. 7.35).
- The width of meniscus may be greater than 12 mm, and the peripheral thickness may be greater than 5 mm.
- Much common in the lateral meniscus (Fig. 7.36).
- Commonly present in both knees.

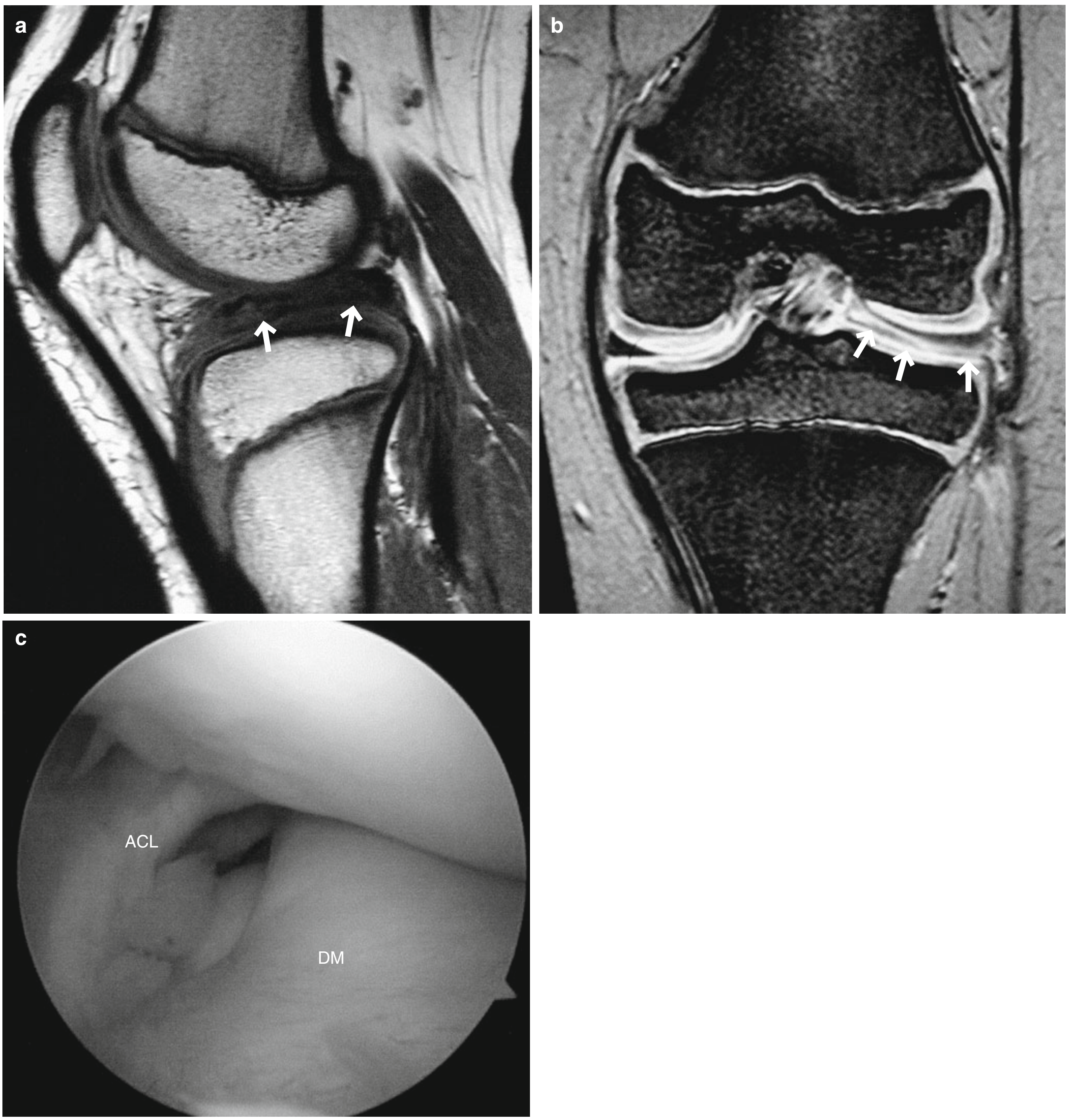

Fig. 7.35 Discoid meniscus. A 10-year-old boy. (**a**) PDWI, (**b**) coronal T2*WI, and (**c**) arthroscopic image. The wide lateral joint space is occupied by a thick discoid meniscus (*DM*, *arrows*), which extends to the proximity of ACL in the intercondylar space. There is intrasubstance hyperintensity suggestive of degenerative changes, but arthroscopy did not reveal any meniscal tear reaching the meniscal surface

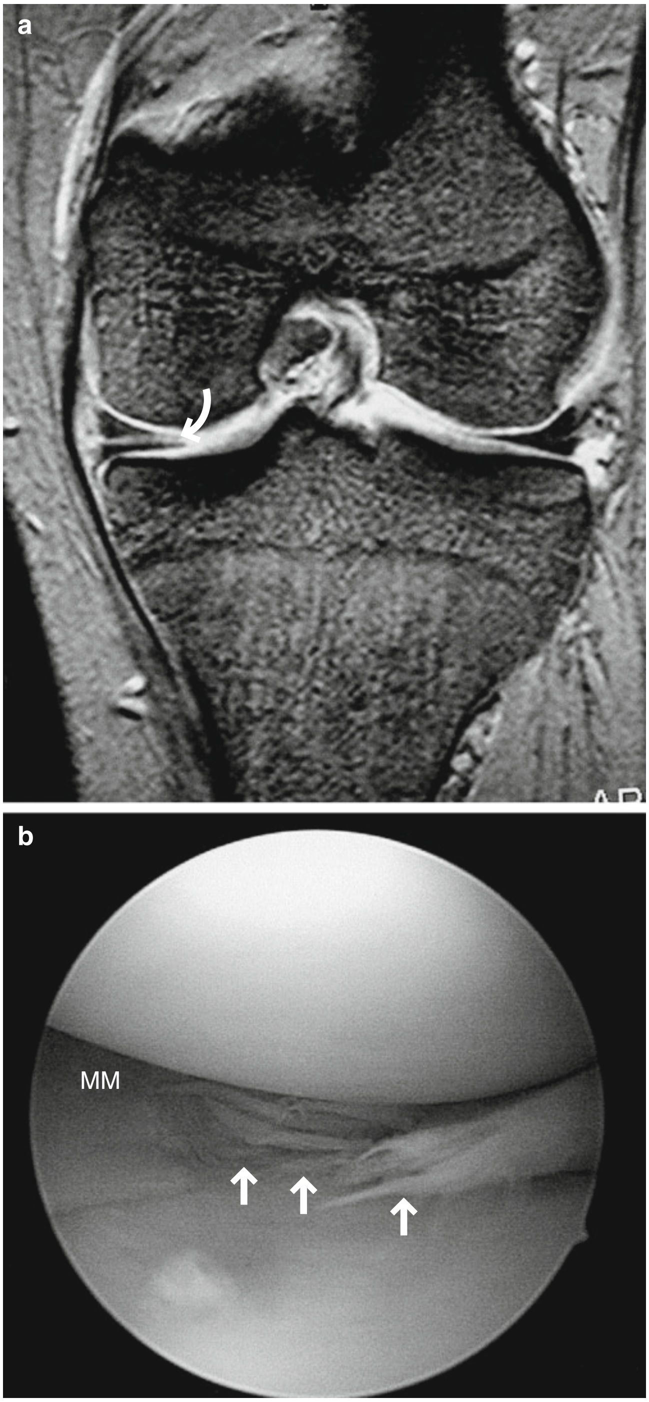

Fig. 7.36 Semidiscoid medial meniscus. A man in his 30s. (**a**) Coronal T2*WI and (**b**) arthroscopic image. Although discoid meniscus is much more common in the lateral compartment, semidiscoid meniscus can occasionally be seen in the medial side. Medial meniscus (*MM*) appears abnormally large extending toward the intercondylar space of the knee joint (*curved arrow*). There is a horizontal tear of the free edge (*arrows*)

Fig. 7.37 Tear of discoid meniscus. A man in his 20s. Coronal T2*WI. There is a tear reaching the inferior surface of the lateral discoid meniscus (*arrow*)

- If the meniscus has a partial discoid shape, it is called semidiscoid meniscus.
- Rarely, Wrisberg variant to discoid meniscus is seen. In this case, the posterior segment/horn is not fixed to the tibia or to the joint capsule, and meniscal hypermobility, extrusion, and pain may result.
- Joint space widening is seen on conventional radiography.
- Discoid or semidiscoid menisci are prone to degenerative changes and tear, even from a relatively small external stress (Fig. 7.37).
- Can be a cause of “knee pain of unknown origin” in children.
- Commonly seen in Oriental persons.

Reference

Silverman J, Mink J, Deutsch A. Discoid menisci of the knee: MR imaging appearance. Radiology. 1989;173:351–4.

7.9 Meniscal Calcification, Ossicles, and Vacuum Phenomenon

7.9.1 Meniscal Calcification

- Menisci calcification is occasionally seen.
- May be associated with chondrocalcinosis of variable etiology.
- Commonly consists of CPPD (calcium pyrophosphate dihydrate).
- Calcified menisci are more prone to degeneration and tear.
- MRI may demonstrate intrasubstance hyperintensity representing calcification (Fig. 7.38).

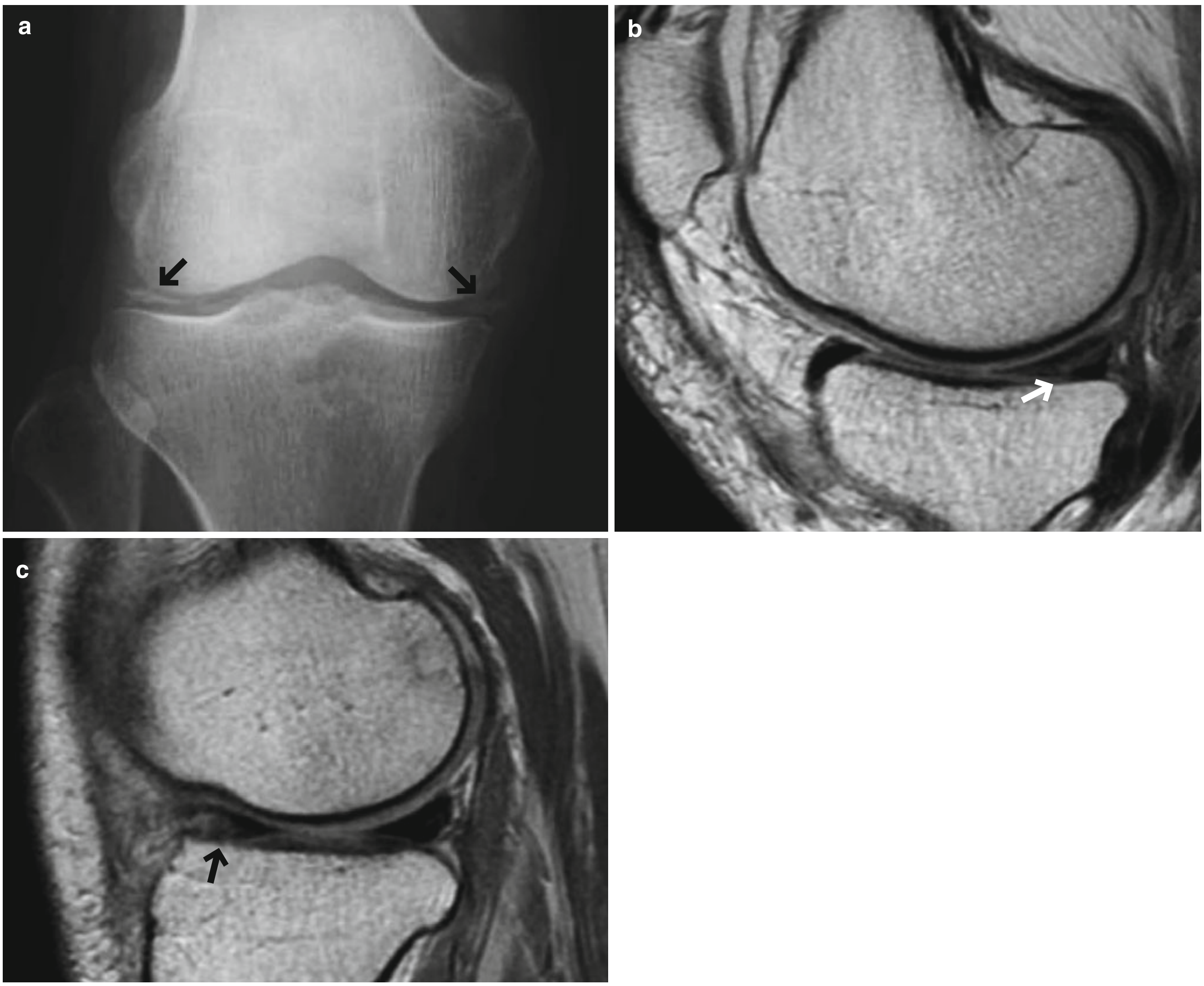

Fig. 7.38 **Meniscal calcification**. A man in his 60s. (**a**) Anteroposterior radiograph and (**b**, **c**) PDWI. (**c**) is a more lateral slice than (**b**). Bilateral calcification is seen in the joint space (*arrow*, **a**). MRI reveals degenerative tear of the posterior segment of the medial meniscus (*arrow*, **b**) and the anterior segment of the lateral meniscus (*arrow*, **c**)

7.9.2 Ossicles

- Ossification of the meniscus is rarely seen in human (cf. it is commonly seen in rodents such as rats).
- Common in the posterior horn of the medial meniscus.
- More common in men.
- It may be mistaken as a free body on radiograph.
- If the ossification becomes sufficiently large, it may exhibit peripheral signal void (representing bone cortex) and internal fat signals from fatty marrow (Fig. 7.39).

Reference

Bernstein RM, Olsson HE, Spitzer RM, Robinson KE, Korn MW. Ossicles of the meniscus. AJR. 1976;127:785–8.

Fig. 7.39 **Meniscal ossicle**. A man in his 40s. (**a**) PDWI, (**b**) coronal T2*WI, and (**c**) conventional radiograph. There is an ossification which includes fatty marrow in the posterior horn of the medial meniscus (*arrow*)

7.9.3 Vacuum Phenomenon

- A small amount of gas within the joint space is usually caused iatrogenically (e.g., arthroscopy and arthrocentesis).
- Intrameniscal gas is thought to occur when gas molecules such as nitrogen dissolved in the joint fluid became gaseous due to negative pressure to the meniscus. This is a mechanism similar to that of vacuum phenomenon in the intervertebral disc.
- Can be seen in young persons and athletes with pain, but arthroscopy does not yield pathologic findings.
- On MRI, it is seen as a linear signal void within the meniscus. This area of signal void becomes enlarged in gradient echo sequences (which are susceptible to magnetic field in homogeneity) and creates artifacts and distortion of the image (Fig. 7.40).

Reference

Shogry ME, Pope TL JR. Vacuum phenomenon simulating meniscal or cartilaginous injury of the knee at MR imaging. Radiology. 1991;180:513–5.

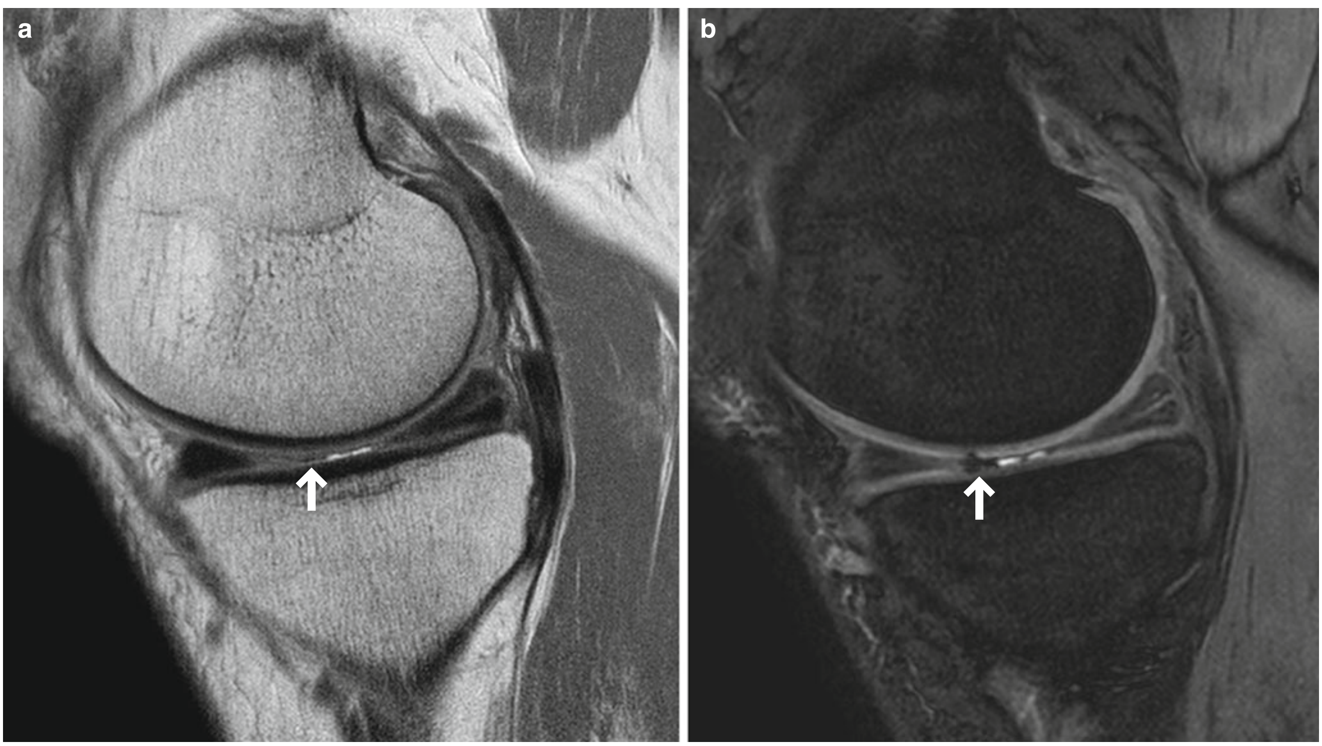

Fig. 7.40 **Vacuum phenomenon**. A man in his 70s. (**a**) PDWI and (**b**) T2*WI. There are discrete signal void that appears like a *dotted line* near the free edge of the anterior segment of the medial meniscus (*arrows*). It is more conspicuous in gradient echo sequence (**b**)

7.10 MRI Findings of Postoperative Menisci

- Menisectomy and suture procedure can be performed arthroscopically.

Menisectomy

- It is performed to remove a tear which is localized within the white zone (near the free edge).
- Tear or fibrillation distant from the free edge are trimmed (Fig. 7.41).
- Following menisectomy, the resected portion of the meniscus is absent or has some irregularities on MRI, so radiologists should check the site of menisectomy when reading such images.
- Absence of the resected portion of meniscus can be confirmed by MRI for several years after surgery (Fig. 7.42).
- Occasionally, the overall shape of the meniscus becomes closer to its original shape before menisectomy during long-term follow-up (Fig. 7.43).

Meniscal suture

- Meniscal suture is performed to treat a noncomplex tear mainly in the red zone (peripheral zone), using fine sutures either from within or through the joint space. Suture materials used may be absorbable and may not be visualized on MRI (Fig. 7.44).
- The sutured section will not fuse, and linear hyperintensity of the lesion will persist for a long time postoperatively. During follow-up, one should look for reopening of the sutured tear and distortion of the meniscal shape.
- Rarely, the suture becomes torn postoperatively and the tear reopens (Fig. 7.45).

Reference

McCauley TR. MR imaging evaluation of the postoperative knee. Radiology. 2005;234:53–61.

White LM, Kramer J, Recht MP. MR imaging evaluation of the postoperative knee: ligaments, menisci, and articular cartilage. Skeletal Radiol. 2005;34:431–52.

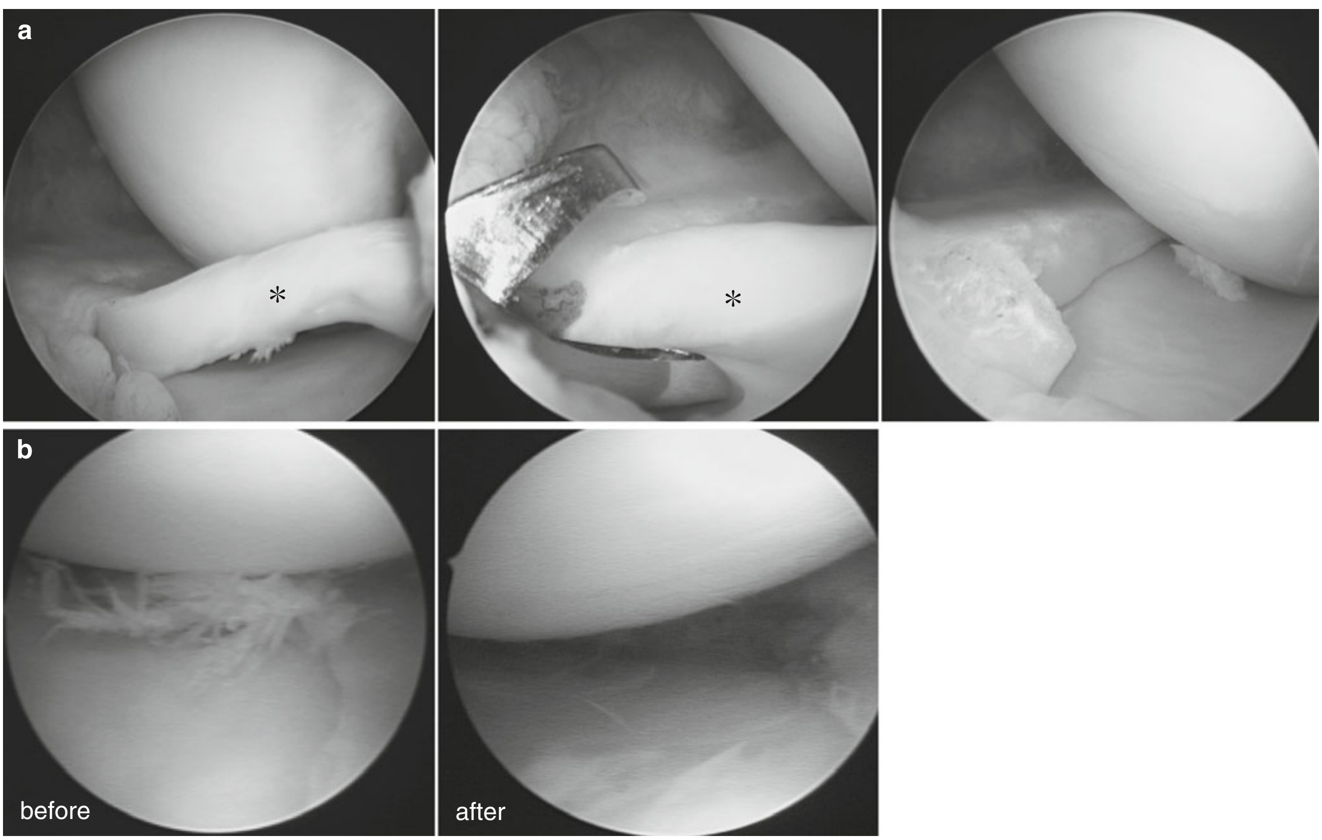

Fig. 7.41 **Arthroscopic menisectomy**. Displaced portion of the bucket-handle tear (*) is excised (**a**), while fibrillated portion is trimmed (**b**)

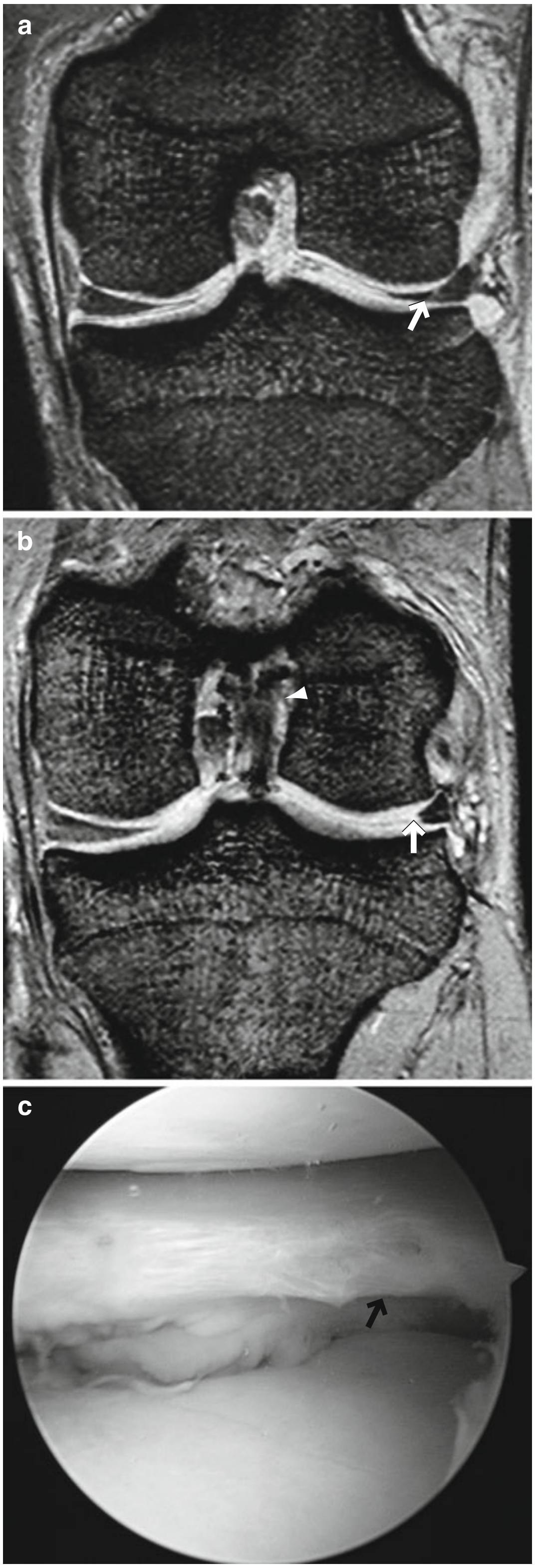

Fig. 7.42 **Lateral menisectomy**. A man in his 30s. (**a**) Coronal T2*WI before surgery and (**b**) 2-years after surgery and (**c**) arthroscopic image at 2-year follow-up. Preoperatively there was a longitudinal tear near the free edge at the middle segment of the lateral meniscus (*arrow*, **a**). The lesion was trimmed under arthroscopy, and the site of trimming is clearly visible 2 years postoperatively (*arrow*, **b**, **c**). In this patient, ACL reconstruction was performed simultaneously (*arrowhead*, **b**)

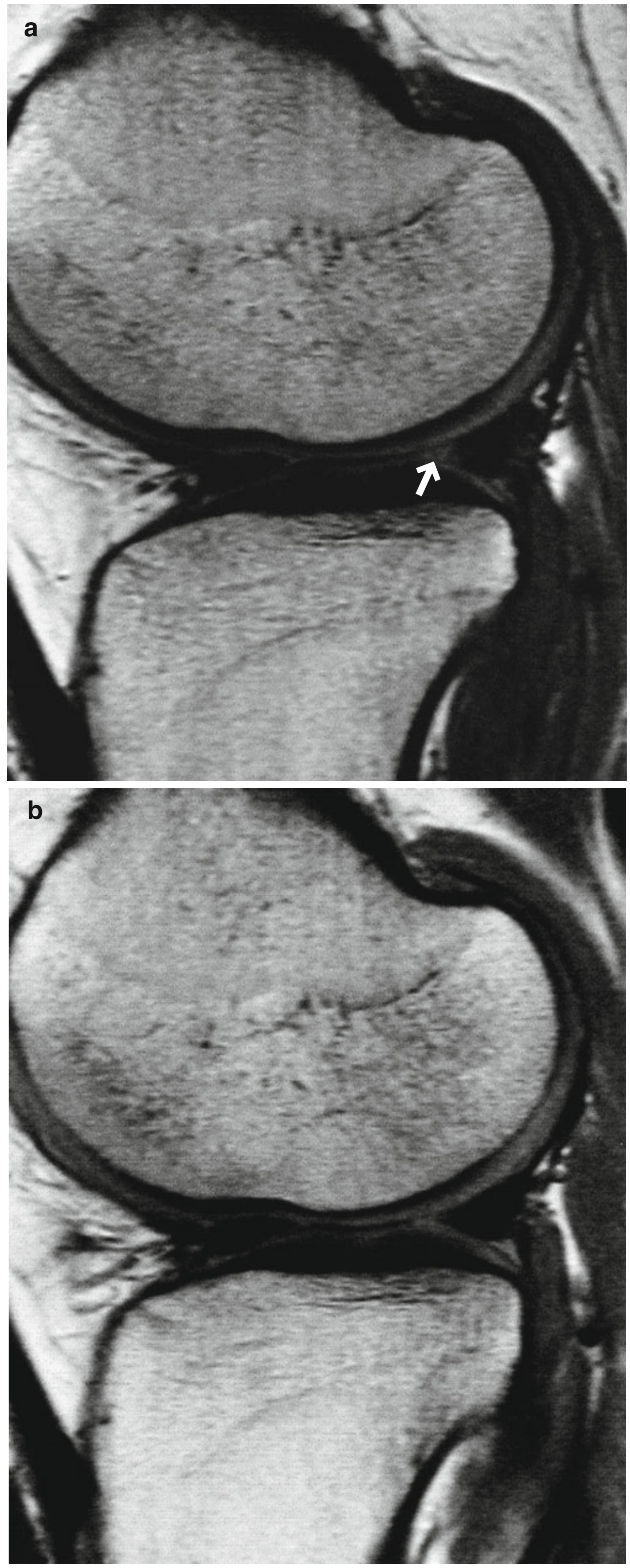

Fig. 7.43 **Longitudinal changes following menisectomy**. A man in his 20s. PDWI (**a**) immediately after surgery and (**b**) 1 year later. A small portion of the free edge in the posterior segment of the lateral meniscus was excised (*arrow*, **a**). One year later, the same portion of the lateral meniscus has the shape close to normal configuration

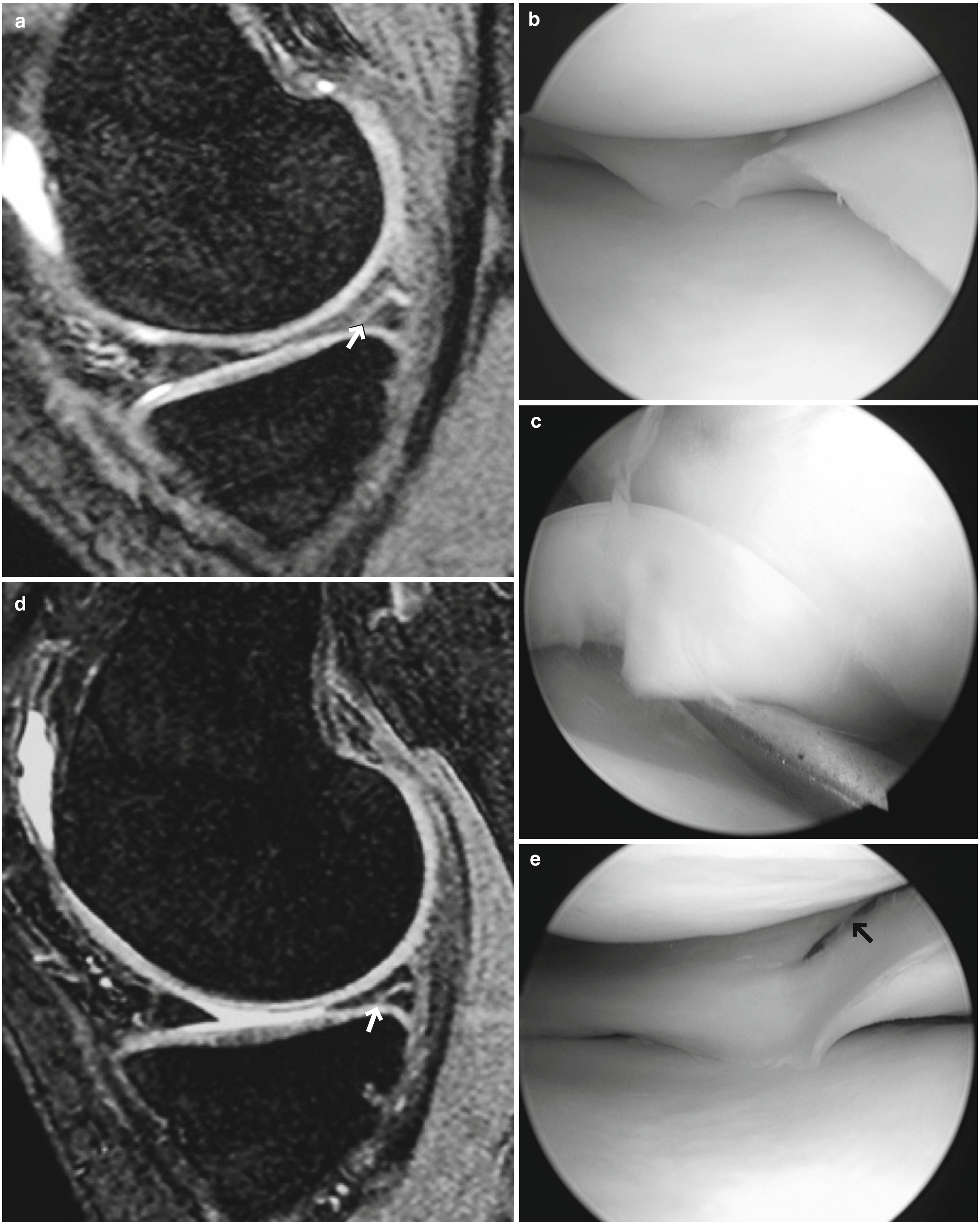

Fig. 7.44 **Meniscal suture**. A man in his 20s. (**a**) T2*WI and (**b**, **c**) arthroscopic images taken preoperatively. (**d**) T2*WI and (**e**) arthroscopic image taken 6 months postoperatively. There is a diagonal tear that reaches the inferior surface of the meniscus in the posterior segment of the medial meniscus (*arrow*, **a**). The lesion was sutured (*arrow*, **e**) but postoperative MRI still shows the linear hyperintensity of the lesion (*arrow*, **d**), unchanged from the preoperative state

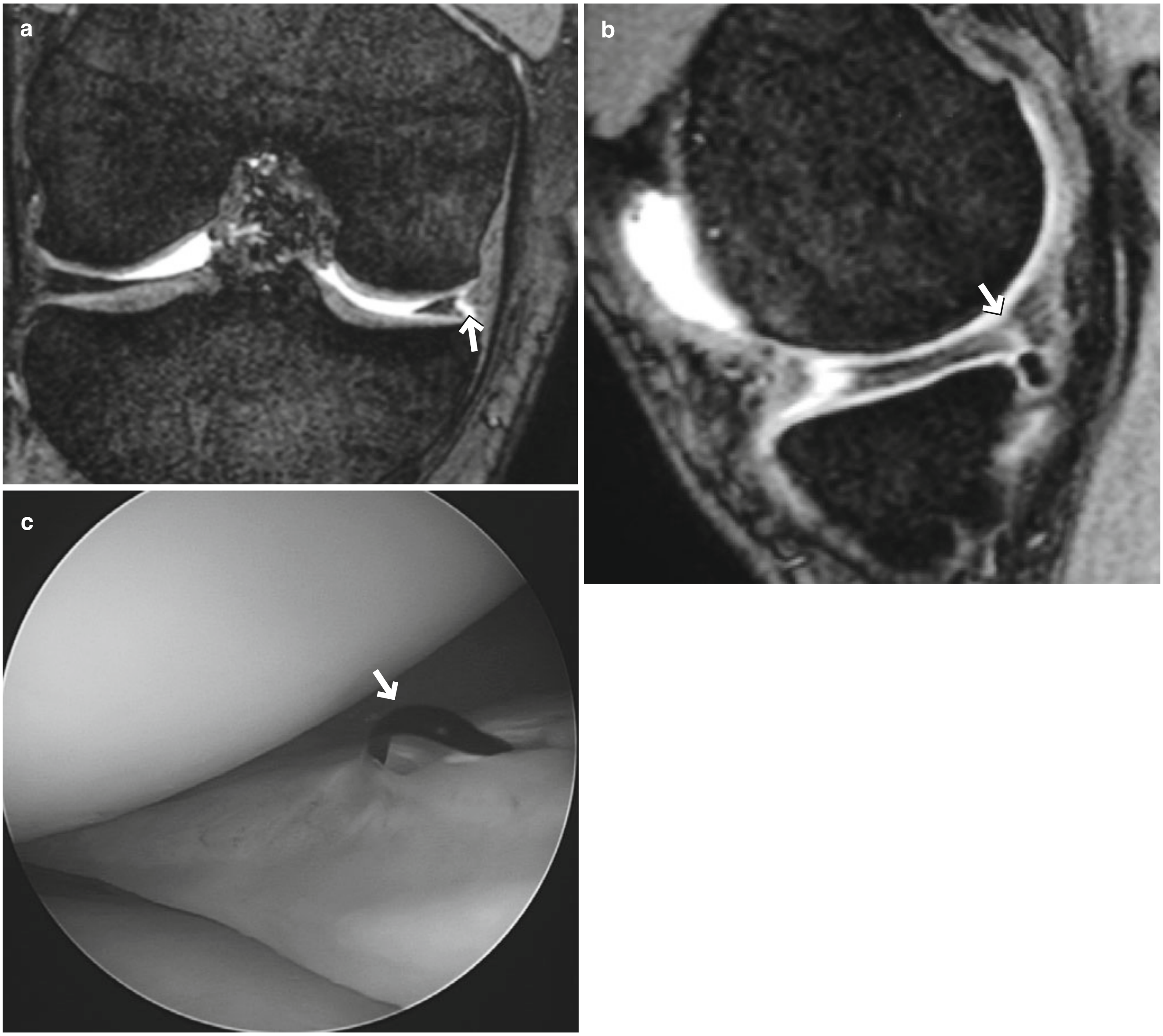

Fig. 7.45 Reopening of the lesion following meniscal suture. A man in his 20s. (**a**) Coronal and (**b**) sagittal T2*WI and (**c**) arthroscopic image. The peripheral portion of the medial meniscus was sutured, but the sutured site is reopened and joint fluid has entered into it (*arrow*, **a**, **b**). Arthroscopy reveals a slack suture (*arrow*, **c**)

7.11 Pitfalls for Imaging of Meniscal Lesions (Table 7.1)

Table 7.1 Pitfalls for imaging of meniscal lesions

Structures as a cause of pitfalls	Affected part
Transverse meniscal ligament	Anterior horn of the lateral meniscus (Figs. 7.46 and 7.47)
Popliteus tendon sheath	Posterior segment of the lateral meniscus (Figs. 7.48 and 6.6)
Wrisberg's or Humphrey's ligament	Posterior horn of the lateral meniscus (Figs. 7.49 and 4.2)

Reference

Watanabe AT, Carter BC, Teitelbaum GP, Seeger LL, Bradley WG Jr. Normal variations in MR imaging of the knee: appearance and frequency. AJR. 1989;153:341–4.

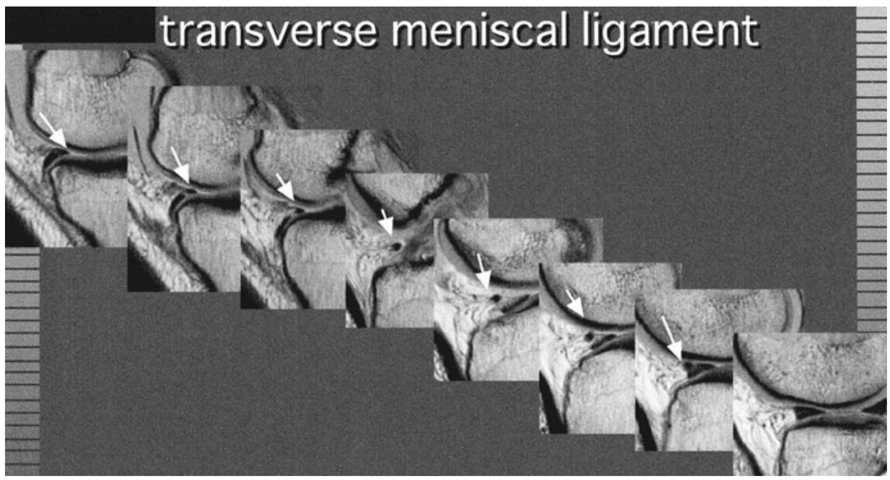

Fig. 7.46 Pitfalls due to the transverse meniscal ligament (1). Transverse meniscal ligament connects the anterior horns of the medial and lateral menisci. When it arises at the anterior horn of the each meniscus, it may be mistaken as a meniscal tear (*arrows*)

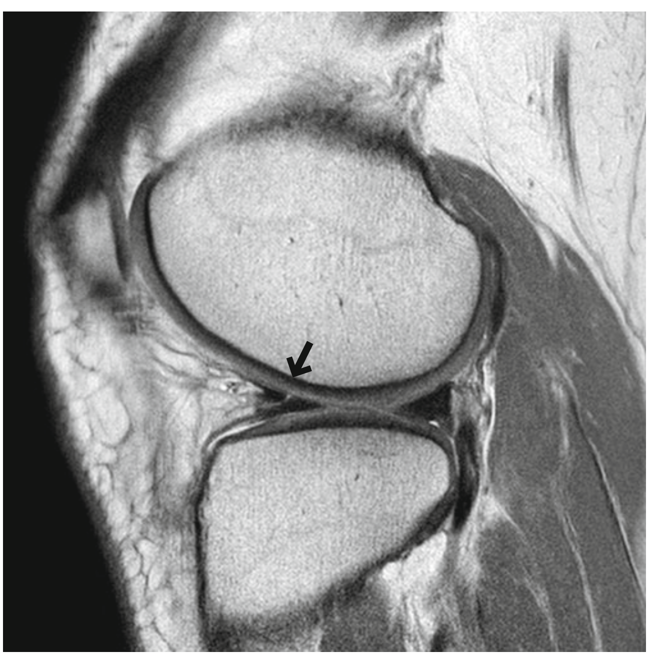

Fig. 7.47 Pitfalls due to the transverse meniscal ligament (2). PDWI. By looking at this single image, it looks as though there is a tear at the anterior horn of the lateral meniscus (*arrow*)

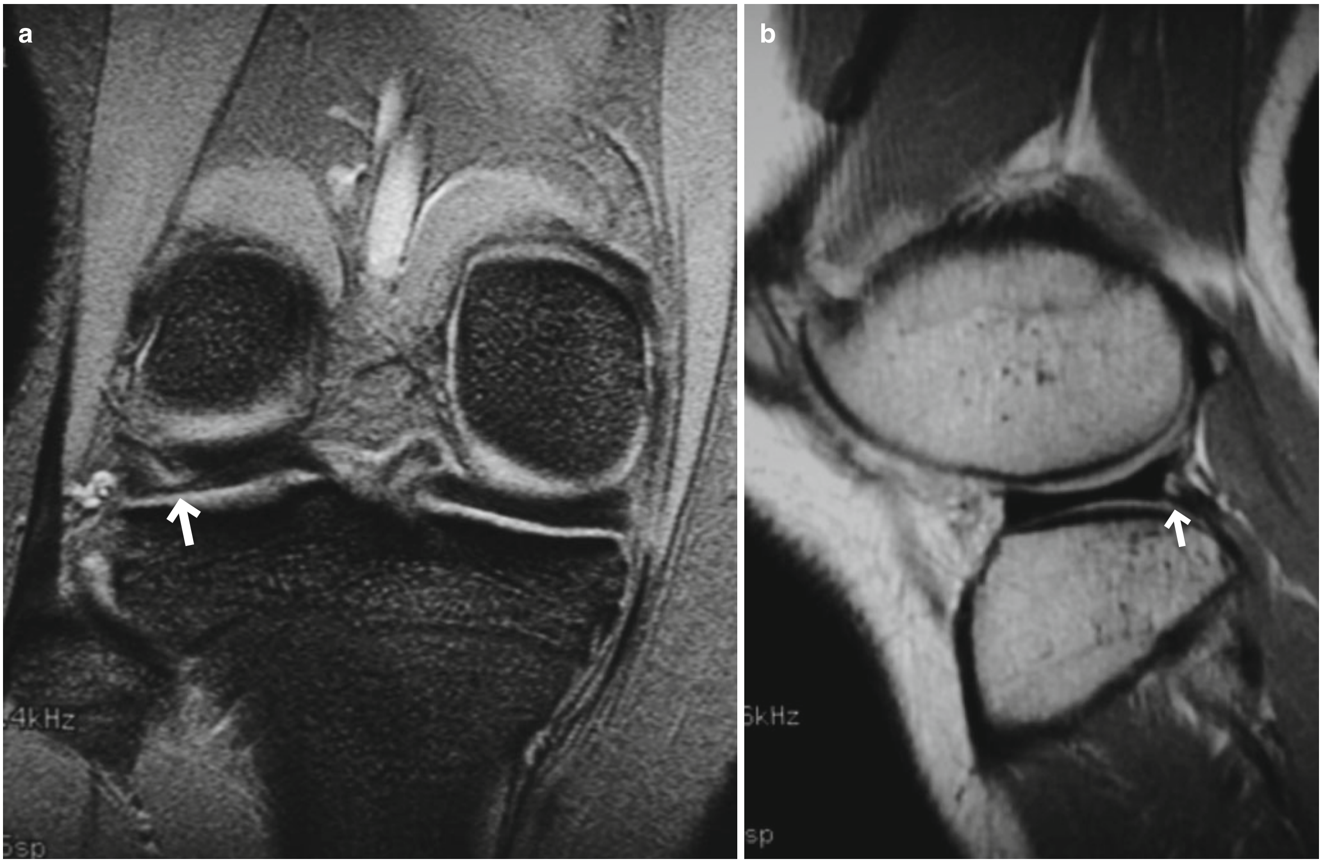

Fig. 7.48 Pitfalls due to the popliteus tendon sheath. (**a**) Coronal T2*WI and (**b**) PDWI. Tear of the posterior segment of the lateral meniscus is suspected in the coronal image (**a**, *arrow*), but the sagittal image reveals that the hyperintensity is due to the popliteus tendon sheath (*arrow*, **b**), not a tear

Fig. 7.49 Pitfalls due to Wrisberg's ligament. PDWI through the lateral meniscus. At the site where Wrisberg's ligament originates (*arrow*), it may be mistaken as a tear of the posterior horn of the lateral meniscus (See also Chap. 4)

Oblique meniscomeniscal ligaments

- These ligaments connect the lateral and medial menisci in the diagonal fashion (Fig. 7.50).
- Medial oblique meniscomeniscal ligament connects the anterior horn of the medial meniscus with the posterior horn of the lateral meniscus. Lateral oblique meniscomeniscal ligament connects the anterior horn of the lateral meniscus with the posterior horn of the medial meniscus.
- Its prevalence is extremely rare (1–4% for both medial and lateral combined).
- Its origin at the posterior horn can be mistaken as a tear. Also, because these ligaments run through the base of the intercondylar space, they can be mistaken as the bucket-handle tear in coronal images (Fig. 7.51).

Reference

Sanders TG, Linares RC, Lawhorn KW, Tirman PF, Houser C. Oblique meniscomeniscal ligament: another potenrial pitfall for a meniscal tear – anatomic description and appearance at MR imaging in three cases. Radiology. 1999;213:213–6.

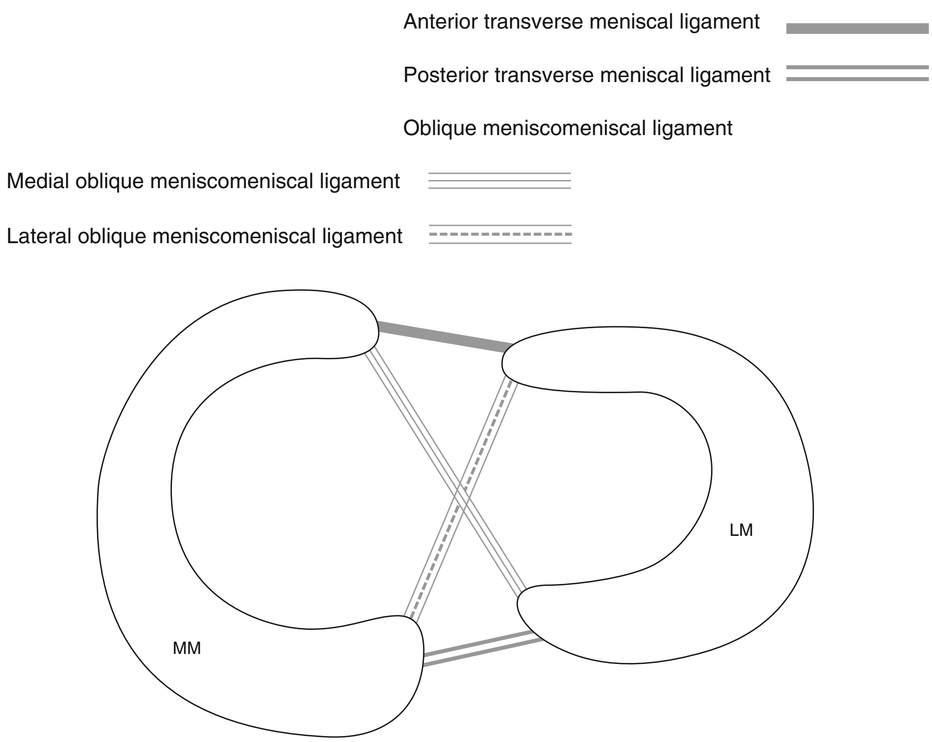

Fig. 7.50 Schematic illustration of the oblique meniscomeniscal ligaments. Prevalence of the anterior transverse meniscal ligament is 58%. In contrast, the posterior transverse meniscal ligament is much rarer with the prevalence of 1–4%. The prevalence of oblique meniscomeniscal ligaments are also rare (1–4%, both combined). *MM* medial meniscus, *LM* lateral meniscus

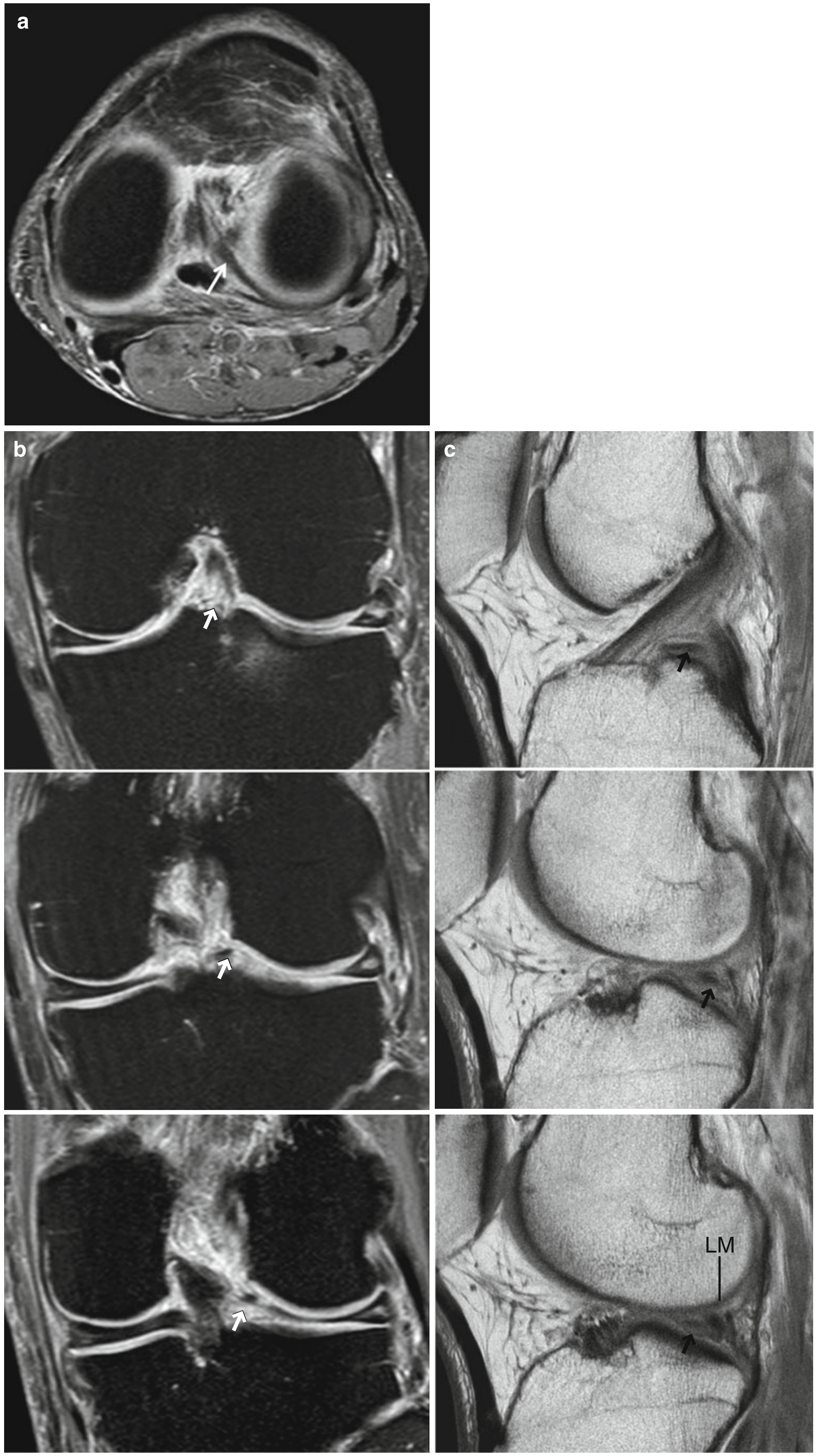

Fig. 7.51 Medial oblique meniscomeniscal ligament. (**a**) Axial- and (**b**) FS PDWI and (**c**) PDWI. Medial oblique meniscomeniscal ligament (*arrow*, **a**) connects the anterior horn of the medial meniscus with the posterior horn of the lateral meniscus. It can be mistaken as a bucket-handle tear in coronal images (*arrows*, **b**). Its origin at the posterior horn of the lateral meniscus (LM) can be mistaken as a tear (*arrows*, **c**)

Pseudobucket-handle tear and pseudodiscoid meniscus

- If the posterior horn is prominent (Fig. 7.52), it can mimic a bucket-handle tear (pseudobucket-handle tear) and a discoid meniscus (pseudodiscoid meniscus).

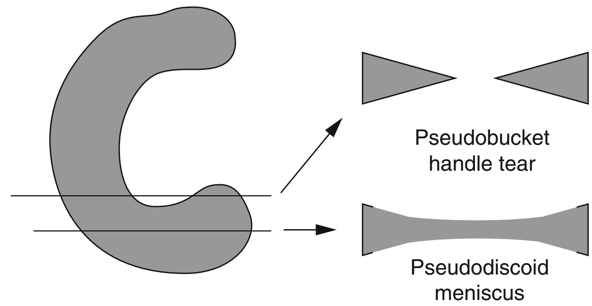

Fig. 7.52 Pseudobucket-handle tear and pseudodiscoid meniscus

Meniscal flounce

- Rarely, the free edge of the middle segment of the medial meniscus becomes slack and folded (Fig. 7.53), and it is called meniscal flounce. It is rarely experienced and may disappear after repeated knee flexion and extension.

- Because the posterior horn of the lateral meniscus is inclined toward the cephalic direction medially, MR signal will increase if TE is short due to the magic angle effect (see Chap. 2).

Reference

Yu JS, Cosgarea AJ, Kaeding, CC, Wilson D. Meniscal flounce MR imaging. Radiology. 1997;203:513–5.

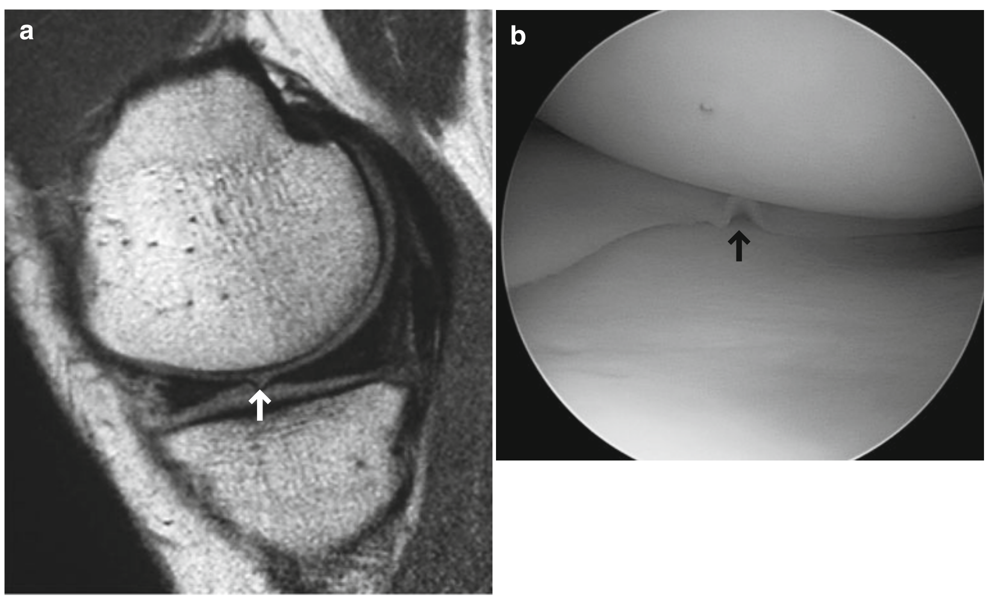

Fig. 7.53 **Meniscal flounce**. (**a**) PDWI and (**b**) arthroscopic image. Meniscal flounce is seen in the free edge of the medial meniscus (*arrows*)

What Is "Internal Derangement" of the Knee?

The knee is the joint for which MRI examination is most frequently performed. This is because the knee is vulnerable to trauma and age-related degeneration, and its skeletal structure makes it an unstable joint unless supported by fully functioning muscles, ligaments, and menisci. Making diagnosis of knee disorders from clinical examination alone is a difficult task. In old days when radiography was the only imaging technique available, it was impossible to know what went wrong inside the knee and thus the term "internal derangement" was used. Modern MRI can reveal all sorts of knee pathologies. Therefore, the term "internal derangement" is thus almost never used nowadays. MRI plays a crucial role in the imaging diagnosis of knee disorders. Knee arthrography has become almost extinct at present. Even arthroscopic examination is only performed when it is absolutely necessary.

8 Fracture, Subluxation, and Muscle Injury

8.1 Tibial Plateau Fracture

- Tibial plateau fracture (fracture of proximal end of tibia) is one of the most common traumatic fracture of the knee joint.
- It is commonly seen in osteoporotic elderly patients, but also frequently seen as traumatic or sports injuries.
- Tibial fracture results following collision of the distal femur and the tibial plateau due to external forces.
- Valgus stress causes fracture of the lateral condyle and commonly accompanied by tear of MCL and cruciate ligaments. Hemarthrosis may also result.
- In clinical practice, Hohl's classification is commonly used (Fig. 8.1).
- Hohl's undisplaced type and other types with little displacement of the fractured bone (Fig. 8.2) are treated conservatively.
- If the lesion includes vertical fracture of the medial or lateral condyle, it requires manipulation and fixation. If there is a depression fracture involving the joint surface, surgical fixation is required (Fig. 8.3).

Reference

Hohl M. Tibial condylar fractures. J Bone Joint Surg. 1967;49-A: 1455–67.

Patella Is the Largest Sesamoid Bone of the Human Body

This can be common sense, but perhaps some people have never thought of it this way. A sesamoid bone is a small circular bone which is embedded within a tendon. I am sure people often think of sesamoids in the hands and feet. Patella is a large sesamoid bone that has hyaline cartilage because it is involved in the patellofemoral joint. Another well-known sesamoid in the knee is the fabella, which is found within the lateral head of the gastrocnemius. A ligament called fabellofibular ligament also exists.

M. Niitsu et al., *Magnetic Resonance Imaging of the Knee*,
DOI 10.1007/978-3-642-17893-1_8, © Springer-Verlag Berlin Heidelberg 2013

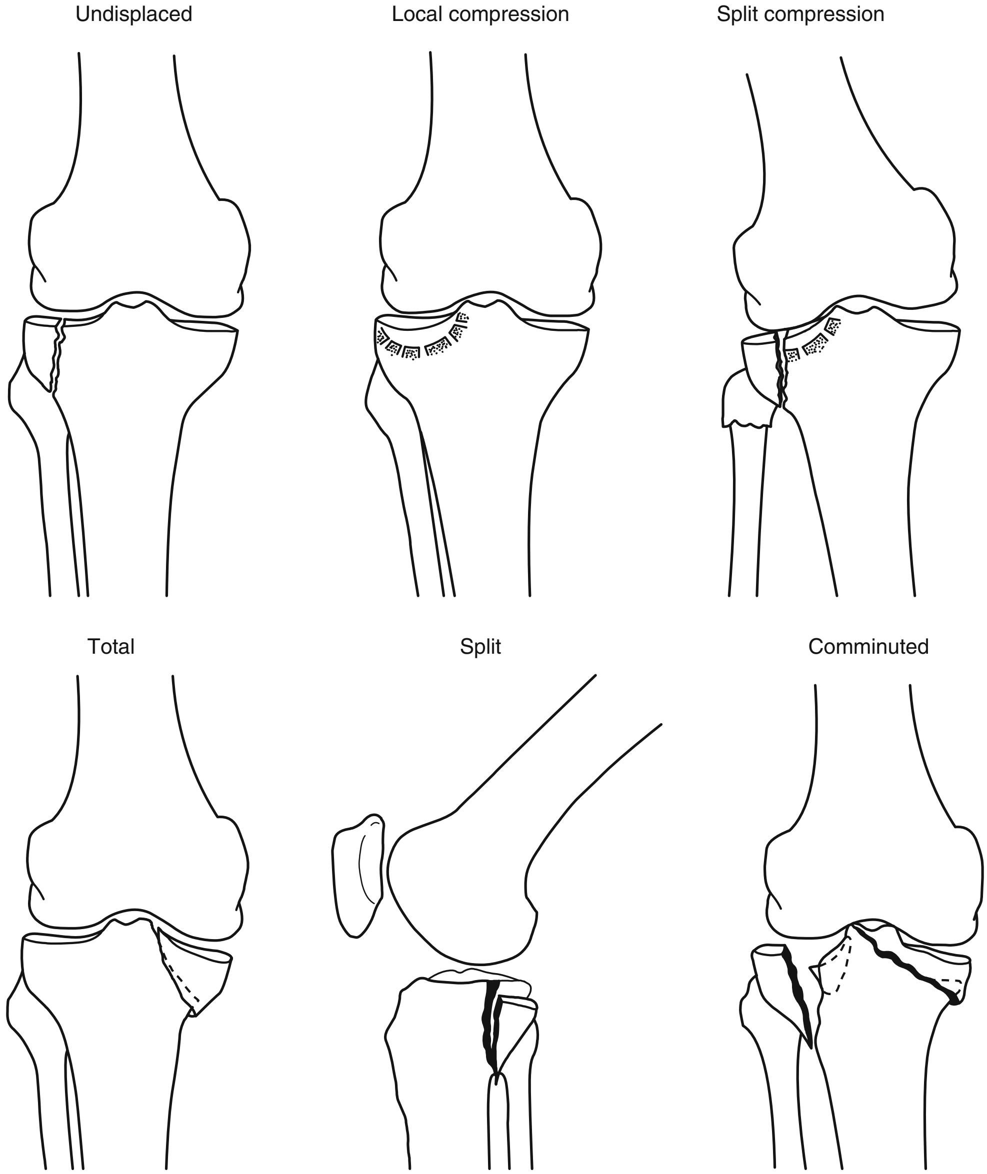

Fig. 8.1 Hohl's classification of the tibial plateau fracture (Images adapted from Hohl's publication)

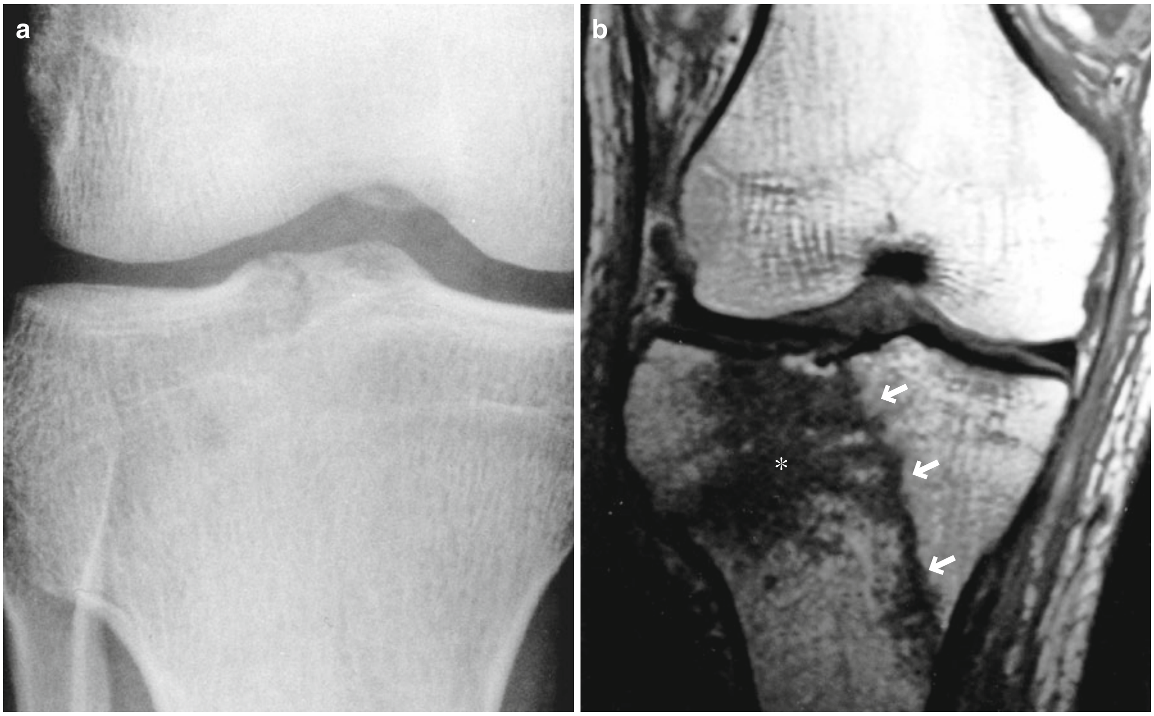

Fig. 8.2 **Tibial plateau fracture, undisplaced type**. A man in his 20s. (**a**) Anteroposterior radiograph and (**b**) coronal T1WI. This is an example of a tibial plateau fracture, undisplaced type, according to the Hohl's classification. It is not clearly visualized on radiograph, but there is a clear linear hypointensity running obliquely from the intercondylar eminence (*arrows*) on MRI. Bone bruise is noted (hypointensity on T1WI (*, **b**) and hyperintensity on T2WI (not shown))

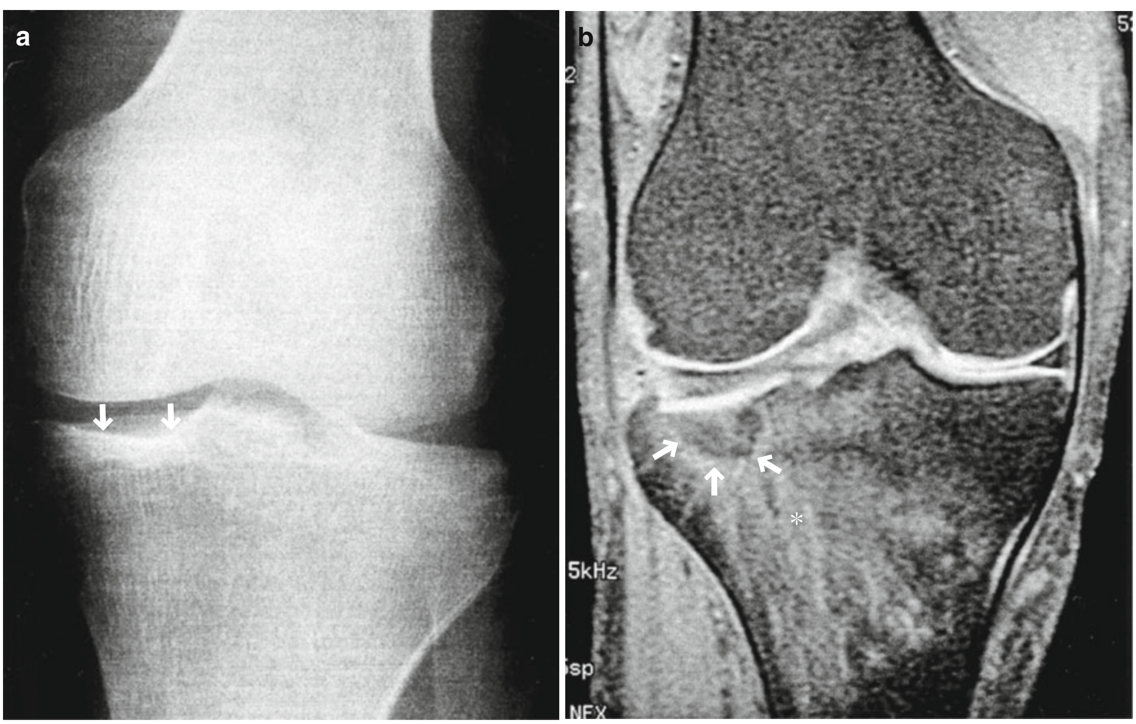

Fig. 8.3 **Tibial plateau fracture, local compression type**. A man in his 50s. (**a**) Anteroposterior radiograph and (**b**) coronal FS T1WI. Radiograph depicts depression of the joint surface (*arrows*), while MRI demonstrates clearly a fracture line (*arrows*) together with extensive bone bruise (*, **b**)

8.2 Patellar Fracture

- Patellar fracture can be classified as transverse fracture and comminuted fracture. Transverse fracture is more common with a frequency of more than 50%.
- Transverse fracture results from a sudden flexion of the knee. Due to eccentric contraction of the quadriceps femoris muscle, patella is torn into two pieces (superior and inferior fragments). The bone fragments are commonly displaced to a large extent.
- Treatment plan will be made depending on the degree of separation of the bone fragments on lateral radiograph taken at knee extension. If the separation is insignificant, conservative treatment will be instituted.
- Comminuted fracture of the patella results from a direct external force applied from the anterior direction, such as a fall or a dashboard injury. In this case, bone fragments tend to remain in the original position.
- Patellar fracture is an intra-articular fracture and thus commonly accompanied by hemarthrosis (Fig. 8.5).
- Patellar fracture in children is rare. If it occurs, it takes the form of patellar sleeve fracture, which is an avulsion fracture of the inferior pole of the patella.

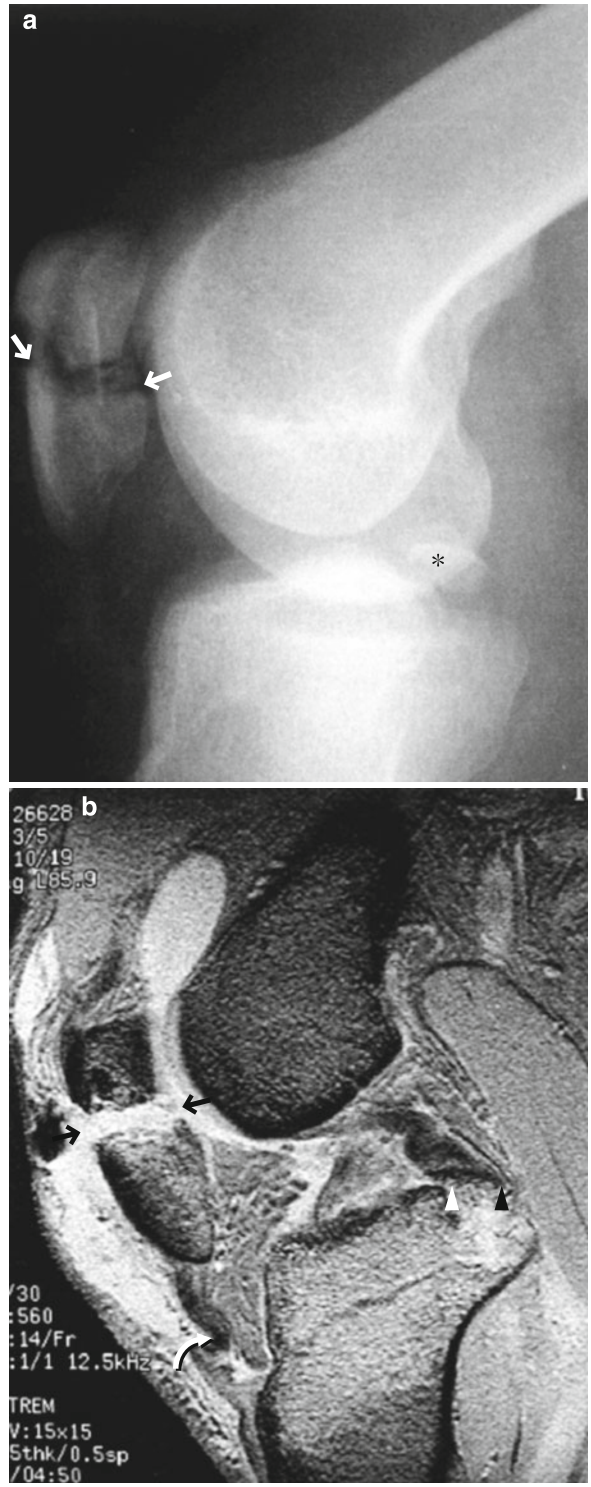

Fig. 8.4 **Patellar fracture**. A man in his 20s following a traffic accident. (**a**) Lateral radiograph and (**b**) T2*WI. The patella is split into two large fragments (*white arrows* in **a** and *black arrows* in **b** mark the space between two fragments). MRI shows kinking of the patellar tendon (*curved arrow*) and the avulsion fracture of the PCL (*arrowheads*, **b**) * avulsed bone fragment (**a**)

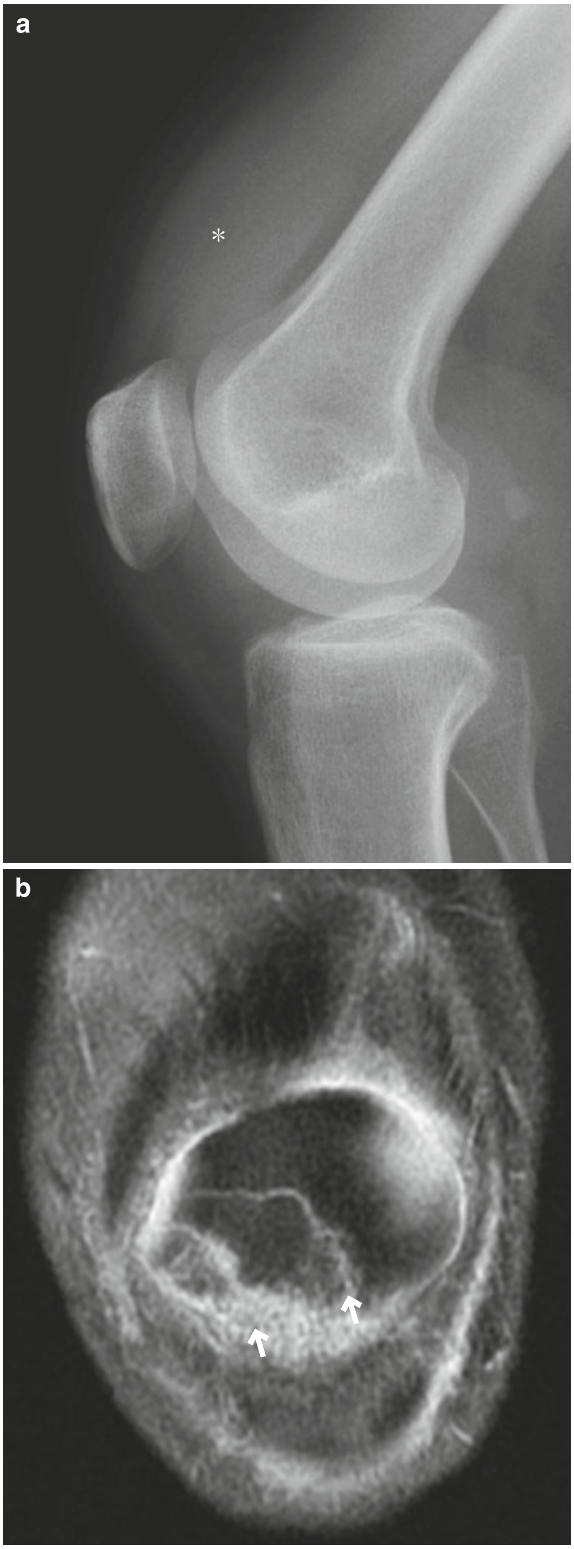

Fig. 8.5 **Patellar fracture**. A woman in her 50s who had a fall 2 days prior and had hemarthrosis at presentation. (**a**) Lateral radiograph and (**b**) coronal FS PDWI. Radiograph shows joint effusion in the suprapatellar bursa (*, **a**). MRI shows two fracture lines in the patella (*arrows*, **b**)

8.3 Patellar Dislocation

- Patella may be dislocated from the patellofemoral groove, in which it normally rests. If the joint surface is partially in contact, it is called subluxation.
- Depending on the direction of the dislocation, it can be classified as lateral, medial, and horizontal dislocation. The horizontal dislocation is accompanied by torn quadriceps femoris or patellar tendon. Lateral dislocation is most commonly seen (Fig. 8.8).
- Patellar dislocation (subluxation) is mostly repetitive. Singularly occurring traumatic dislocation without a known history of repetitive dislocation is rare.
- Risk factors for repetitive patellar dislocation include malalignment of the lower limb (e.g., valgus) in general, malalignment of the patellofemoral joint, patella alta, generalized joint laxity, and other congenital and developmental factors.
- Hypermobility of the patella may cause instability and pain without causing dislocation. This is called patellar instability.
- Patella can be morphologically classified using Wiberg classification (Fig. 8.6).
- Repetitive dislocation is common in young women. With the knee lightly flexed, external rotation of the distal lower limb and strong contraction of the quadriceps femoris cause the lateral dislocation/subluxation of the patella (Fig. 8.7).
- Traumatic dislocation (acute dislocation) is commonly accompanied by a tear or injury of the medial retinaculum. Traumatic dislocation may occur in persons who are predisposed to repetitive dislocation due to aforementioned risk factors (Fig. 8.8).
- Lateral dislocation can often be naturally reduced, and by the time the patient comes to a hospital, the patient has pain but the patella is positioned normally.
- Patella dislocation may coexist with the tangential osteochondral fracture (see later description), which can be detected by MRI.

Reference

Kirsch MD, Fitzerald SW, Friedman H, Rogers LF. Transient lateral patellar dislocation: diagnosis with MR imaging. AJR. 1993;161: 109–13.

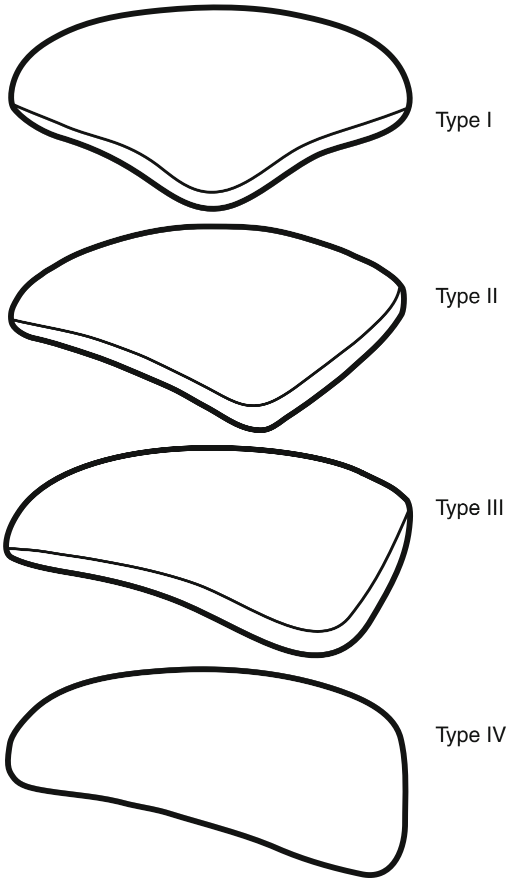

Fig. 8.6 **Wiberg classification of the patellar shape**. *Type I*: the facets are concave, symmetrical, and of equal size. *Type II*: the medial facet is smaller than the lateral facet and flat or only slightly convex. The lateral facet is concave. *Type III*: the convex medial facet is markedly smaller than the concave lateral facet, and the angle between the medial and lateral facets is nearly 90°. *Type IV*: The unifacet patella which is also called Jaegerhut shape

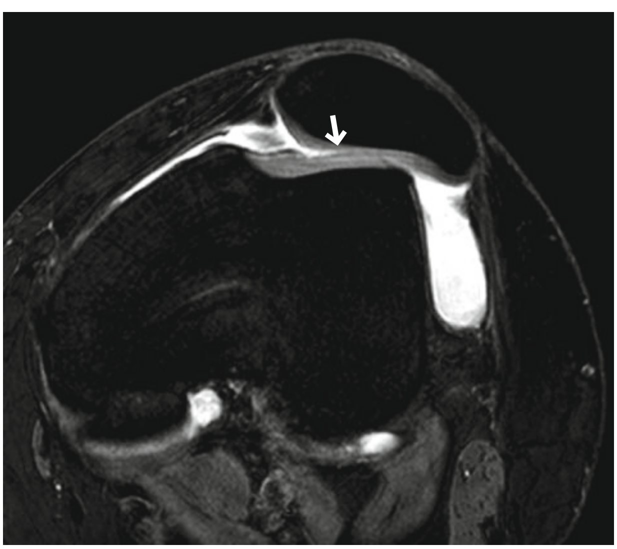

Fig. 8.7 **Malalignment of the patellofemoral joint**. A woman in her 50s with patellar instability with a history of repetitive patellar subluxation. Axial FS PDWI shows the Wiberg type III patella. Note the thinning of the cartilage of the lateral facet (*arrow*)

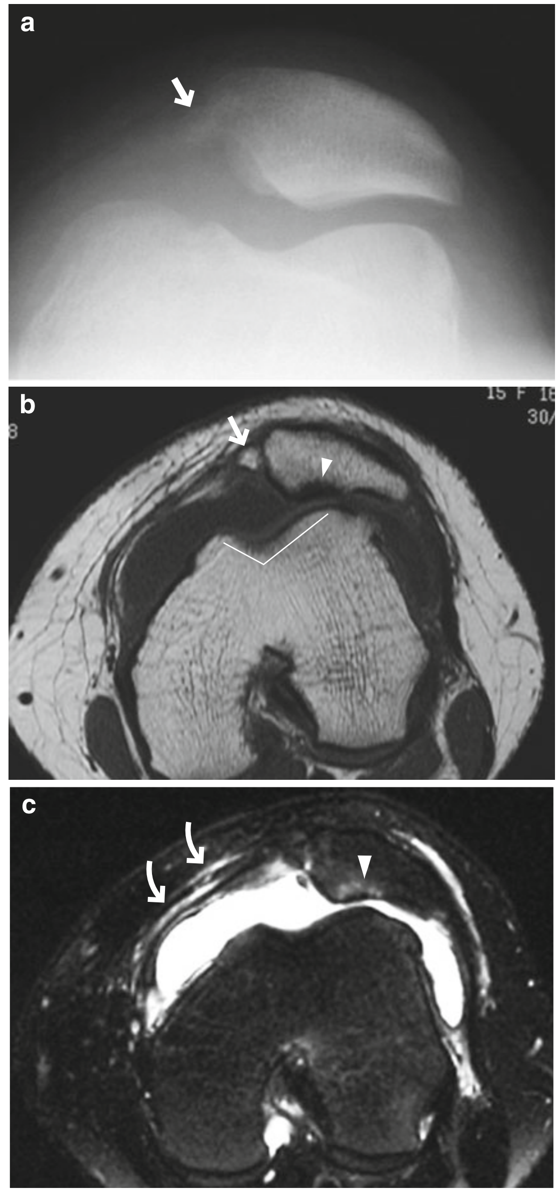

Fig. 8.8 **Traumatic lateral patellar dislocation in a patient with known patellar instability and repetitive patellar dislocation**. A woman in her late teens. (**a**) Skyline view radiograph, (**b**) axial PDWI, and (**c**) axial FS T2WI. Note the Wiberg type III patella and a shallow patellofemoral groove (*bent white line*, **b**). Partial loss of cartilage in the lateral facet and subchondral signal changes are noted (*arrowheads*, **b**, **c**). Medially, there is a small bone fragment (*arrow*, **a**, **b**). Medial retinaculum is torn due to trauma (*curved arrow*, **c**)

Patella alta

- Patella alta is an abnormally high (proximal) patella in relation to femur and can cause patellofemoral malalignment, increasing the risk of patellar instability including patellar dislocation.
- It may also occur as a result of patellar tendon tear or patellar sleeve fracture.
- It is defined as Insall-Salvati index ≥1.2. Patella baja is defined as Insall-Salvati index ≤0.8 (Fig. 8.9).

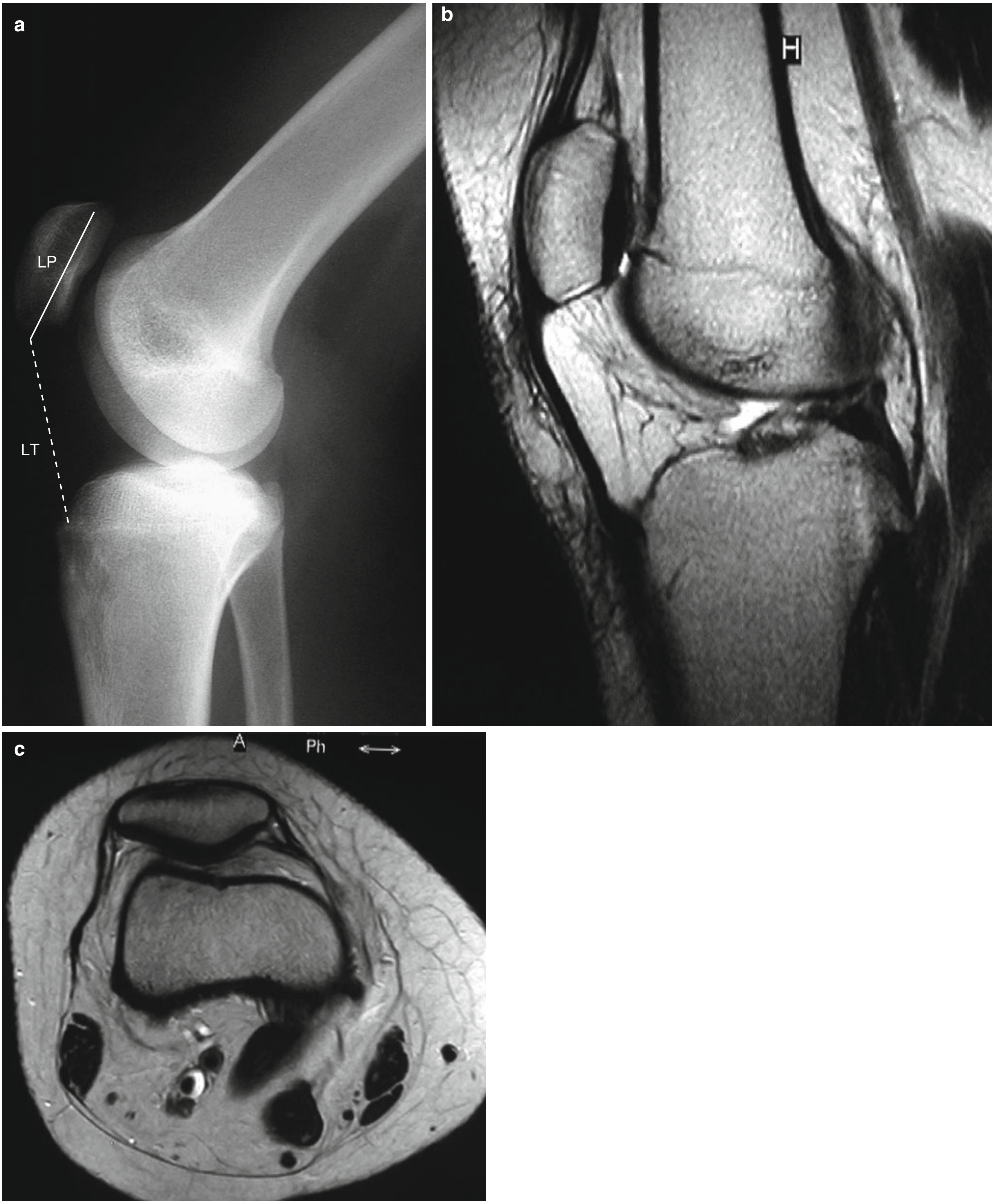

Fig. 8.9 Patella alta. A 14-year-old girl with a history of repetitive patellar subluxation. (**a**) Lateral radiograph, (**b**) sagittal, and (**c**) axial T2WI. Insall-Salvati index (=*LT*/*LP*) is greater than 1.2, which is consistent with patella alta. Axial image shows patellofemoral malalignment (Images courtesy of Dr. Ryuji Sashi, Yaesu Clinic, Japan)

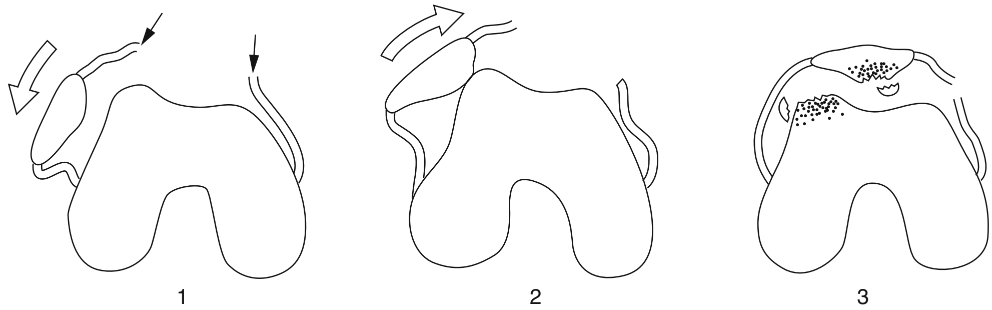

Fig. 8.10 Mechanism of tangential osteochondral fracture. During the spontaneous reduction of the patella following its lateral dislocation, as the patella is moved medially, its medial facet rubs tightly sideways over the surface of the lateral femoral condyle, causing cartilage (and subchondral bone) to be sheared off from the subchondral bone

8.4 Tangential Osteochondral Fracture

- Intra-articular cartilage and bone becomes separated due to trauma.
- Commonly occurs during the spontaneous reduction of the patella following its lateral dislocation.
- As the patella is moved medially, its medial facet rubs tightly sideways over the surface of the lateral femoral condyle, causing cartilage (and subchondral bone) to be sheared off from the subchondral bone (Fig. 8.10).
- Commonly occurs in early teens and following sports injuries. (Fig. 8.11)
- It may be associated with repetitive patellar dislocation, and this fracture is common in women and recurrence is common as well.
- Immediately after this fracture, patients will complain of pain and swelling of the knee due to hemarthrosis and pain on palpation of the medial side of the patella.
- Radiography may show detached bony fragments, but superimposition with the femur makes it difficult to visualize in many cases.
- If only cartilage is sheared off, radiography cannot detect the detached fragment and MRI will be the only method for imaging diagnosis. MRI is especially useful for evaluation of cartilage, but difficulty may arise if there are intra-articular blood clots which obscure the view of fracture site or detached fragments.

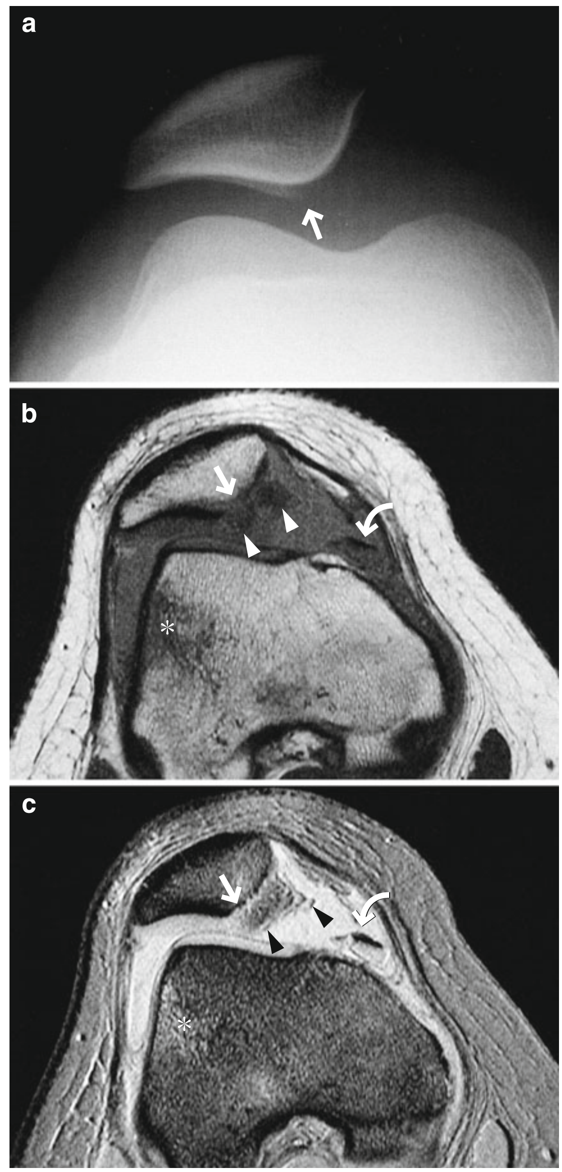

Fig. 8.11 Tangential osteochondral fracture. A 14-year-old girl. (**a**) Skyline view radiograph of the knee, (**b**) axial T1WI, and (**c**) axial T2*WI. There are cartilage loss and irregularity in the medial facet of the patella (*arrows*). Bone bruise is present in the lateral femoral condyle (*). A detached bony/cartilaginous fragment shows hypointensity (*curved arrow*). Within the joint space filled with blood, some debris-like objects are present (*arrowheads*)

References

Milgram JE. Tangential osteochondral fracture of the patella. J Bone Joint Surg Am. 1943;25:271–80.

Sanders TG, Paruchuri NB, Zlatkin MB. MRI of osteochondral defects of the lateral femoral condyle: incidence and pattern of injury after transient lateral dislocation of the patella. AJR. 2006;187:1332–7.

Imaging Diagnosis of Knee Trauma: A Radiologists' Perspective

Knee trauma is said to be the second most common presenting complaint following the foot trauma among patients visiting orthopedic outpatient clinics. Diagnosis of knee trauma often needs to be made immediately at presentation, and as such orthopedic surgeons may wish to make clinical diagnosis without consulting radiologists. However, this way of clinical practice is a thing of the past. Thanks to modern imaging techniques, including high-resolution CT and MRI, diagnosis of the knee trauma is made taking into account all available information, including clinical examinations and diagnostic imaging. Thus, nowadays radiologists have a lot more opportunities to see the images of knee trauma compared to old days. A key issue is that we should exchange information with orthopedic surgeons to make sure effective collaboration to treat the patient.

8.5 Patellar Sleeve Fracture

- Occurs when the inferior pole of the patella of a child or adolescent is pulled off together with parts of articular cartilage. This is an avulsion fracture of the patellar tendon attachment site.
- It is a rare trauma, but commonly seen in young persons.
- Clinically, patients cannot or have difficulty to extend the knee.
- Radiography may not reveal any obvious pathology if the fractured segment contains little bony component. In this case, the only positive radiographic finding may be the abnormally high patella and localized swelling.

Key points for MRI interpretation

- If the avulsed fragment cannot be visualized by radiography, MRI is needed to detect the bony and cartilaginous fragments and to assess patellar tendon injuries (Fig. 8.12).

Reference

Gardiner JS, McInerney VK, Avella DG, Valdez NA. Pediatric update #13. Injuries to the inferior pole of the patella in children. Orthop Rev. 1990;19:643–9.

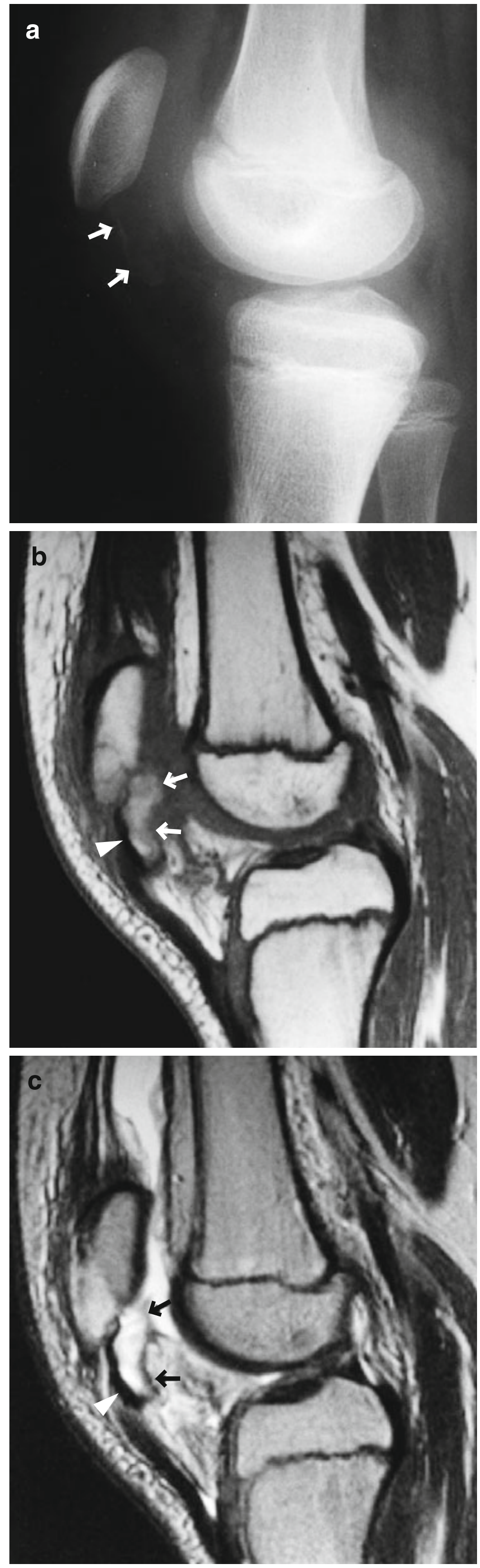

Fig. 8.12 Patellar sleeve fracture. A man in his late teens. (**a**) Lateral radiograph, (**b**) T1WI, and (**c**) T2WI. On the radiograph, an avulsed bony fragment is faintly visible (*white arrows*), and the patella is located abnormally high. On MRI, avulsed bony fragments show signal void (*arrowheads*), while cartilaginous fragments including hemorrhagic component show hyperintensity (*white arrows* in **b**, *black arrows* in **c**) (Image courtesy of Dr. Toshiki Muramatsu, Department of Orthopaedics, Showa General Hospital, Japan)

8.6 Osteochondritis Dissecans

- Osteochondritis dissecans (OCD) is a term for osteochondral fracture. An osteochondral fragment may be present in situ, detached incompletely or completely. A loose body is seen if completely detached.
- More than 80% of the cases involve the lateral aspect of the medial femoral condyle. In contrast, spontaneous osteonecrosis of the medial femoral condyle which shows similar MRI appearance is more likely to occur in the weight-bearing surface of the medial femoral condyle (Table 8.1, Fig. 8.13).
- Bilateral occurrence is seen in 20–30% of cases.
- Common in male teenagers (Fig. 8.14).
- Rarely occurs in the lateral condyle (about 10%) and the patellofemoral joint (a few %, Fig. 8.16).
- Repetitive stress from sports or other reasons are suggested risk factors.
- On radiography, the lesion is depicted as a localized lucency within the subchondral bone at an early stage. Gradually, the lesion becomes sclerotic and bone fragment becomes visible. Imaging of the intercondylar space is helpful for diagnosis, especially tomographic imaging including CT.
- MRI enables visualization of signal changes within cartilage and subchondral bone which are not detectable by

Table 8.1 Comparison between osteochondral dissecans and spontaneous osteonecrosis

	Osteochondritis dissecans	Spontaneous osteonecrosis
Likely location	Lateral side of the medial femoral condyle	Weight-bearing surface of the medial femoral condyle
Age	Young persons	Middle age to elderly
Gender	Common in men	Common in women

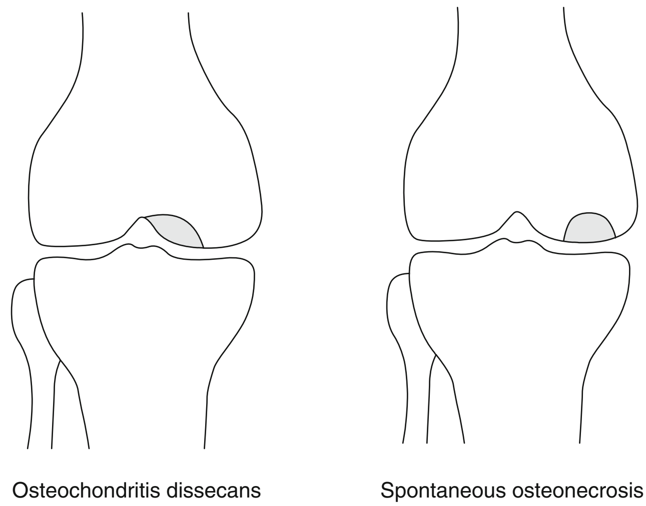

Fig. 8.13 Schematic illustration showing the likely locations of the osteochondritis dissecans and spontaneous osteonecrosis

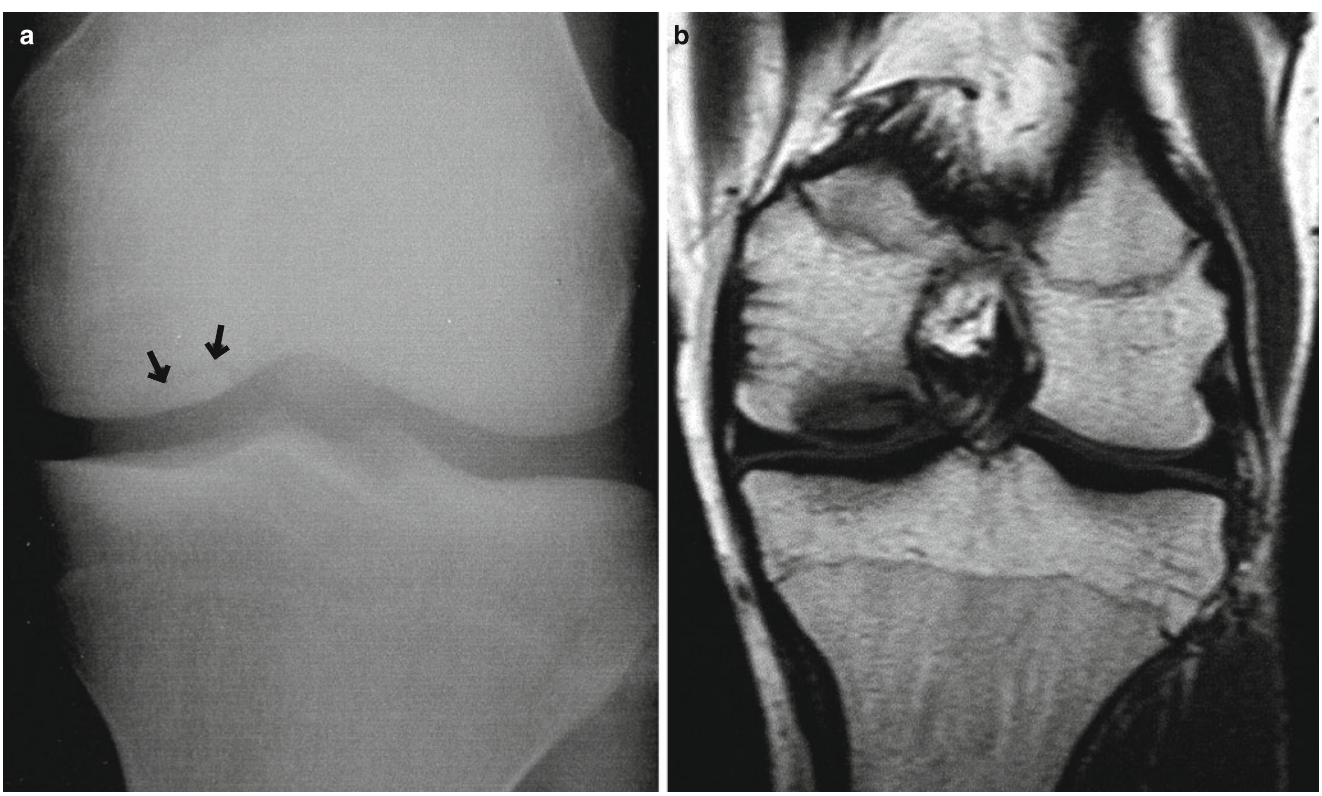

Fig. 8.14 Osteochondritis dissecans. A man in his late teens. (**a**) Anteroposterior radiograph, (**b**) coronal T1WI, (**c**) coronal T2*WI, and (**d**) coronal T2*WI with MTC. Radiograph shows a fragment surrounded by linear lucency in the lateral side of the medial femoral condyle (*arrows*, **a**). On MRI, the lesion generally shows hypointensity on T1WI and hyperintensity on T2*WI. There is linear hyperintensity between the lesion and the femoral surface (*arrows*), but its signal is suppressed on T2*WI with MTC, suggesting that this linear hyperintensity represents cartilage rather than joint fluid. The lesion therefore is not unstable

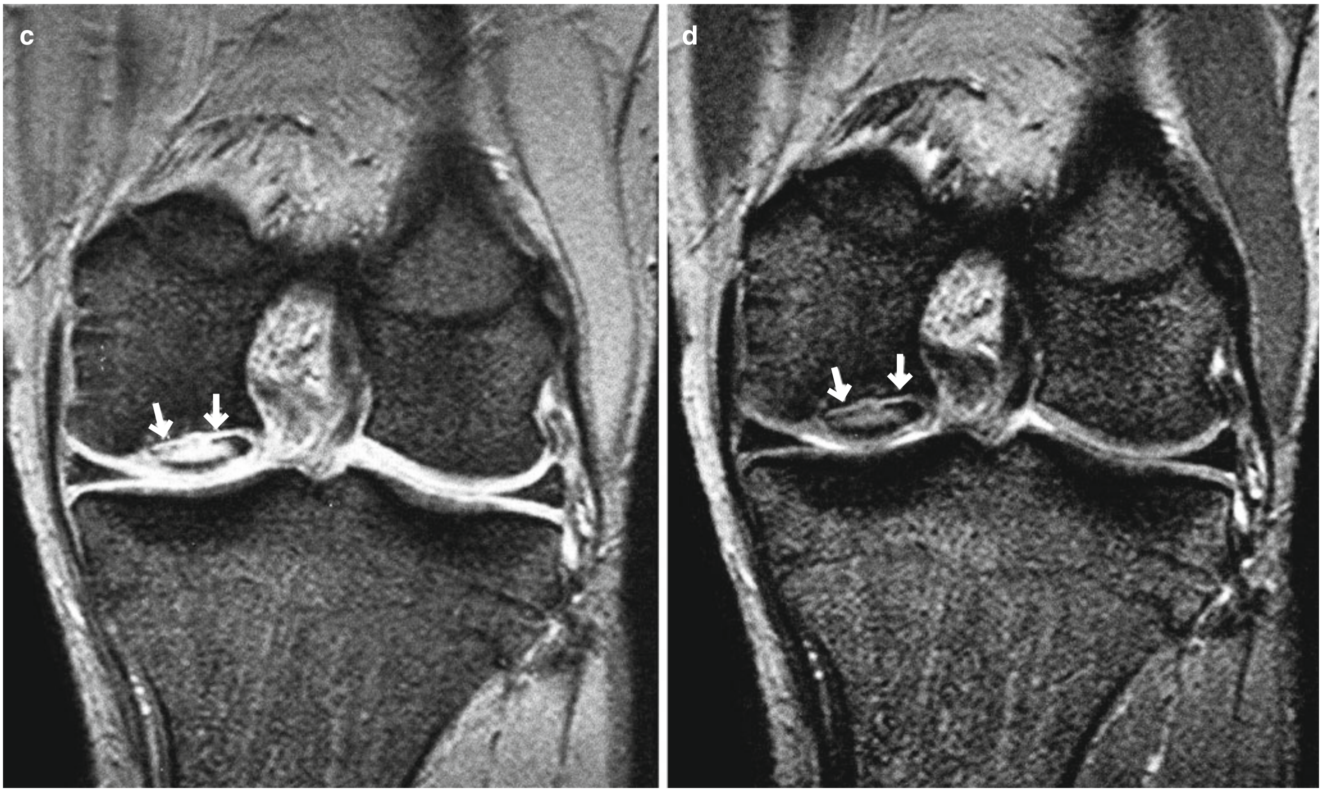

Fig. 8.14 (continued)

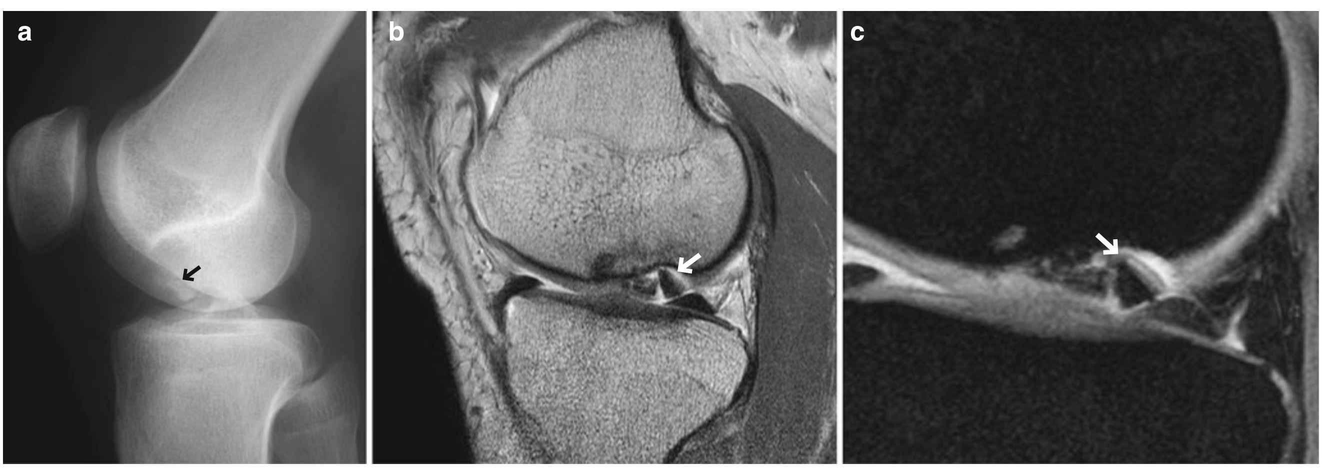

Fig. 8.15 Osteochondritis dissecans. A man in his 20s. (**a**) Lateral radiograph, (**b**) PDWI, and (**c**) FS PDWI (*enlarged*). Detached bony fragment is visible (*arrow*, **a**) just inferior to the medial femoral condyle. MRI shows the presence of joint fluid between the fragment and the femoral condyle (*arrow*, **b**), and the cartilaginous surface is inverted and facing the femoral surface (*arrow*, **c**). This is considered unstable

radiography. It may thus be possible to catch the lesion at a very early stage.

- At an early stage, the lesions show hypointensity on T1-weighted image and hyperintensity on T2-weighted image. Later on, the lesions show hypointensity on both sequences reflecting the sclerotic and necrotic changes.
- If the joint fluid enters the space between the fragment and the femoral surface, the lesion becomes unstable (Fig. 8.15). Joint fluid will be seen as a band-like hyperintensity on T2-weighted images. The lesion may undergo cystic changes.
- MTC is effective for differentiation between joint fluid and cartilaginous tissue, both of which show hyperintensity on T2-weighted images (Fig. 8.14).
- Osteochondral dissecans is surgically treated by fixing the detached fragment to its original site using absorbable pins, expecting fusion to occur (Fig. 8.17).

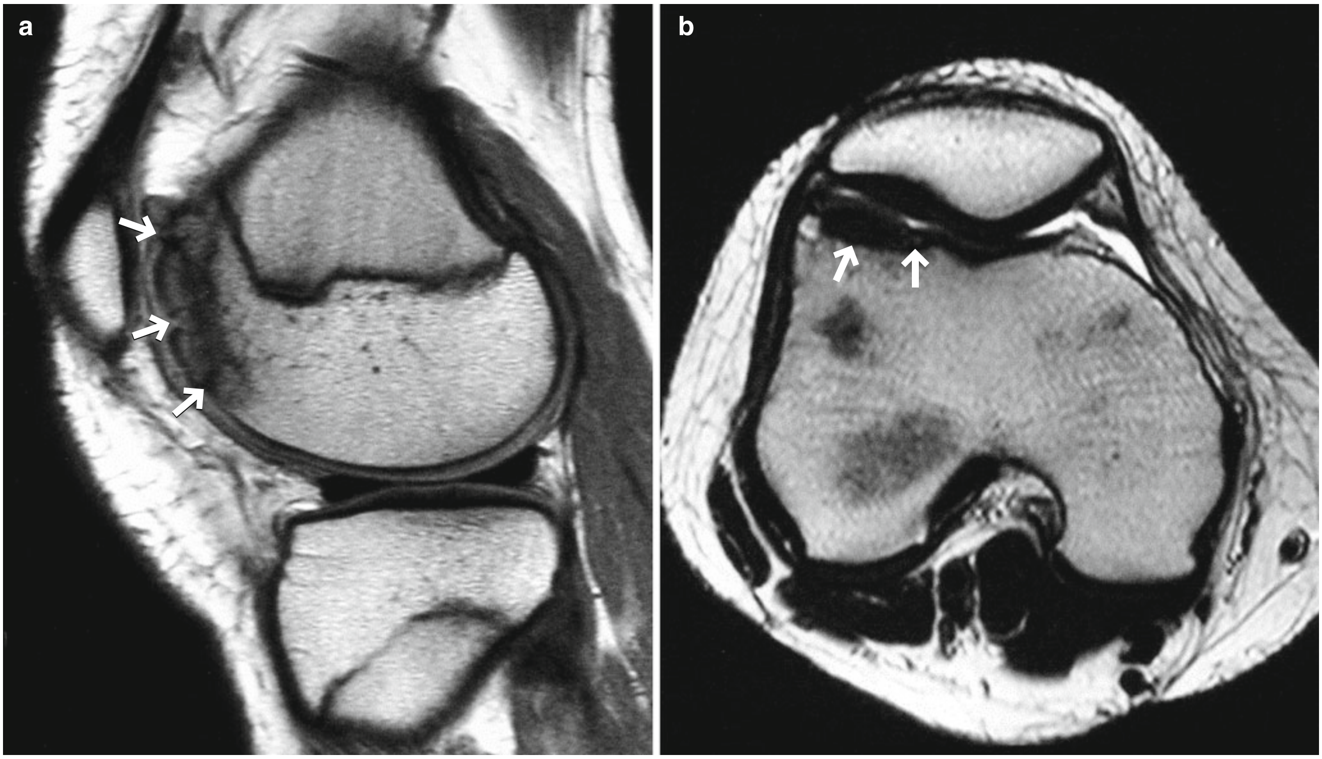

Fig. 8.16 Osteochondritis dissecans in the patellofemoral joint. A 14-year-old woman. (**a**) PDWI and (**b**) axial T2WI. An osteochondral lesion (*arrows*) with irregularity of the cartilage and subchondral bone is present in the anterior aspect of the lateral femoral condyle, facing the lateral facet of the patella

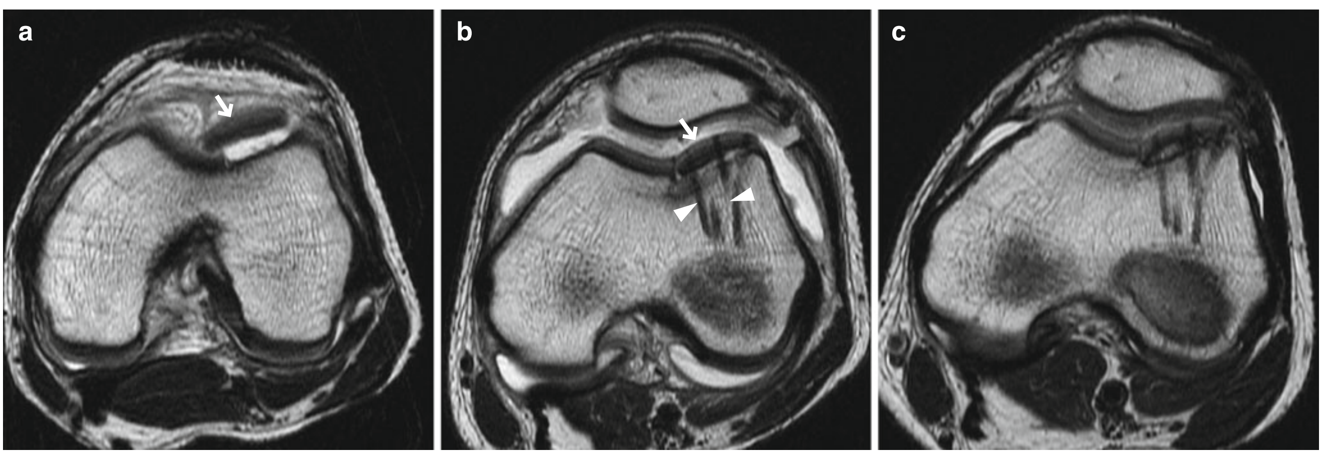

Fig. 8.17 Surgical repair of the patellofemoral osteochondritis dissecans. A man in his 20s. (**a**) Axial T2WI before surgery, (**b**) immediately after surgery, and (**c**) 4 months after surgery. There is a detached osteochondral lesion in the lateral femoral trochlea (*arrows*, **a**, **b**), which is fixed to its original site using absorbable pins (*arrowheads*, **b**). During follow-up, the osteochondral lesion becomes fused to the femur, and absorbable pins become less clearly visible (**c**)

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De Smet AA, Fisher DR, Graf BK, et al. Osteochondritis dessicans of the knee: value of MR imaging in determining lesion stability and the presence of articular cartilage defects. AJR. 1990;155:549–53.

Boutin RD, Januario JA, Newberg AH, Gundry CR, Newman JS. MR imaging features of osteochondritis dessicans of the femoral sulcus. AJR. 2003;180:641–5.

Key points for MRI interpretation

- MRI is useful for detecting lesions at a very early stage.
- MRI is used to detect detachment of the osteochondral lesion, the presence of joint fluid between the detached lesion and the femoral surface, and loss of cartilage.

8.7 Traumatic Hemarthrosis

- Traumatic intra-articular bleeding arises from:

1. Blood vessels present within the joint capsule, cruciate ligaments, and synovium covering the periphery of menisci (Fig. 8.18).
2. Bone marrow hemorrhage due to intra-articular fracture and osteochondral fracture.

- Hemorrhage from the bone marrow of the patella, femur, and tibia may contain fatty droplets, which may form fluid-fluid level at the interface between the oily and hemorrhagic component (Fig. 8.19). Hemorrhage occurs immediately after injury and reaches the maximum extent within 24 h.
- It is said that the intra-articular hemorrhage does not coagulate.

Fig. 8.18 Traumatic hemarthrosis of the knee. A man in his 20s, 2 days after ACL tear. Axial T2WI shows a large amount of intra-articular hemorrhage, which is separated into three layers: superficial blood plasma (*) and two layers of sedimentation

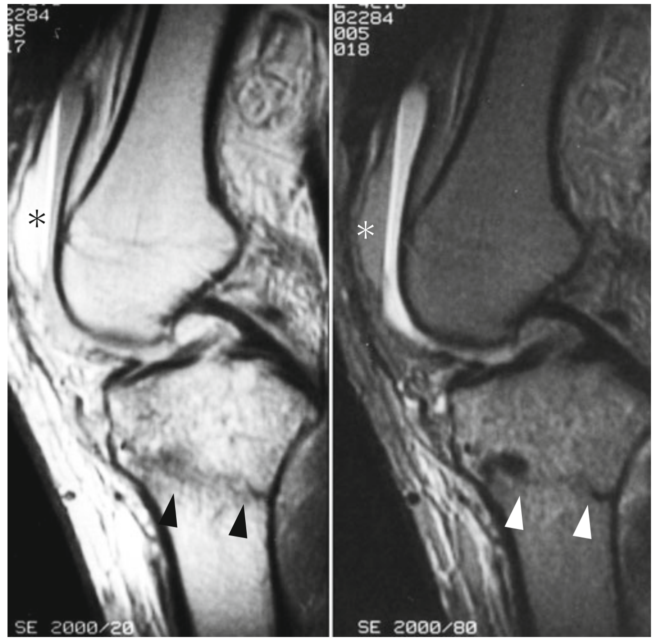

Fig. 8.19 Tibial plateau fracture and intra-articular fat. A man in his 20s. PDWI (*left*) and T2WI (*right*). A transverse fracture line runs within the tibial metaphysis (*arrowheads*) and is surrounded by bone bruise. There is a fluid-fluid level in the joint space due to the presence of fat (*) and blood

8.8 Stress Fracture and Fatigue Fracture

- Stress fracture is a chronic bone injury which occurs when the bone is subjected to repetitive stress.
- Stress fracture includes fatigue fracture and insufficiency fracture.
- Fatigue fracture is a type of stress fracture caused by repeated mechanical stress, exceeding the ability of normal bone to functionally adjust to the demands being placed on it. It is commonly seen in the vertebrae, pelvic bone, tibia, femur, and calcaneus of young athletes.
- Insufficiency fracture is caused by normal or physiologic stress on weakened bone due to pathology such as osteoporosis, osteomalacia, and postradiotherapy status. It is common in elderly patients. It may present as an occult fracture because it is difficult to spot on radiography due to coexistent bone pathology such as osteoporosis.
- Stress fracture commonly occurs in both femur and tibia (Fig. 8.20).
- Fat-suppressed proton-density-weighted or T2-weighted MRI is useful for detection of bone marrow edema, which is suggestive of a fracture.

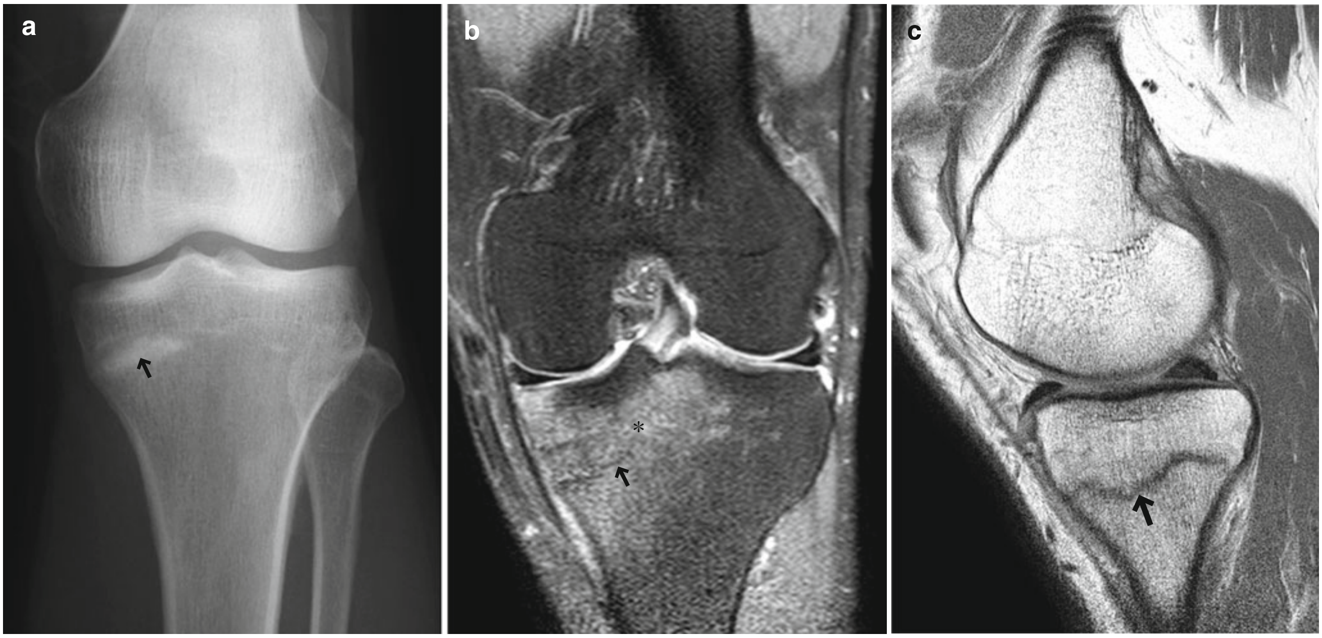

Fig. 8.20 **Tibial fatigue fracture**. A man in his 40s. He started jogging 2 months prior to presentation, and he now complains of knee pain. (**a**) Anteroposterior radiograph, (**b**) coronal FS PDWI, and (**c**) PDWI. There is a linear hypointensity representing a fracture line (*arrows*, **b**, **c**) which has already sclerosed (*arrow*, **a**). There is extensive bone marrow edema (*, **b**) in the tibia

8.9 Bone Bruise

- MRI signal abnormalities (lower signal than the normal bone marrow on T1-weighted image and higher signal on T2-weighted image) are often seen at the site of bone trauma due to direct external force or collision of bones. This signal abnormality is said to represent bone marrow edema, hemorrhage, and microfracture of the trabecular network.
- The term "bone bruise" was created after MRI became available in the clinical practice.
- It is commonly seen in the lateral femoral condyle and the posterior part of the lateral tibial condyle (see Chap. 3) together with the ACL tear.
- This MRI signal abnormality may disappear after several months. However, after long-term follow-up, occasionally, radiography may show a mild depression at the site of bone bruise and arthroscopy may demonstrate chondromalacia or irregularity of cartilage surface.

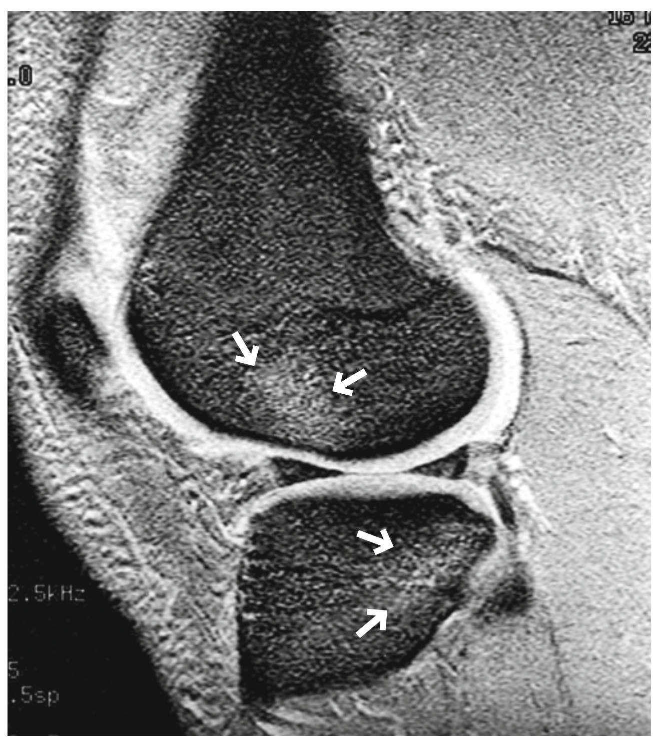

Fig. 8.21 **Bone bruise**. Patient with complete ACL tear. T2*WI shows ill-defined hyperintensity in the anterior aspect of the lateral femoral condyle and posterolateral tibial plateau (*arrows*)

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Miller MD, Osborne JR, Gordon WT, Hinkin DT, Brinker MR. A prospective study of magnetic resonance imaging-detected trabecular microfractures in patients with isolated medial collateral ligament injuries. Am J Sports Med. 1998;26:15–19.

Common Sites of Bone Bruise Occurrence in Association with Knee Ligamentous Injuries

ACL tear: lateral femoral condyle + posterolateral tibial plateau
PCL tear: anterior tibia
MCL tear: lateral femoral condyle

8.10 Musculotendinous Injury

- Musculotendinous injuries are very common in and around the knee joint.
- In particular, injuries to the musculotendinous junction and the tendon attachment site are common. In the injuries of the tendon attachment site, avulsion fracture and the resultant bone fragment can also be seen.
- On MRI, one should look for the continuity of the muscles (intermedial signal intensity) and tendons (hypointense bands).
- Quadriceps femoris has 2–3 layers in the sagittal image. If three layers are visible, they are, from superficial to deep, rectus femoris, combined vastus lateralis and medialis, and vastus intermedius (Fig. 8.22).
- Tear of a tendon may be complete or partial, in which tendon continuity is partially maintained (Figs. 8.23 and 8.24). In case of quadriceps femoris rupture, the aforementioned three-layer structure is disrupted.
- Hematoma and the surrounding edematous swelling are seen at the site of injury
- Complete tear of major tendons commonly need surgical repair, and thus radiologists need to report the distance between the ruptured edges, characters of the rupture edges, and presence of hematoma.
- Muscular injury is characterized on MRI by edema due to microrupture of muscle fibers, intra- or extramuscular hematoma, discontinuity of muscular fascia, and discontinuity of muscle bundles themselves (Fig. 8.25). Clinically, a global term "muscle strain" represents these features.

Fig. 8.22 Three-layered structure of the quadriceps femoris tendon. PDWI. (*1*) The superficial layer consists of rectus femoris. (*2*) The thick intermediate layer comprises conjoint tendon of the vastus lateralis and medialis. (*3*) The deep layer represents vastus intermedius

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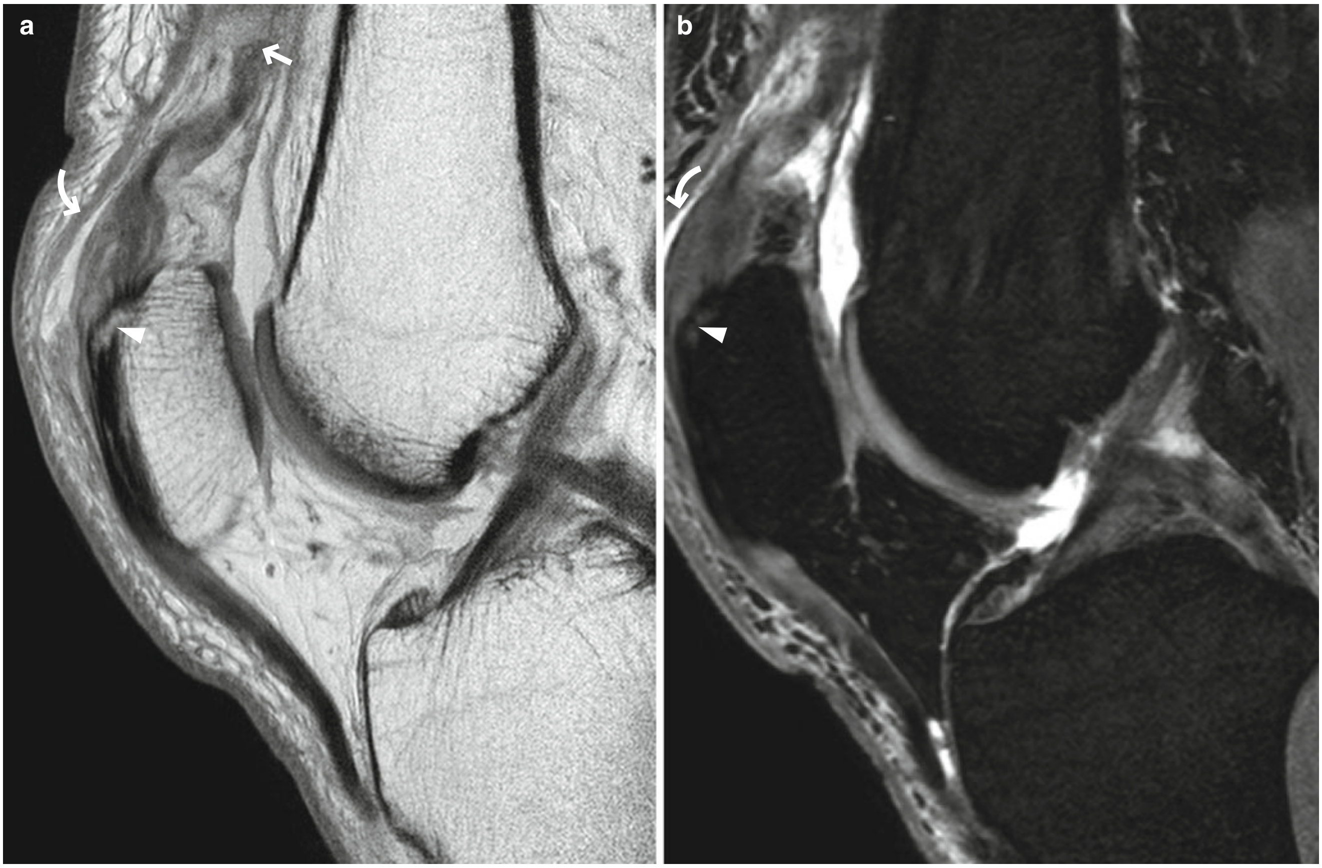

Fig. 8.23 Quadriceps femoris rupture. A man in his 60s. (**a**) PDWI and (**b**) FS T2*WI. Quadriceps femoris tendon is completely ruptured at several centimeters above the patella (*straight arrow*, **a**). There is a dissecting osteal lesion (*arrowhead*) in the anterosuperior part of the patella. There is also fluid accumulation (*curved arrows*) and subcutaneous swelling in the prepatellar region

Fig. 8.24 Patellar tendon rupture. A man in his 70s. Sagittal PDWI. Patellar tendon is completely ruptured at the middle portion, and the rupture edges are more than 1 cm apart from each other (*arrows*). There is prepatellar subcutaneous edematous swelling (*)

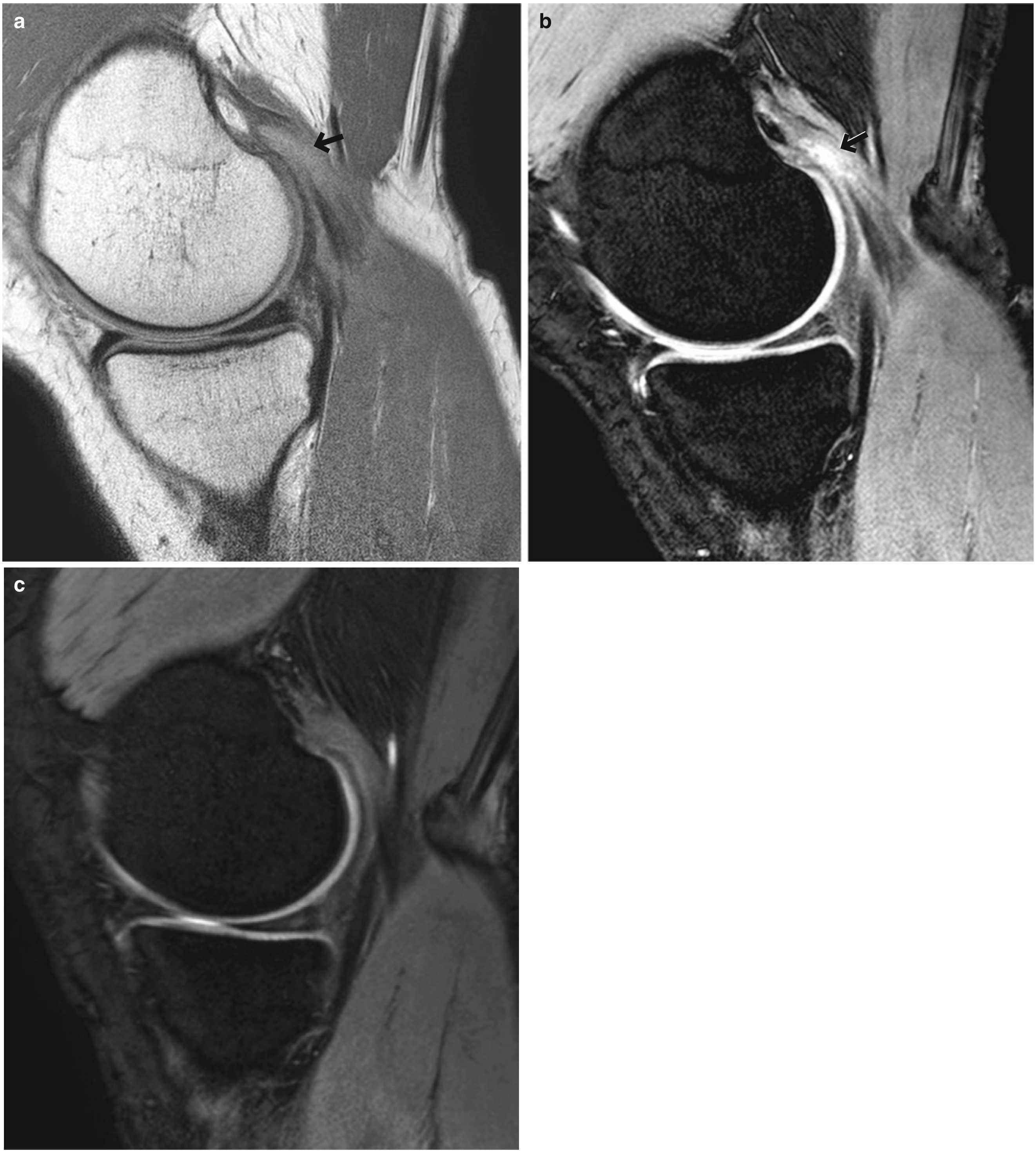

Fig. 8.25 **Strain of the medial head of gastrocnemius**. A woman in her 30s. (**a**) PDWI and (**b**) FS T2*WI at the time of injury. (**c**) FS T2*WI 6 months later. There is edematous swelling of the medial head of gastrocnemius (*arrows*, **a**, **b**). Six months later, this lesion is almost disappeared

9 Pediatric and Adolescent Disorders of the Knee

9.1 Distal Femoral Cortical Irregularity

- Irregular appearance of the distal femur on radiograph.
- On anteroposterior radiograph, there is a round lucency within the femoral metaphysis together with sclerotic changes around it. On lateral radiograph, there is irregularity of the posterior femoral surface which mimics the periosteal reaction. In the past, malignant lesions were suspected and biopsy performed on these lesions.
- In old days, it was also called “cortical desmoid.”
- In fact, this is a bony irregularity due to traction by the medial head of gastrocnemius.
- The attachment site of the adductor magnus is in the close proximity and may also be a cause for this lesion. The lesion will be located more medially in this case (Fig. 9.1).
- Mostly bilaterally present in young persons, but may also be found in adults.

Key points for MRI interpretation

- An area of hypointensity representing sclerotic changes of the bone and varied signal changes within it (Fig. 9.2).

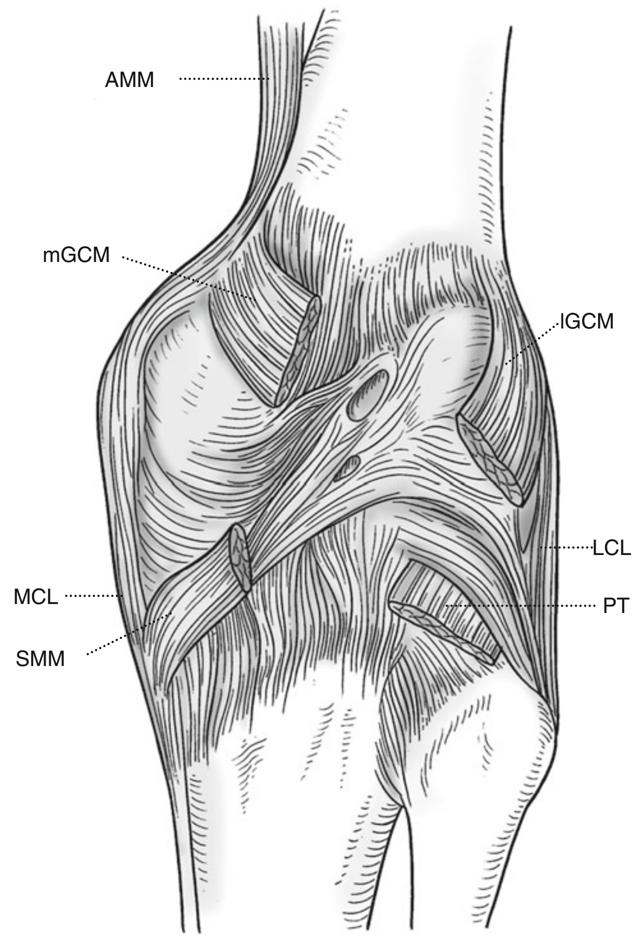

Fig. 9.1 The attachment sites of the medial head of gastrocnemius and adductor magnus. (Posterior view of the popliteal fossa.) The medial head of gastrocnemius (*mGCM*) and adductor magnus (*AMM*) attach to the medial side of the distal femur in the close proximity to each other. Distal femoral cortical irregularity occurs at these sites. *lGCM* lateral head of the gastrocnemius, *PT* popliteus tendon, *SMM* semimembranosus, *MCL* medial collateral ligament, *LCL* lateral collateral ligament

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DOI 10.1007/978-3-642-17893-1_9, © Springer-Verlag Berlin Heidelberg 2013

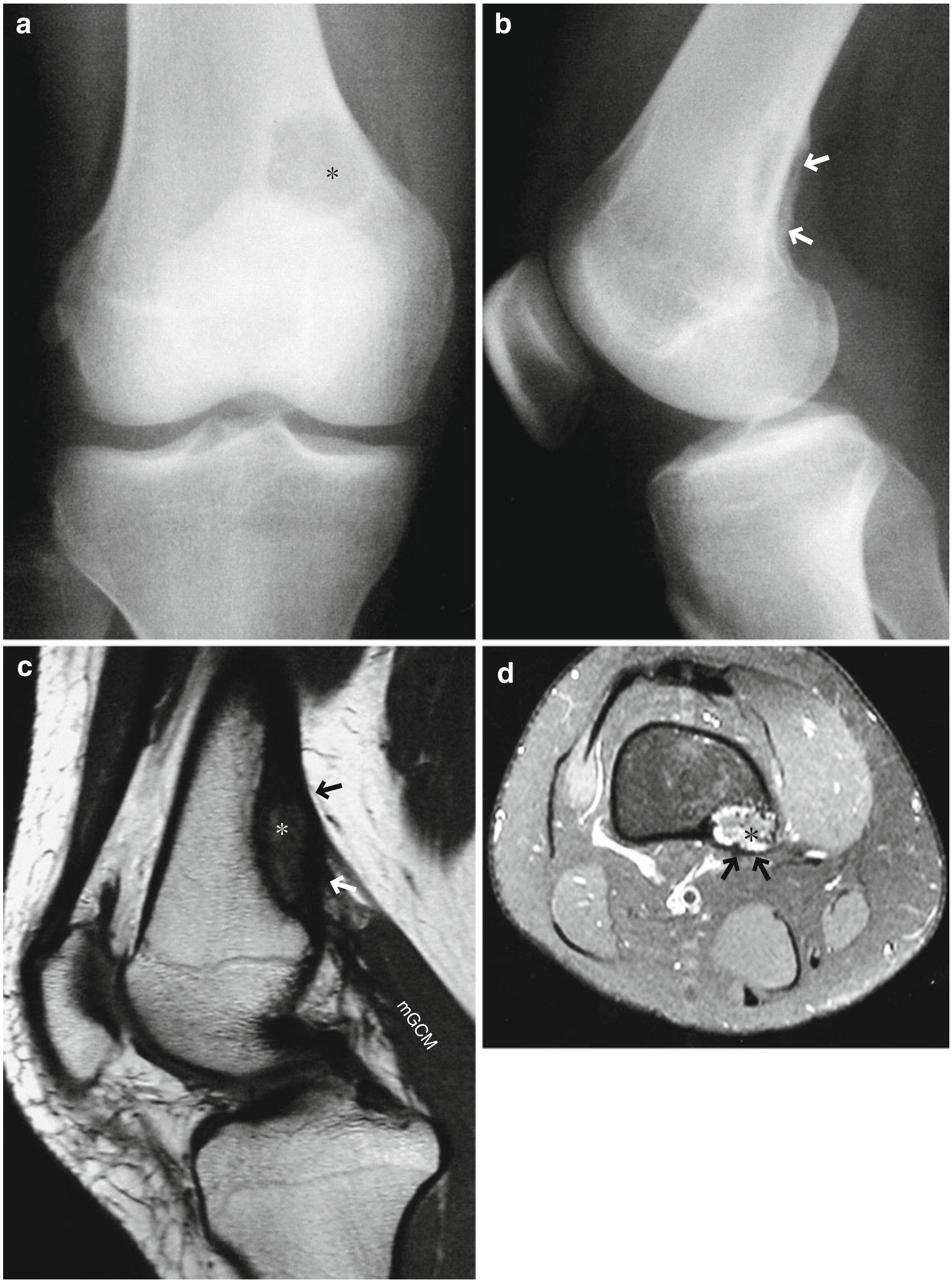

Fig. 9.2 Distal femoral cortical irregularity. A woman in her late teens. (**a**) Anteroposterior and (**b**) lateral radiographs. (**c**) PDWI and (**d**) axial FS T2WI. There is a round lucency in the distal femoral metaphysis (*, **a**) and the surrounding sclerotic changes on anteroposterior radiograph. Lateral radiograph shows protruding irregularity of the posterior femur (*arrows*). On MRI, near the attachment site of the medial head of gastrocnemius (*mGCM*), there is a band of hypointensity corresponding to the sclerotic changes and varied signal intensities within it (*). Similar changes were also in the contralateral femur

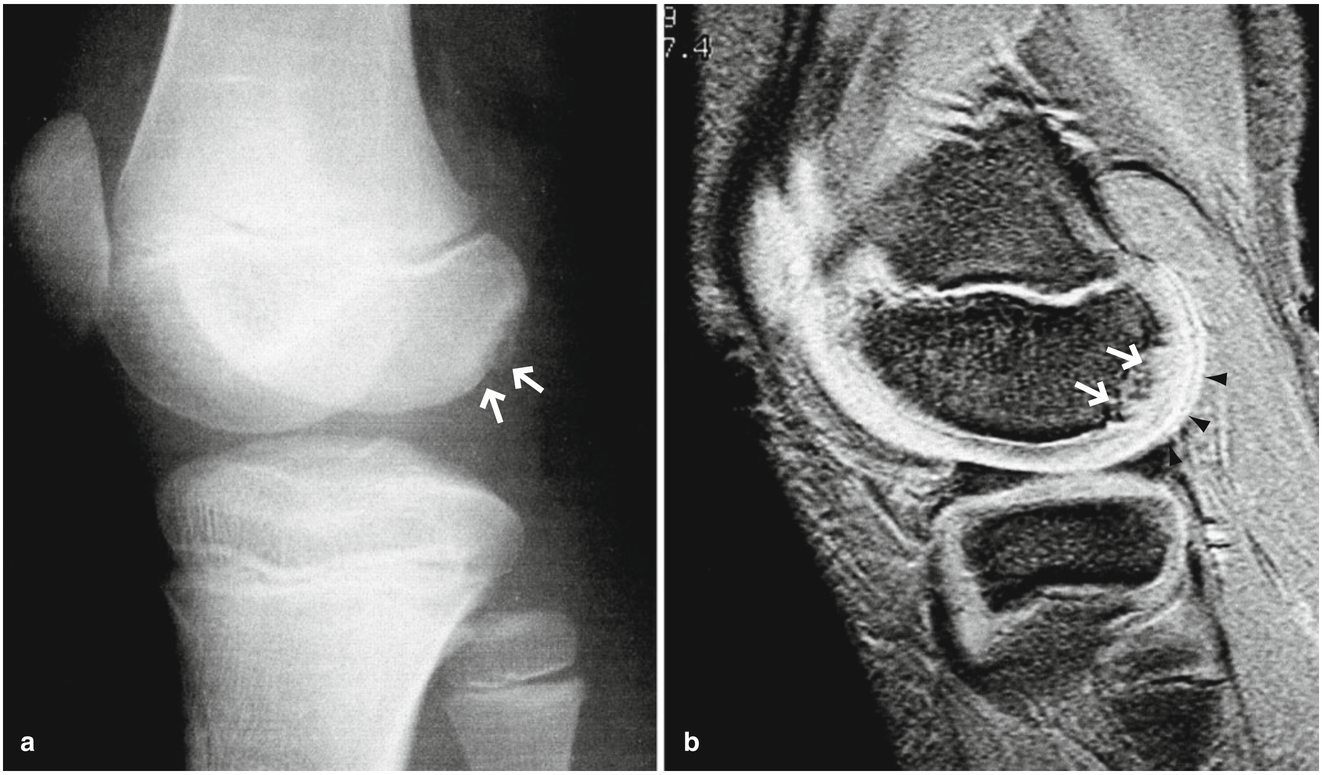

Fig. 9.3 **Femoral condyle irregularity**. An 11-year-old boy. (**a**) Oblique view radiograph and (**b**) T2*WI. There is a minute irregularity of the posterior aspect of the lateral femoral condyle (*arrows*) on radiograph. On MRI, there is irregularity of cortical bone (*arrows*), but the articular cartilage is absolutely normal (*arrowheads*). Similar changes were also seen in the contralateral knee

Fig. 9.4 **Femoral condyle irregularity of the medial femoral condyle**. A 10-year-old boy. PDWI. There is irregularity of cortical bone in the posterior aspect of the medial femora condyle (*arrows*), but the articular cartilage is absolutely normal (*arrowheads*)

9.2 Femoral Condylar Irregularity

- Commonly seen in children who are 2–6 years old (in more than 40% of cases). Also common in teenagers.
- May be an incidental finding on radiograph, and the patient may then be sent to have an MRI (Fig. 9.3).
- More common in the lateral femoral condyle (40% of cases involve the lateral condyle only) but can also occur in the medial condyle (Fig. 9.4).
- Commonly seen in the posterior side of the femoral condyle (Fig. 9.5). (cf. Osteochondritis dissecans (OCD) commonly occurs in the lateral side of the medial femoral condyle. See Chap. 8 for differential diagnosis of OCD and spontaneous osteonecrosis.) Therefore, the lesion may not be visible on anteroposterior radiograph. Tunnel view radiograph may be useful.
- Articular cartilage is normal.
- Patients are asymptomatic and the irregularity disappears after a few years (Fig. 9.6).

Key points for MRI interpretation

- The site of the lesion is the key for correct diagnosis. Imaging appearance may be similar to OCD, but the site of lesion is different. Diagnosis of femoral condylar irregularity can be confirmed by the presence of normal cartilage on MRI.

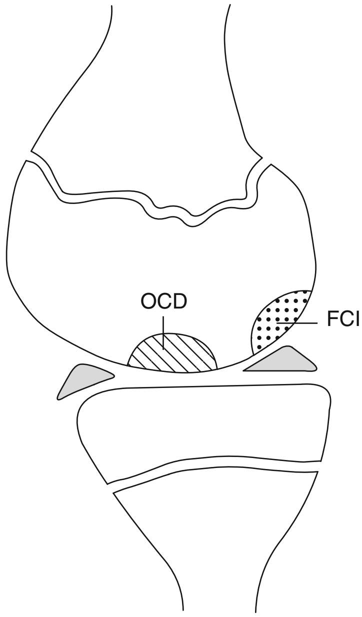

Fig. 9.5 Common sites of occurrence of the femoral condyle irregularity (FCI) and osteochondritis dissecans (OCD) (Schematic illustration of a sagittal knee image in a young person)

Reference

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Disorders Characteristics to Knees of Children and Adolescents

There are painful knee disorders that characteristically occur in children and adolescents, commonly due to overuse of the bone, cartilage, and ligaments which are subjected to excessive mechanical stress following strenuous sports activities. Such disorders include Osgood-Schlatter disease and Sinding-Larsen-Johansson disease, both of which are thought to be osteochondrosis.

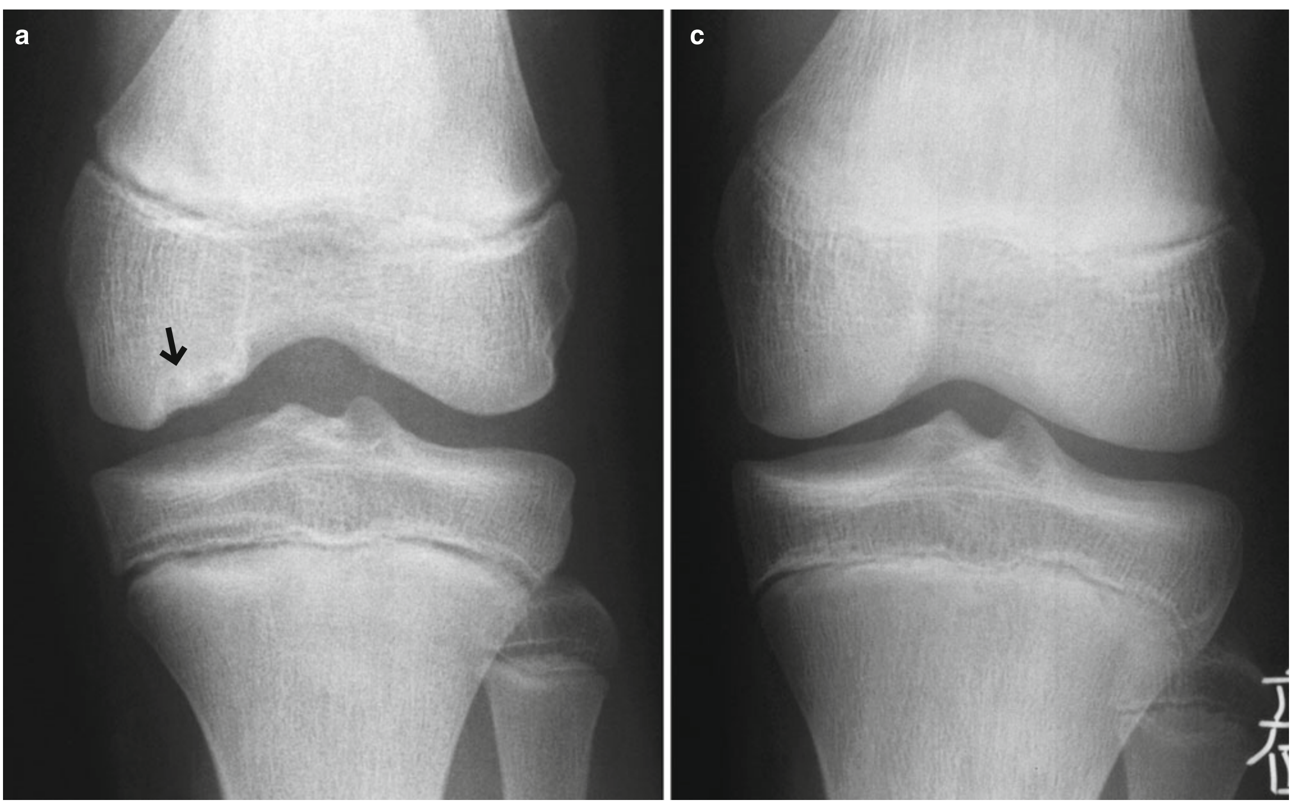

Fig. 9.6 **Femoral condyle irregularity that disappeared after 2 years**. A 12-year-old boy (at the time of initial diagnosis). (**a**) Tunnel-view radiograph and (**b**) T2WI at the time of presentation. (**c**) Tunnel-view radiograph and (**d**) T2WI 2 years later. There is a femoral condyle irregularity in the weight-bearing portion of the medial femoral condyle (*arrows*). However, the lesion disappeared 2 years later (Image courtesy of Dr. Shigeru Ehara, Department of Radiology, Iwate Medical University, Japan)

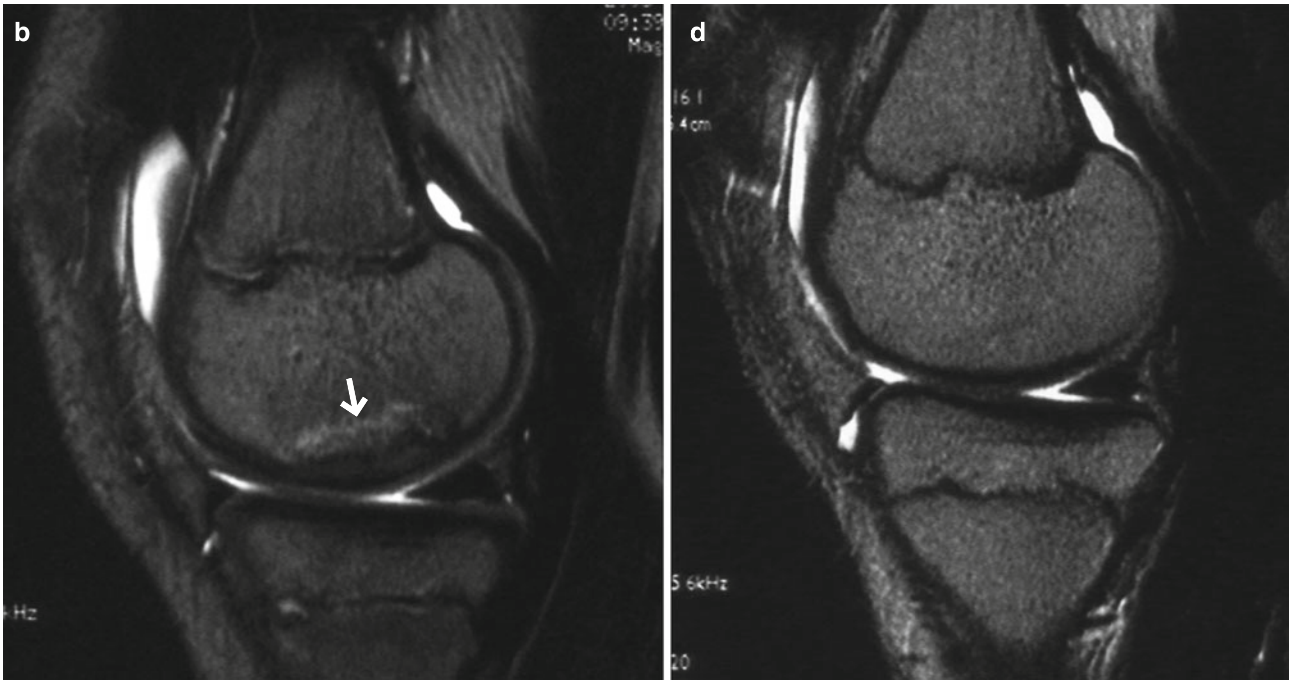

Fig. 9.6 (continued)

9.3 Painful Patella Partita

- Patella partita is a malformation of the patella which comprises more than one part.
- It is thought to be caused by incomplete ossification process of two or more ossification centers, or by excessive stress from sports, but it is considered to be a normal variant. Bilateral knees are affected in approximately half the cases. Most cases are thought to naturally heal before the adolescence.
- More common in boys.
- A classification system developed by Saupe is commonly used (Fig. 9.7). Saupe type III is the most common (Fig. 9.8) because of poor vascular supply in the superolateral pole of the patella, to which the vastus lateralis attaches.
- Patella bipartita has two parts (Fig. 9.8), while patella tripartita has three parts (Fig. 9.9).
- Usually asymptomatic, but pain may be triggered by excessive stress by sports or other reasons. Such a case is called painful patella partita and is common in teenage boys (Fig. 9.10).
- On radiography, the site of separation appears rounded edges and may accompany sclerotic changes. Skyline view radiograph is useful for confirming the position of the accessory fragment or the presence of pseudoarthrosis due to a tilt.

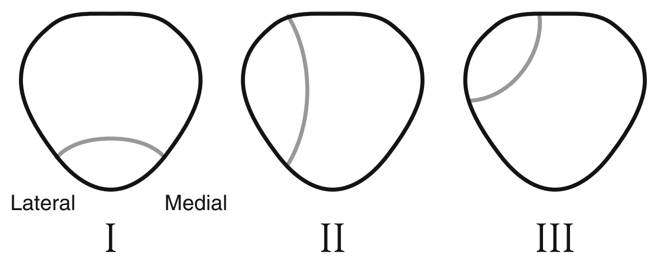

Fig. 9.7 Saupe classification of the patella bipartita. *Type I*: accessory fragment is located at the inferior pole of patella. *Type II*: accessory fragment is located on the lateral margin. *Type III*: accessory fragment is located at the superolateral pole

References

Lawson JP. Symptomatic radiographic variants in extremities. Radiology. 1985;157:625–31.

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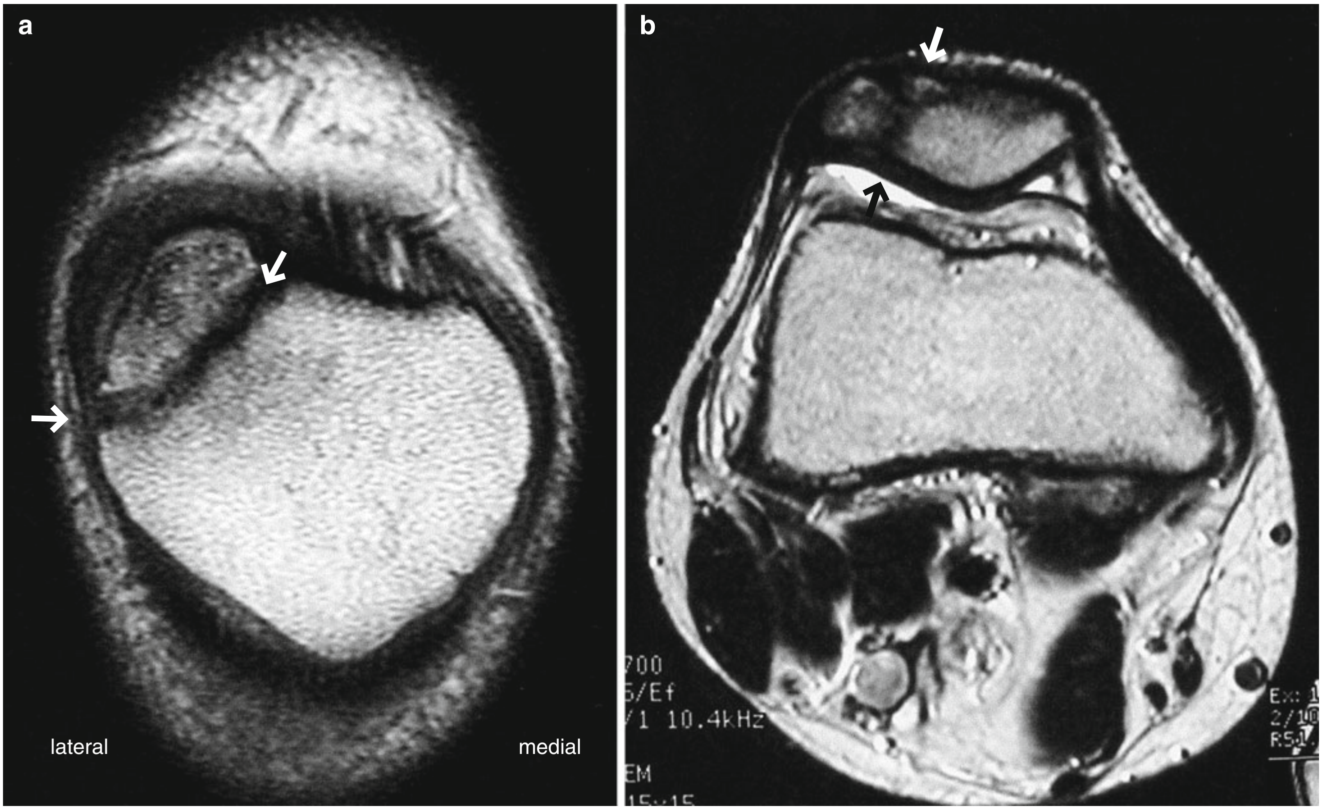

Fig. 9.8 **Patella bipartita**. A man in his 30s. (**a**) Coronal T1WI and (**b**) axial T2WI. This is an example of the Saupe type III, in which the accessory fragment is located at the superolateral pole (*arrows*), which is the attachment site of the vastus lateralis. In this case, articular cartilage is continuous around the accessory fragment. In general, radiography and MRI are needed to check for the displacement of the accessory fragment

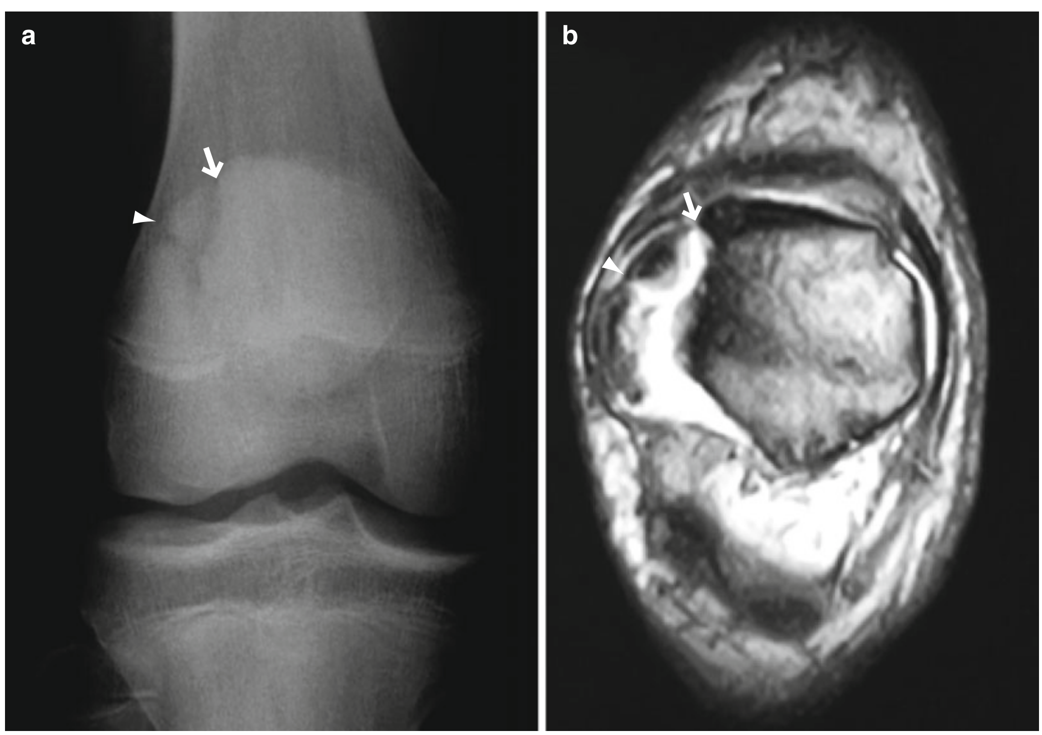

Fig. 9.9 **Patella tripartita**. A 13-year-old boy. (**a**) Anteroposterior radiograph, (**b**) coronal T2*WI, and (**c**) axial CT image. There is a linear lucency that separates the accessory fragment at the superolateral pole (*arrows*), but there is an additional linear lucency (*arrowheads*) making this lesion patella tripartita rather than patella bipartita. On CT, periphery of the site of fragmentation shows sclerotic changes, which suggest chronic fragmentation

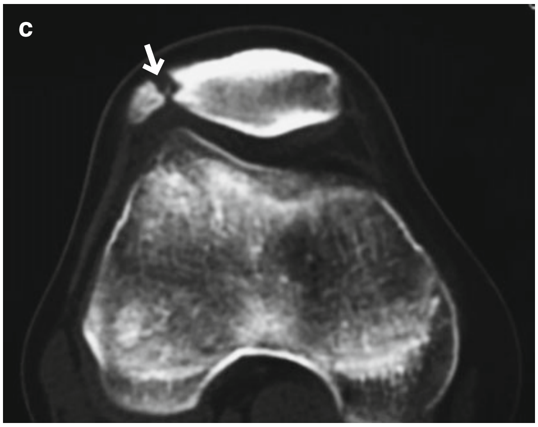

Fig. 9.9 (continued)

MRI Is Not Just About T1- and T2-Weighted Images

Perhaps, many doctors and technicians automatically think of T1- and T2-weighted images when it comes to MRI. However, the beauty of MRI is that it is not limited to these two pulse sequences. For example, for diagnostic imaging of the knee joint, proton-density-weighted or intermediate-weighted sequences and T2*-weighted gradient echo sequence are useful. In clinical practice, we certainly need to add T2-weighted sequence or fat suppression, and for assessment of tumors, T1-weighted sequence with or without gadolinium contrast enhancement is essential. In any case, we should not be only thinking of T1- and T2-weighted images.

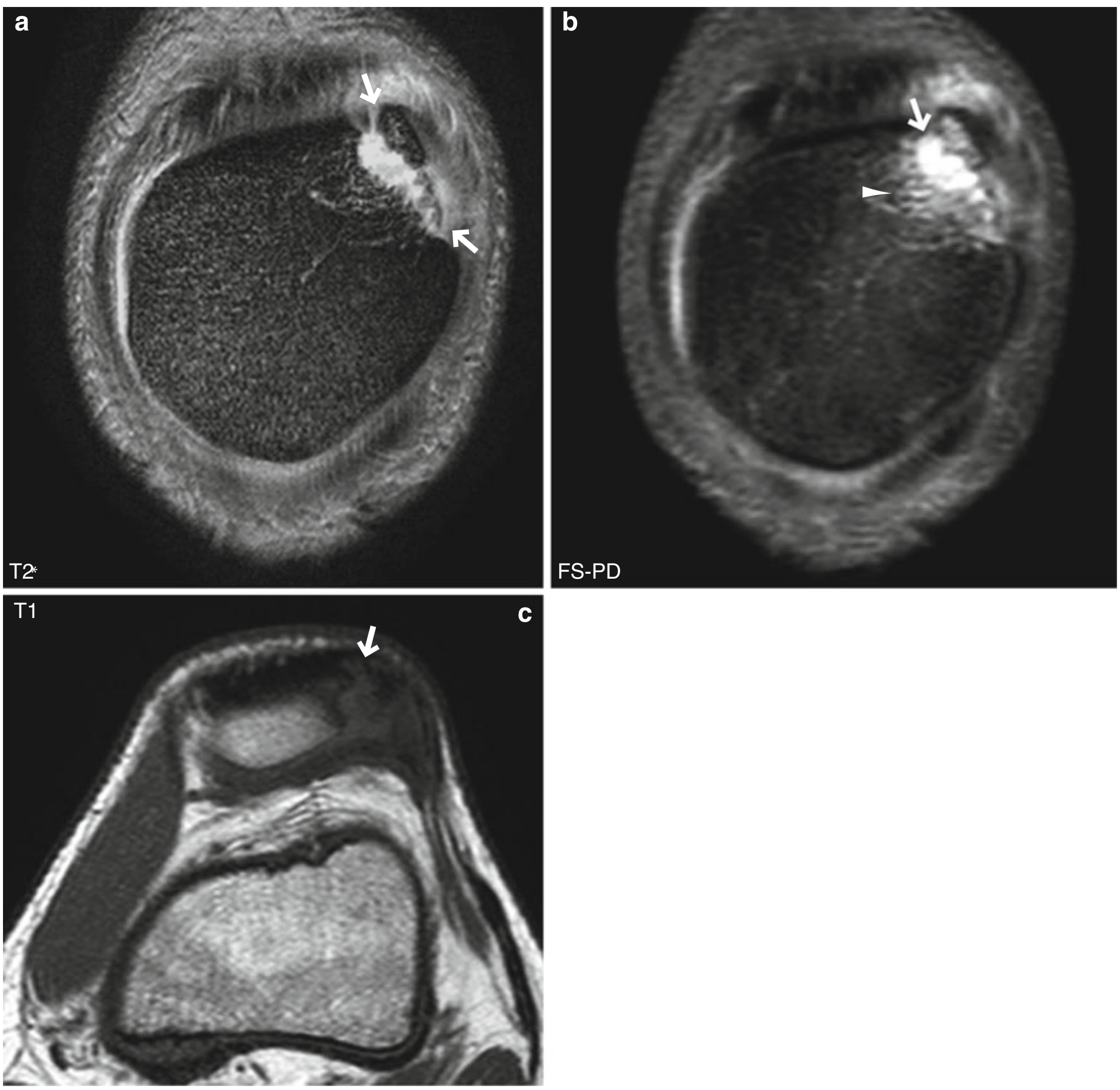

Fig. 9.10 Painful patella bipartita. A 14-year-old man who presented with peripatellar pain during exercise. (**a**) Coronal T2*WI, (**b**) coronal FS T2WI, and (**c**) axial T1WI. This is a Saupe type III lesion (*arrows*) with localized bone marrow edema in the patella (*arrowhead*), which suggests a painful lesion. Axial image reveals a wide separation of the accessory fragment from the patella and suggests the presence of pseudoarthrosis

9.4 Dorsal Defect of the Patella

- A well-defined round subcortical lucency is detected in the posterior aspect of the patella on radiograph (average diameter is about 9 mm on initial detection).
- It is of unknown etiology, but is thought to be a result of abnormal ossification of the patella. It may coexist with patella partita.
- The lesion is characteristically located in the postero- and superolateral aspect of the patella (which may be because it is associated with traction by vastus lateralis). Usually found on radiograph incidentally.
- In a majority of cases, it is found incidentally in asymptomatic persons. Rarely, it can be painful, but the pain is more likely due to coexistent patella partita or patellar subluxation.
- Incidence is about 1% and common in young persons. Often regresses naturally. Some authors report higher incidence in women, but others report no gender differences.
- Differential diagnoses include subchondral cysts associated with osteoarthritis, infection, and Brown tumor due to hyperparathyroidism. Tumors of the patella are rare, but occasionally it may need to be differentiated from neoplasm such as chondroblastoma.

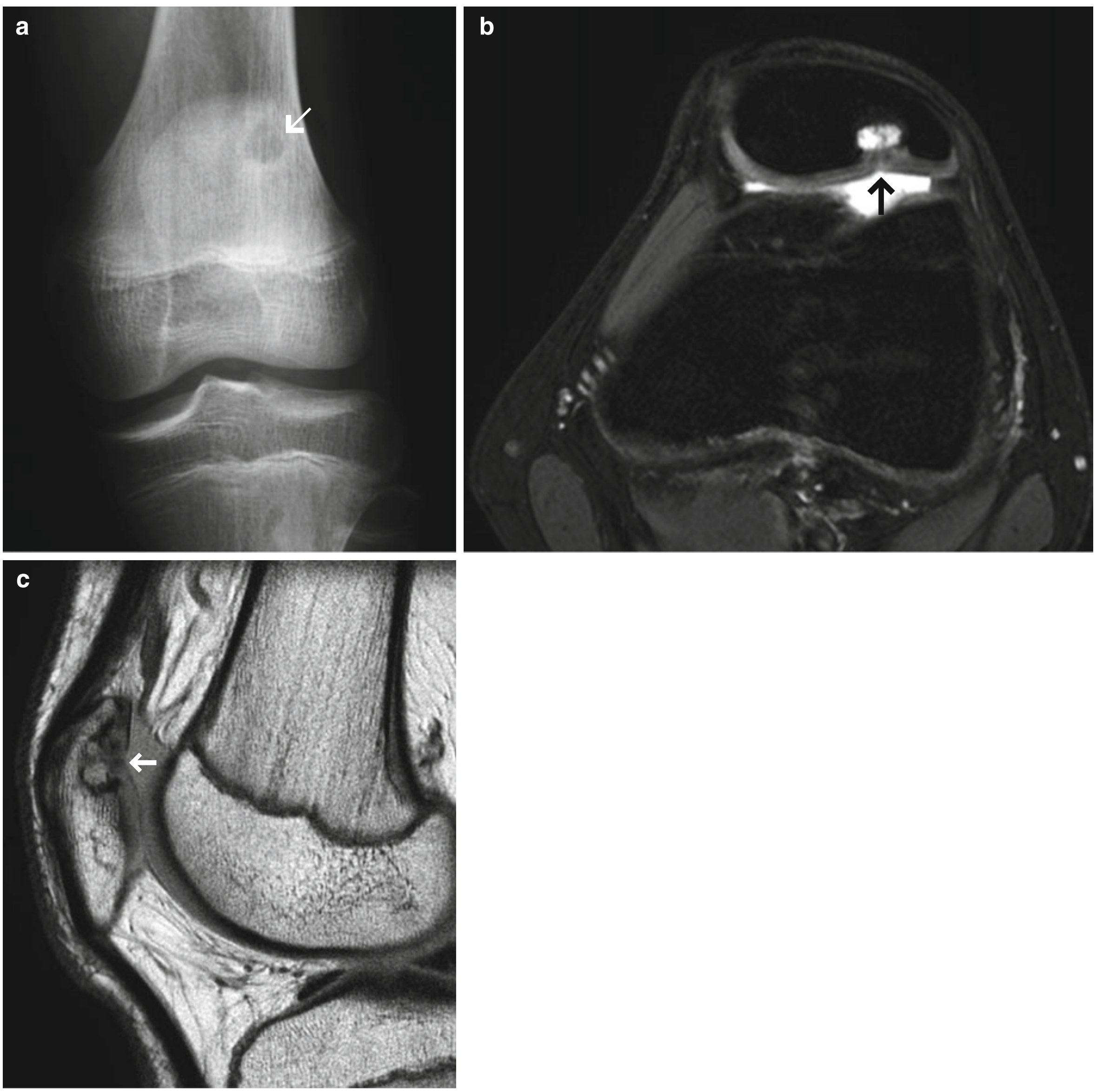

Fig. 9.11 Dorsal defect of the patella. A 14-year-old boy. (**a**) Anteroposterior radiograph, (**b**) axial T2*WI, and (**c**) PDWI. There is a 10-mm well-defined circular lucency in the superolateral aspect of the patella on radiograph (*arrow*, **a**). On MRI, there is subchondral hyperintensity at the posterior aspect of the patella, and the cartilage overlying the lesion is thinned and partially lost (*arrows*, **b**, **c**) (Images courtesy of Dr. Hiroyasu Okumura, Tobukawama Orthopaedic Clinic, Japan)

Key points for MRI interpretation

- Well-defined round osteolytic lesion involving the postero- and superolateral aspect of the patella shows hypointensity on T1-weighted images and hyperintensity on T2-weighted images (=nonspecific finding). Overlying patellar cartilage may be thinned or lost (Fig. 9.11). Bone marrow edema is not seen.

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Ehara S, Kyurana JS, Kattapuram SV, et al. Osteolytic lesions of the patella. AJR. 1989;153:103–6.

9.5 Osgood-Schlatter Disease

- Tibial attachment site of the patellar tendon becomes irritated due to chronic excessive stimulation from the quadriceps femoris contraction. As a result, deep fibers of the patellar tendon shows microrupture and cartilage becomes detached from the tibia, causing swelling and tenderness at the anterior aspect of the tibia.
- It is said to result from overuse in sports and thus is very common in boys in early teens. Radiographs show protrusion of tibial surface and abnormal bone shadow (Fig. 9.12).
- If the tibial surface is not yet ossified and still cartilaginous, radiography may not reveal any abnormalities
- It often heals naturally when the epiphyseal cartilaginous plate closes, but bony swelling and patellar tendon thickening will persist.

Reference

Ogden JA, Southwick WO. Osgood-Schlatter's disease and development of the tibial tuberosity. Clin Orthop. 1976;116:180–9.

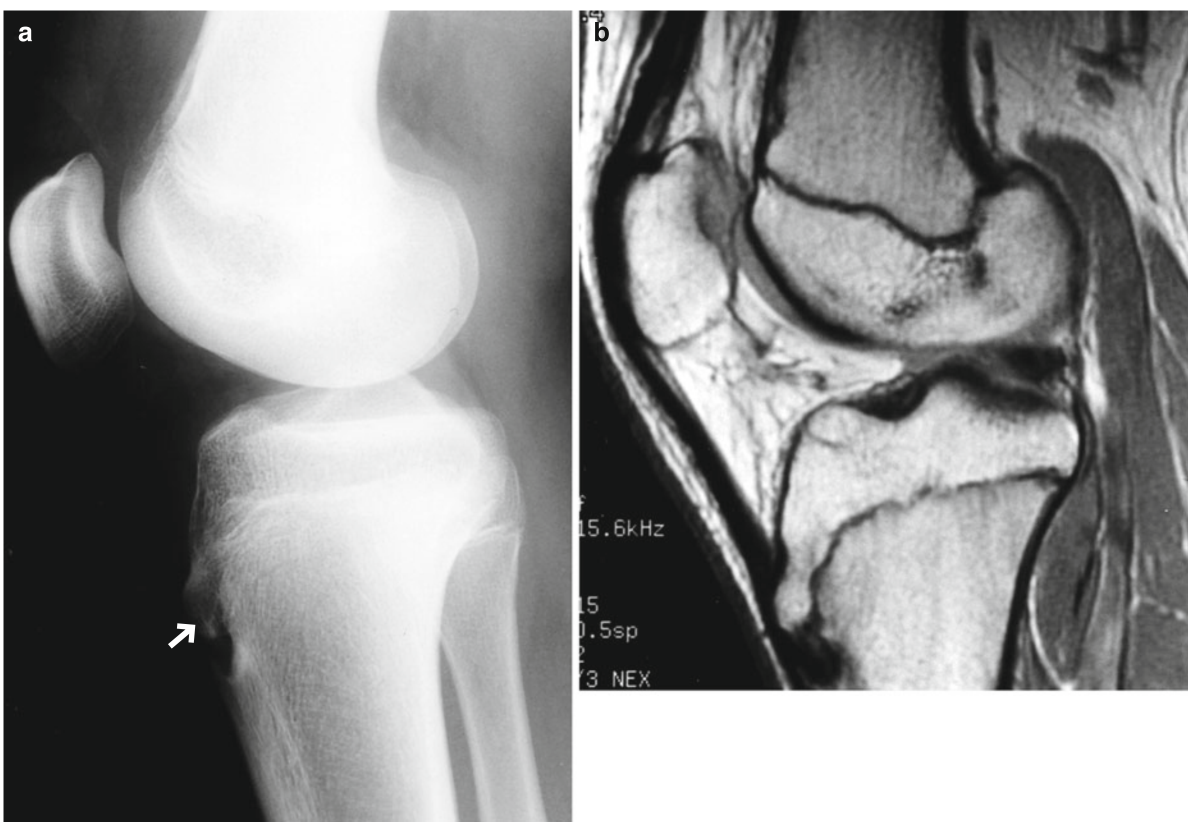

Fig. 9.12 Osgood-Schlatter disease. A man in his late teens. (**a**) Lateral radiograph and (**b**) PDWI. There is a bony swelling (*arrow*) at the tibial tuberosity. There is no patellar tendon abnormality on MRI

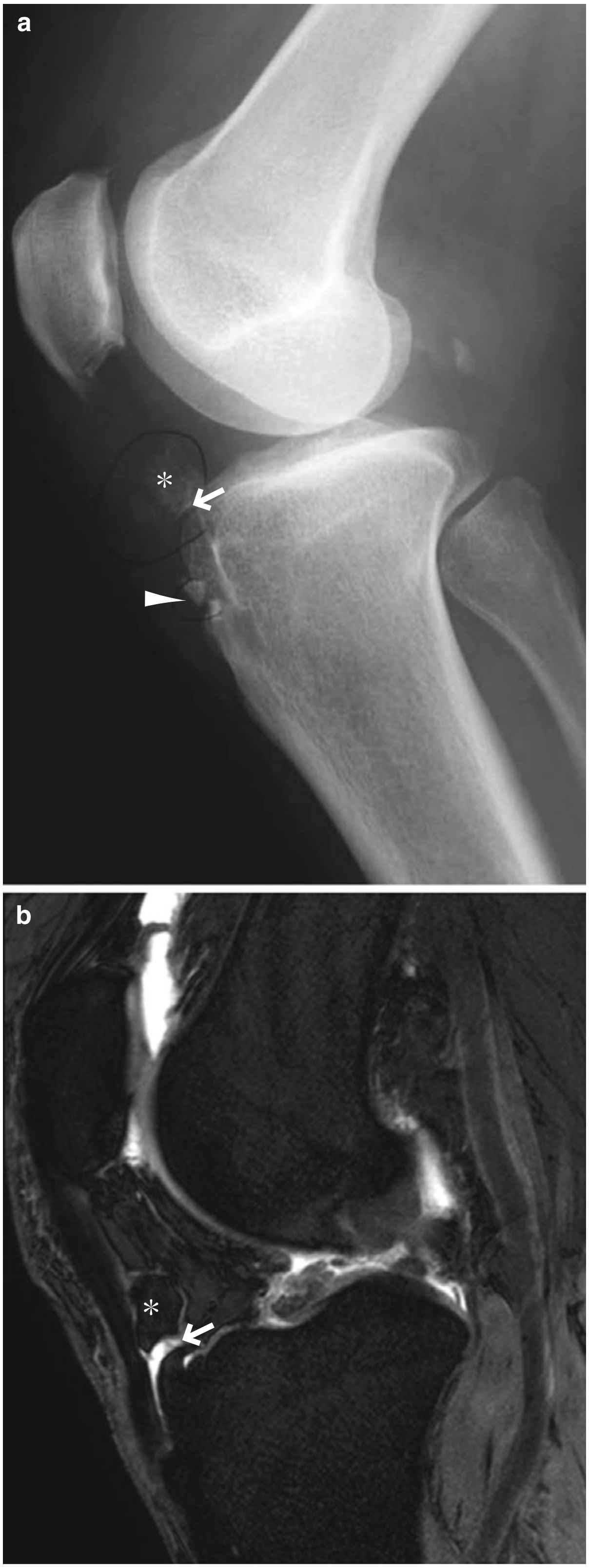

Fig. 9.13 Osgood-Schlatter disease. A man in his 50s. (**a**) Lateral radiograph and (**b**) T2*WI. There is a bony fragment just superior to the tibial tuberosity (*). The fragment is detached from the tibia, as demonstrated by the presence of joint fluid between it and the tibia (*arrow*), and instability was suspected (although the patient was asymptomatic). There is another small bony fragment inferior to the aforementioned lesion (*arrowhead*) (Images courtesy of Dr. Koichi Sato, Sato Orthopaedic Clinic, Japan)

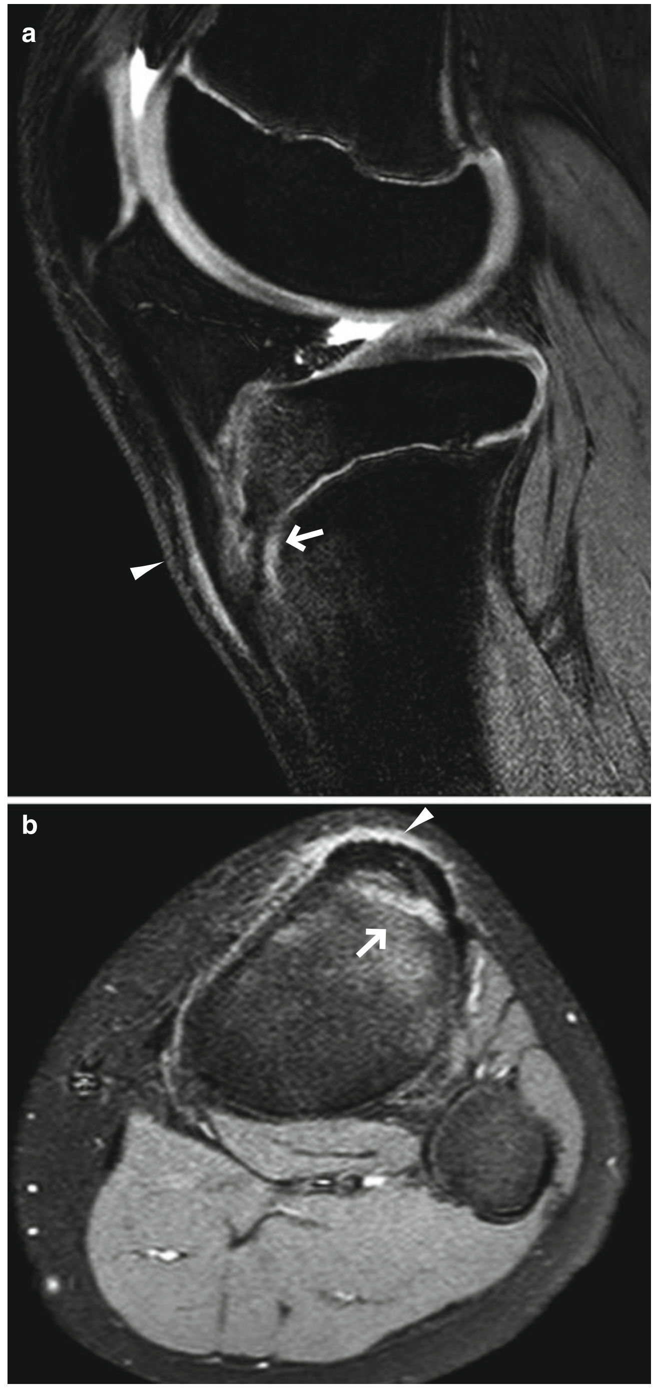

Fig. 9.14 Osgood-Schlatter disease with suspected inflammation. An 11-year-old boy. (**a**) FS T2*WI and (**b**) axial FS PDWI. There is a mild bony swelling at the tibial tuberosity and edematous changes involving epiphysis (*arrows*). There is edematous swelling subcutaneously and at the patellar tendon attachment site (*arrowheads*)

9.6 Sinding-Larsen-Johansson Disease

- Sinding-Larsen-Johansson disease (SLJ) affects the proximal end of the patellar tendon as it inserts into the inferior pole of the patella. It represents a chronic traction injury of the immature osteotendinous junction.
- Its pathogenesis is thought to be similar to that of Osgood-Schlatter disease.
- Common in 10–14-year-old boys.
- On radiograph, dystrophic calcification/ossification may be seen at the inferior pole of the patella (Fig. 9.15).
- Its radiographic appearance resembles that of patellar sleeve fracture (see Chap. 8), but the abnormal ossification resolves within a few months. Also, point tenderness and pain on exercise at the inferior pole of the patella are present at presentation, but they also resolve within a few months following restriction of exercise.

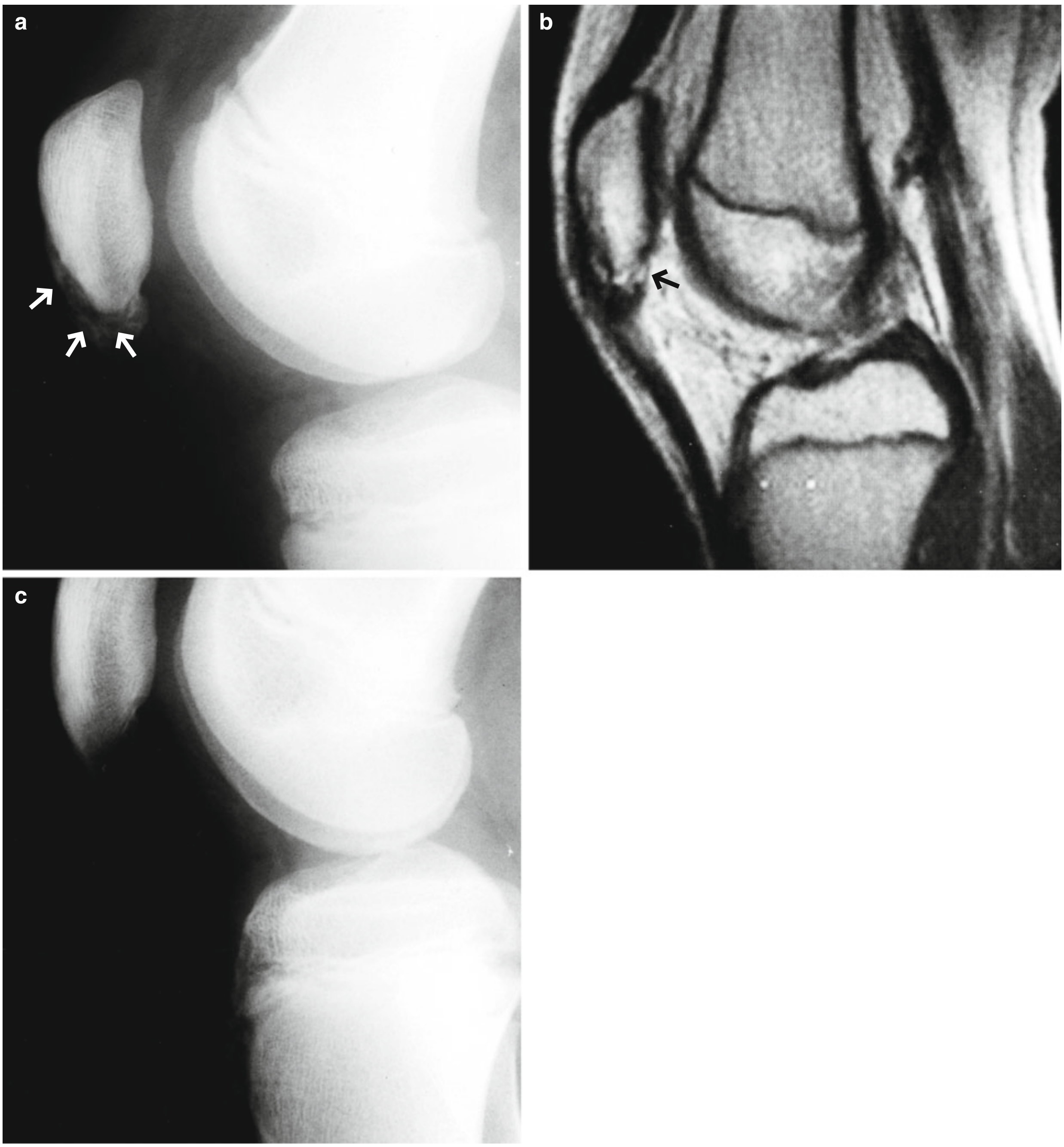

Fig. 9.15 Sinding-Larsen-Johansson disease. A 10-year-old boy. (**a**) Lateral radiograph and (**b**) T2WI at presentation. (**c**) Lateral radiograph taken 1 year later. Dystrophic ossification is seen at the inferior pole of the patella (*arrows*), and the differential diagnoses includes SLJ and patellar sleeve fracture. On MRI, there is abnormal hyperintensity and irregularity at the inferior pole of the patella (*arrow*). One year later, the abnormal findings seen at presentation are not present (Image courtesy of Dr. Atsushi Hirano, Department of Orthopaedics, Mito Kyoto Hospital, Japan)

References

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Gardiner JS, McInerney VK, Avella DG, Valdez NA. Pediatric update #13. Injuries to the inferior pole of the patella in children. Orthop Rev. 1990;19:643–9.

9.7 Jumper's Knee

- Jumper's knee is a relatively common cause of pain in the inferior patellar region in athletes who are involved in jumping sports such as basketball and volleyball. Tenderness and pain on exercise are caused by patellar tendinitis.
- Its pathologic mechanism is thought to be due to intrasubstance microtear, fibroid necrosis, and mucoid degeneration of the patellar tendon.
- Mostly occurs in athletes under age 40 and more common in men than women.
- It is a chronic patellar tendinitis and does not include acute injury or inflammation.
- Jumper's knee is also used as a general term including Osgood-Schlatter disease, SLJ disease, and quadriceps femoris tendinitis, but strict definition of jumper's knee refers only to chronic patellar tendinitis.

Fig. 9.16 Patellar tendinitis. A woman in her 40s. FS T2WI. Swelling and intrasubstance hyperintensity of the patellar tendon is seen for its entire length (*arrows*). Inflammatory changes are also seen extending into Hoffa's fat pad

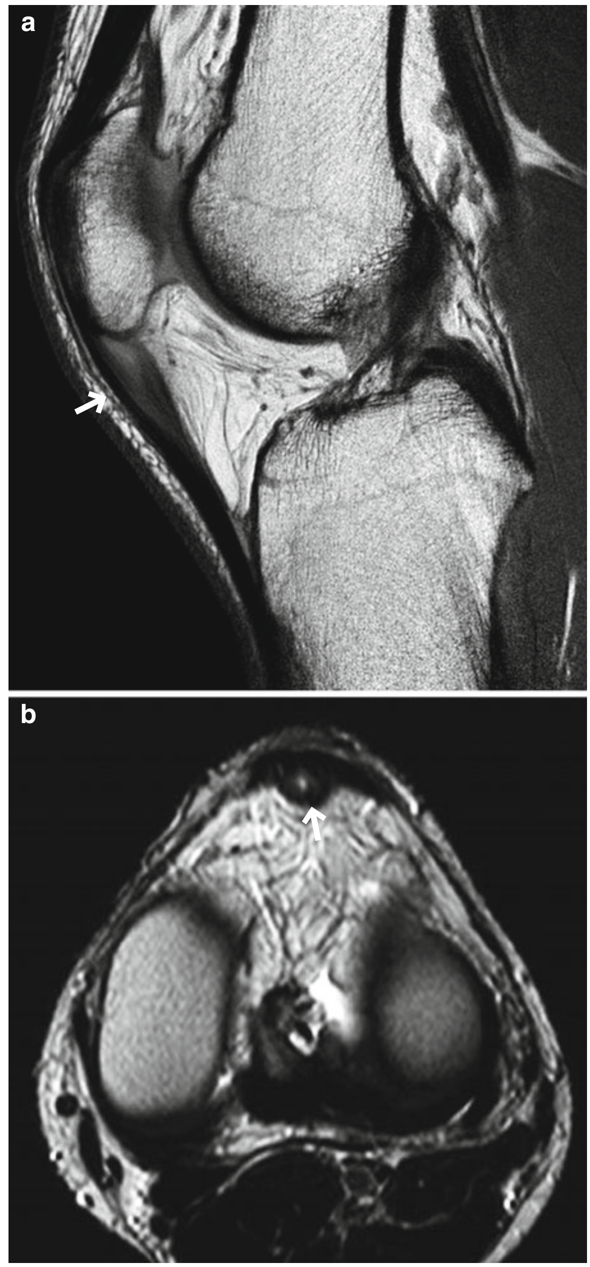

Fig. 9.17 Patellar tendinitis. A man in his 30s. (**a**) PDWI and (**b**) axial T2WI. Swelling and hyperintensity are present at the proximal portion of the patellar tendon (*arrow*). Axial image shows the signal changes are seen in the posteromedial part of patellar tendon

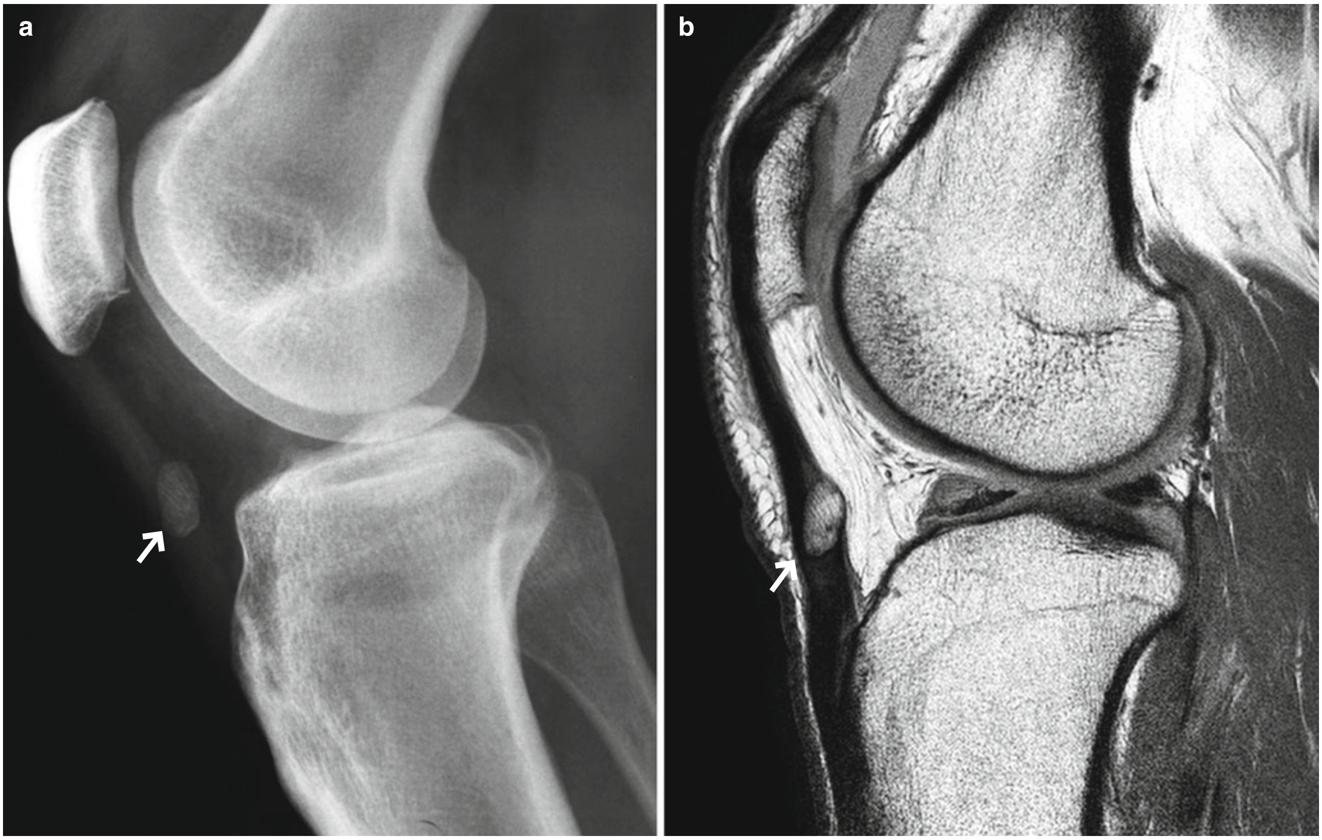

Fig. 9.18 Stone-like calcification within the patellar tendon. A man in his 40s. (**a**) Lateral radiograph and (**b**) PDWI. Within the patellar tendon, there is a 10-mm stone-like calcification within the patellar tendon (*arrows*) (Images courtesy of Dr. Motosugi, Kaijo Building Orthopaedic Clinic, Japan)

- Fat-suppressed MRI is useful to detect early disease (Fig. 9.16). Signal abnormalities and thickening are detected on the posteromedial part of patellar tendon (Fig. 9.17).
- Radiographs may not show any abnormality, but may occasionally show localized calcification. Rarely, intrasubstance stone-like calcification or ossification is seen within the patellar tendon (Fig. 9.18).

References

El-Khoury GY, Wira RL, Berbaum KS, et al. MR imaging of patellar tendinitis. Radiology. 1992;184:849–54.

Yu JS, Popp JE, Kaeding CC, Lucas J. Correlation of MR imaging and pathologic findings in athletes undergoing surgery for chronic patellar tendinitis. AJR. 1995;165:115–8.

9.8 Blount Disease

- Developmental disorder of the posteromedial aspect of the proximal tibial physis, epiphysis, and metaphysis.
- Growth plate is partially disrupted because of physeal bar formation.
- Results in tibia vara.
- Etiology is unknown, but is thought to be trauma or dysplasia. Deformity of medial epiphyseal plate and its early closure lead to beak-like deformity and segmentation of the proximal tibial metaphysis.
- Seen in children aged 2 or above, and if the deformity is mild, it may naturally be resolve in adolescence.
- MRI enable direct visualization of the epiphyseal plate (Fig. 9.19).

References

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Borsa JJ, Peterson HA, Ehman RL. MR imaging of physeal bars. Radiology. 1996;199:683–7.

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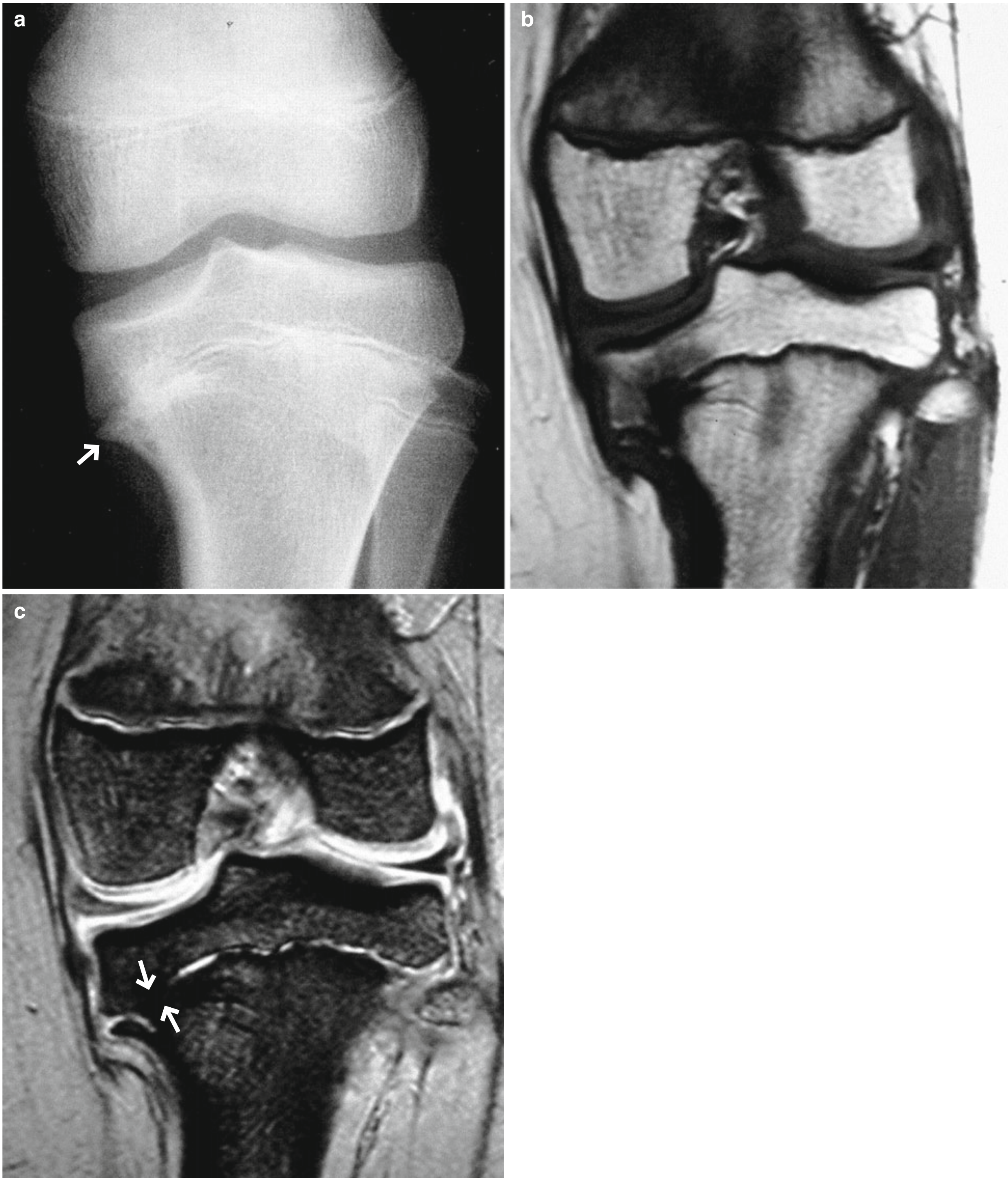

Fig. 9.19 Blount disease. A 9-year-old girl. (**a**) Anteroposterior radiograph, (**b**) coronal T1WI, and (**c**) T2*WI. Medial tibial epiphysis and metaphysis shows irregularity and beak-like deformity (*arrow*) on radiograph. MRI demonstrates early closure of epiphyseal plate, as shown by loss of epiphyseal cartilage signal (*arrows*, **c**)

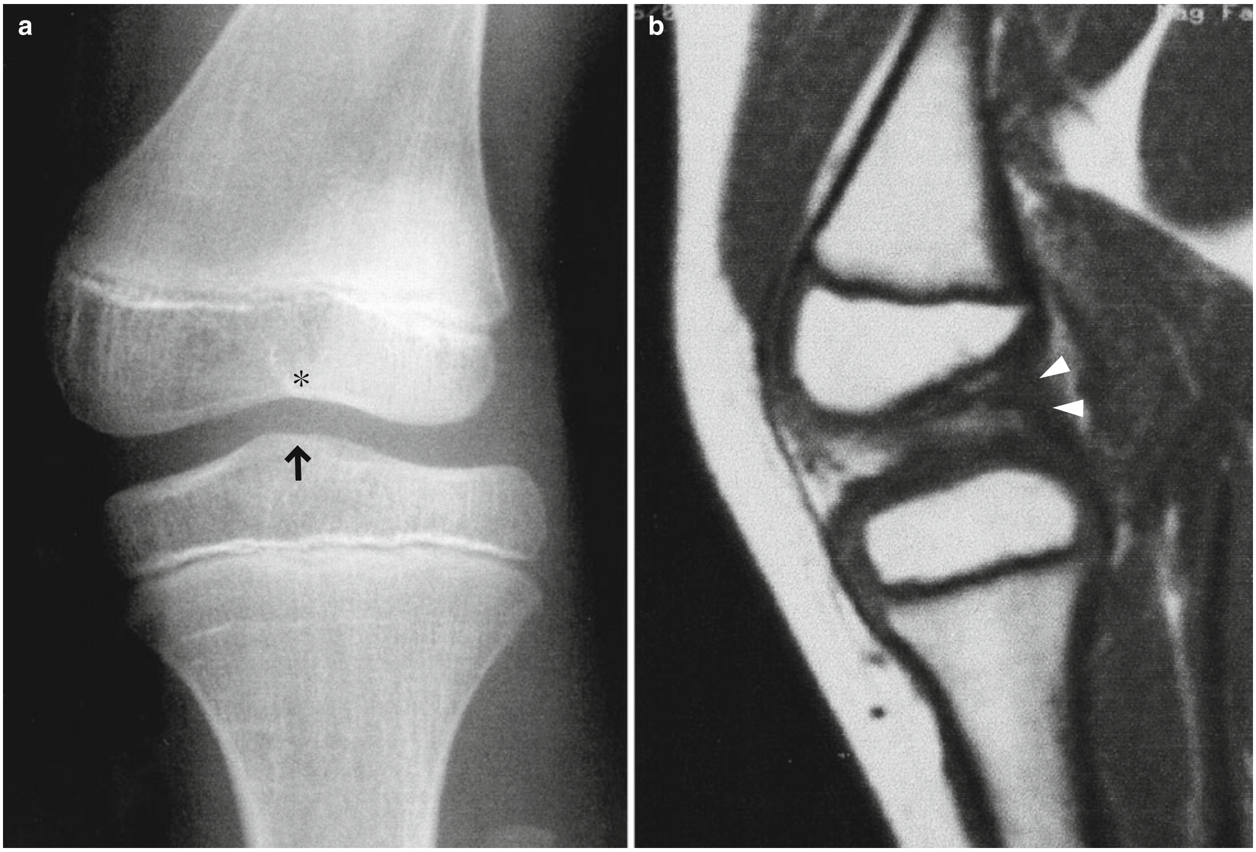

Fig. 9.20 **Congenital absence of the ACL**. An 8-year-old girl. (**a**) Anteroposterior radiograph and (**b**) T1WI. Hypoplasia of the lateral femoral condyle and the intercondylar space (*) are present. Intercondylar eminence is unimodal rather than bimodal (which is normal). Consequently, tibia becomes abnormally short. MRI shows absence of ACL, but PCL is present (*arrowheads*)

9.9 Congenital Absence of the ACL

- Rarely, absence or hypoplasia of ACL is present.
- PCL may be missing simultaneously.
- Commonly associated with congenital developmental disorder of the knee joint or the lower limbs.
- Intercondylar eminence may be missing or deformed (Fig. 9.20).
- Commonly asymptomatic, but as the patient grows older, signs of ACL absence such as anterior drawer sign may appear.

10 Osteoarthritis and Bone Marrow Signal Changes

10.1 Osteoarthritis

- Osteoarthritis (OA) is a joint disease represented by degeneration of cartilage, meniscus, subchondral bone, and other tissues due to ageing and mechanical load, abnormal proliferation of synovium, and bone and cartilage overgrowth.
- Of all joints of the body, the tibiofemoral joint of the knee is the most commonly affected site.
- Common in elderly women.
- Medial knee OA and varus deformity due to a loss of the medial joint space is more common than lateral knee OA.

Key points for MRI interpretation

- Joint space narrowing, osteophyte formation, sclerosis of subchondral bone, and cyst formation, all of which can also be detected by radiography. MRI-specific findings include articular cartilage thinning and loss, meniscal damage, and degeneration (Fig. 10.1).
- Due to the high frequency of medial knee OA, deformity, and degeneration of the middle and posterior segments of the medial meniscus is frequently seen.
- Joint effusion is commonly seen, reflecting the presence of cartilage and meniscal lesions (Fig. 10.2). Joint fluid in OA

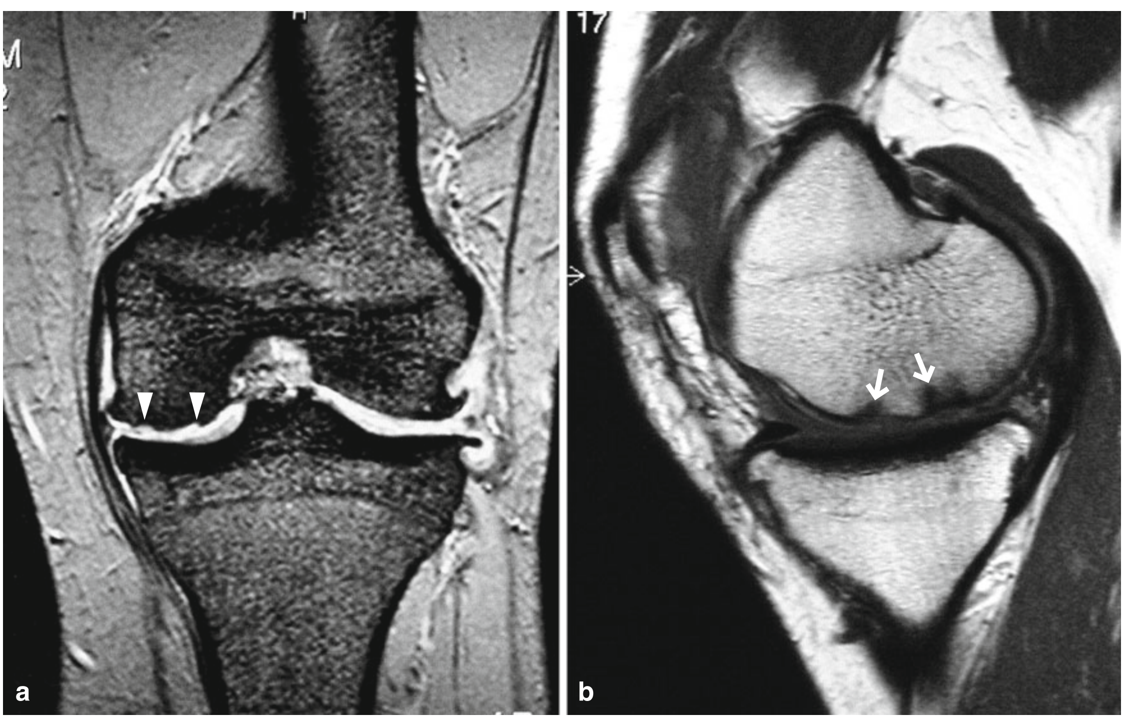

Fig. 10.1 **Knee osteoarthritis**. A woman in her 50s. (**a**) Coronal T2*WI and (**b**) PDWI. Medial joint space narrowing and the osteophyte formation are seen in the tibiofemoral joint. In the weight-bearing part, there is articular cartilage thinning (*arrowheads*), and subchondral sclerosis (*arrows*), degenerative tear, and loss of meniscus are seen

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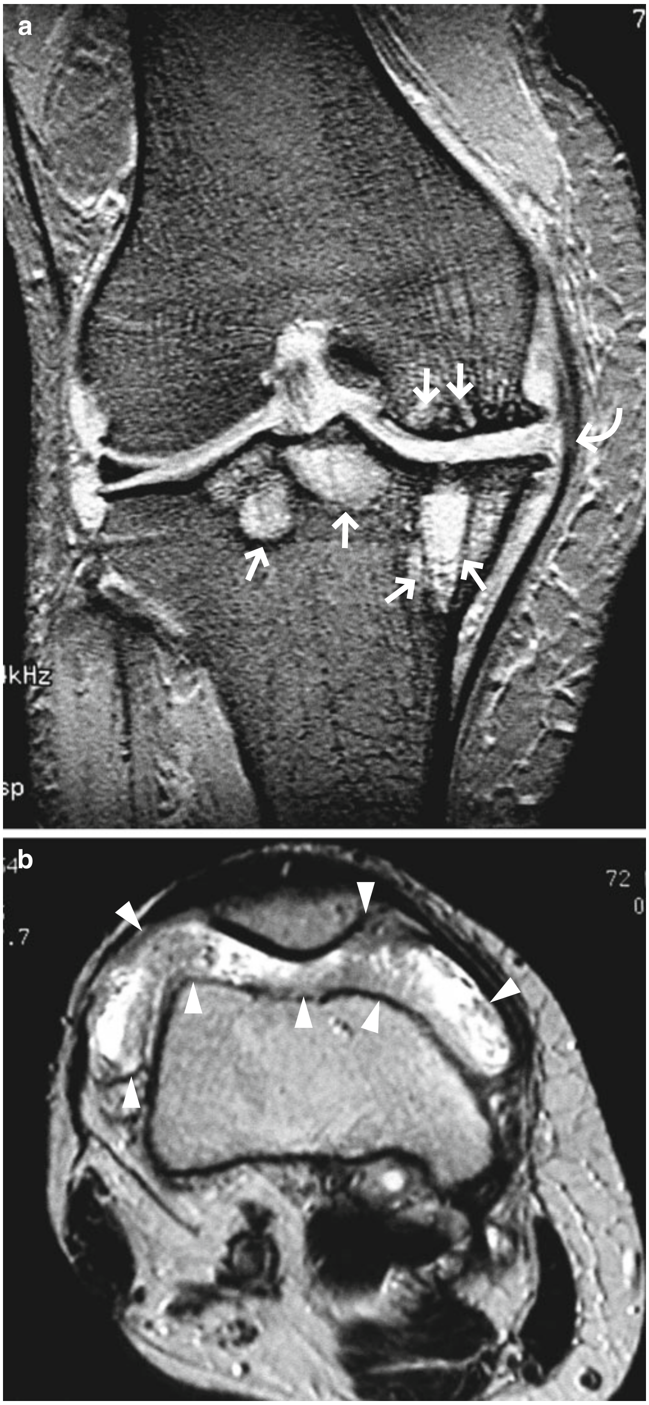

Fig. 10.2 **OA and joint effusion**. A woman in her 70s. (**a**) Coronal T2*WI and (**b**) axial T2WI. There are numerous subchondral cysts mainly in the medial tibiofemoral joint (*arrows*). MCL is extended in a bow shape due to the presence of medial osteophytes (*curved arrow*). Medial meniscus is severely degenerated and is almost completely macerated, but the medial joint space is not completely lost. A large amount of joint effusion is present together with proliferated synovium (*arrowheads*). Differential diagnosis may include synovial disorders such as pigmented villonodular synovitis in certain cases

is clear, but MRI may show mucoid or mass-like signal changes within the joint space filled with effusion, representing secondary changes in a chronic stage. Proliferated synovium and denuded bone are prone to bleeding, and idiopathic hemarthrosis will recur in severe OA. In such cases, differential diagnoses include inflammatory arthritis and synovial disorders such as pigmented villonodular synovitis.

Reference

Hayashi D, Guermazi A, Crema MD, Roemer FW. Imaging in osteoarthritis: what have we learned and where are we going? Minerva Med. 2011;102:15–32.

Intra-articular loose body

- In chronic OA, ossified loose bodies may be found within the joint (Fig. 10.3)
- It may appear as if it is continuous with an osteophyte (bony spur)
- Loose bodies may freely move within the joint and may become stuck in a joint space, causing pain and limitation of range of joint movement.
- Intra-articular loose bodies may also be associated with chronic arthritis, OCD, osteochondral fracture, and synovial osteochondromatosis.

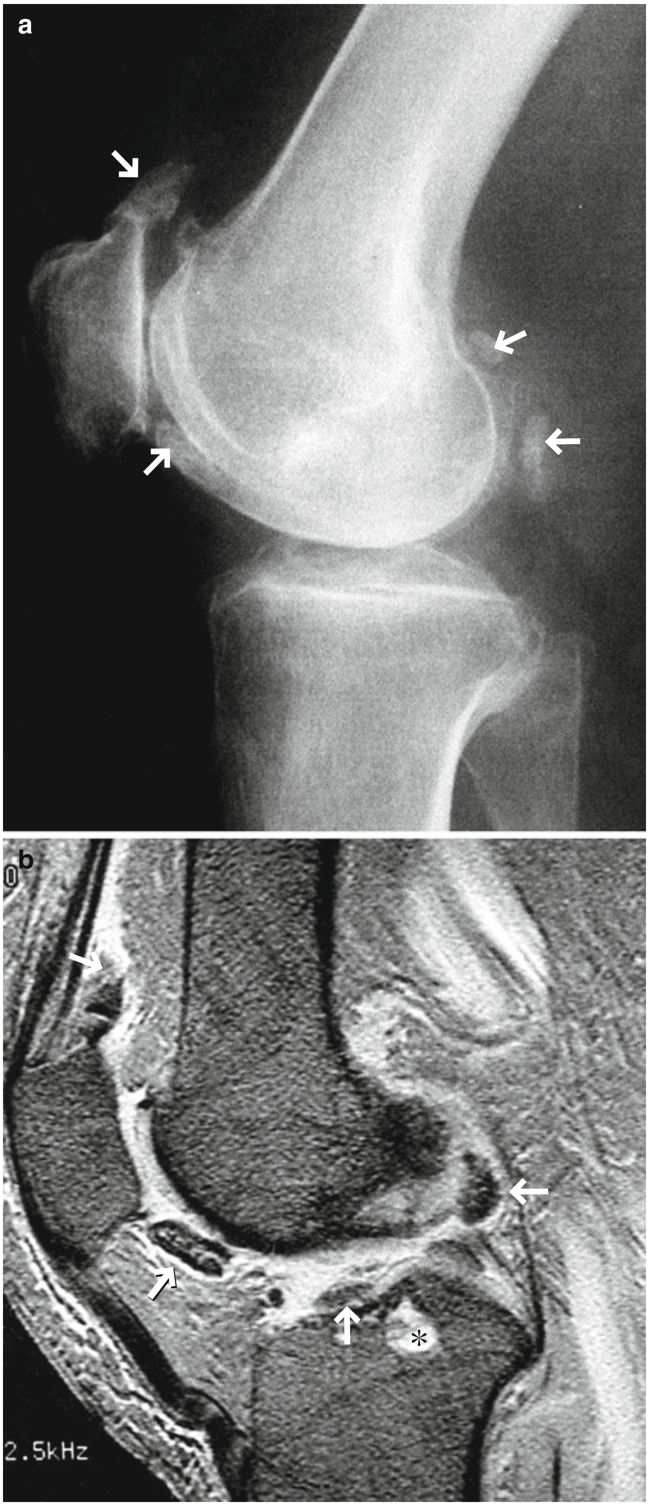

Fig. 10.3 **Intra-articular loose body associated with OA**. A woman in her 70s. (**a**) Lateral radiograph and (**b**) T2*WI. A large osteophyte is seen at the superior pole of the patella. There are multiple intra-articular ossifications representing loose bodies (*arrows*), which show signal void on MRI. * subchondral cyst

10.2 Spontaneous Osteonecrosis/Subchondral Insufficiency Fracture

- Occurs specifically in the weight-bearing portion of the medial femoral condyle (see Chap. 8 for differential diagnosis with OCD).
- Precise cause is unknown, but it is thought to be due to mechanical load and meniscal damage.
- Spontaneous osteonecrosis is common in elderly women. However, subchondral insufficiency fracture seems to be more common in middle-aged men.
- May be triggered by excessive intake of alcohol and the use of steroid.
- Most of the spontaneous osteonecrosis is thought to occur following subchondral insufficiency fracture.
- Pain without any trigger may be experienced at night.
- On radiograph, no obvious pathologic findings are seen at an early stage. When the disease reaches an advanced stage, a characteristic lucency surrounded by a sclerotic rim is seen. If the diseases progresses further, there will be joint space narrowing and osteophyte formation, showing OA-like appearance.

References

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Lecouvet FE, van de Berg BC, Maldague BE, et al. Early irreversible osteonecrosis versus transient lesions of the femoral condyles: prognostic value of subchondral bone and marrow change on MR imaging. AJR. 1998;170:71–7.

Key points for MRI interpretation

- Visualization of spontaneous osteonecrosis at a very early stage is possible.
- Necrotic part shows hypointensity on T1-weighted image, representing loss of normal fatty marrow which shows hyperintensity on T1-weighted image. Deformity and loss of articular cartilage and subchondral bone are delineated (Fig. 10.4).
- In subchondral insufficiency fracture, there is a small lens-like hypointensity in the subchondral bone and the surrounding bone marrow edema at the time of onset. The edema will later regress and may form cystic lesions. Later on, cortical depression will be the only remaining feature (Fig. 10.5).

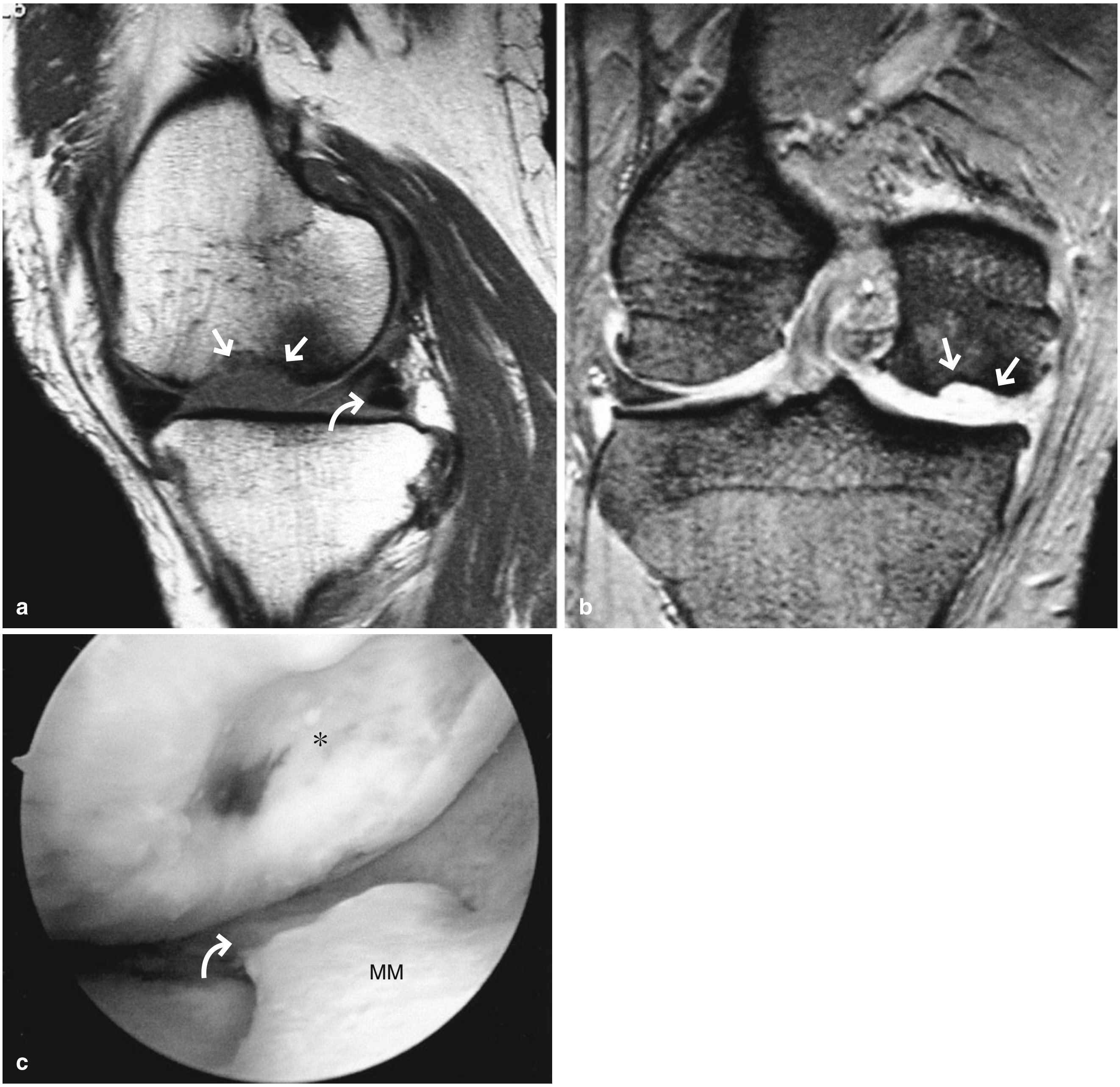

Fig. 10.4 Spontaneous osteonecrosis. A man in his 50s. (**a**) PDWI, (**b**) coronal T2*WI, and (**c**) arthroscopic image. There is a large defect of articular cartilage and subchondral bone at the weight-bearing portion of the medial condyle (*arrows*), and denuded trabecular bone is visible (*). There is a degenerative tear in the posterior segment of the medial meniscus (*curved arrows*)

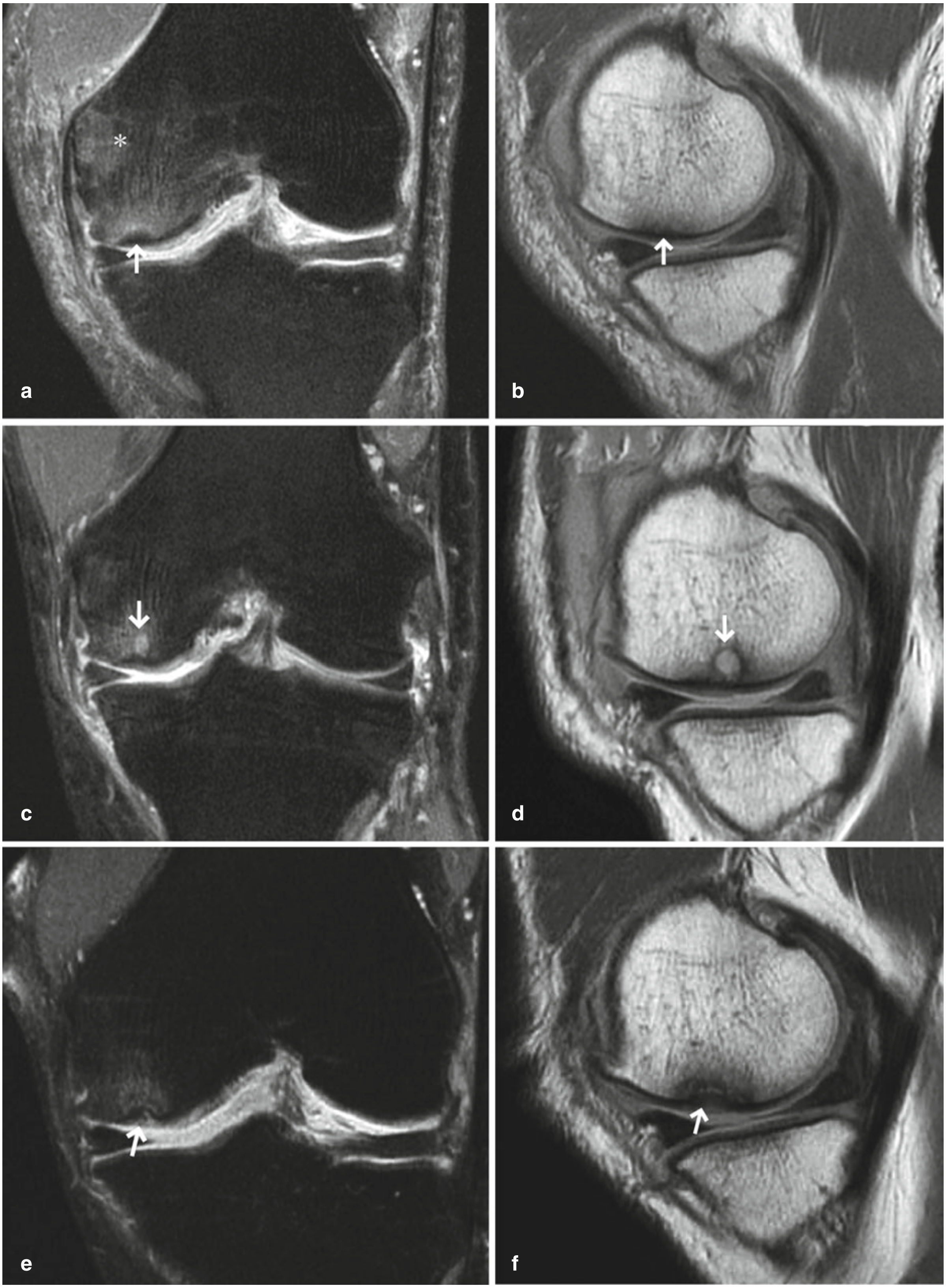

Fig. 10.5 Subchondral insufficiency fracture. A man in his 60s. (**a**) Coronal FS PDWI and (**b**) PDWI at the time of onset. (**c**, **d**) Taken 6 months later. (**e**, **f**) Taken 1.5 years later. At the time of onset, there is a small lens-like hypointensity in the subchondral bone of the anterior weight-bearing portion of the medial femoral condyle (*arrows*, **a**, **b**). It is surrounded by bone marrow edema (*). Six months later, the edema regressed and a cystic lesion appeared (*arrows*, **c**, **d**). One and a half years later, the only remaining finding is the cortical depression (*arrows*, **e**, **f**)

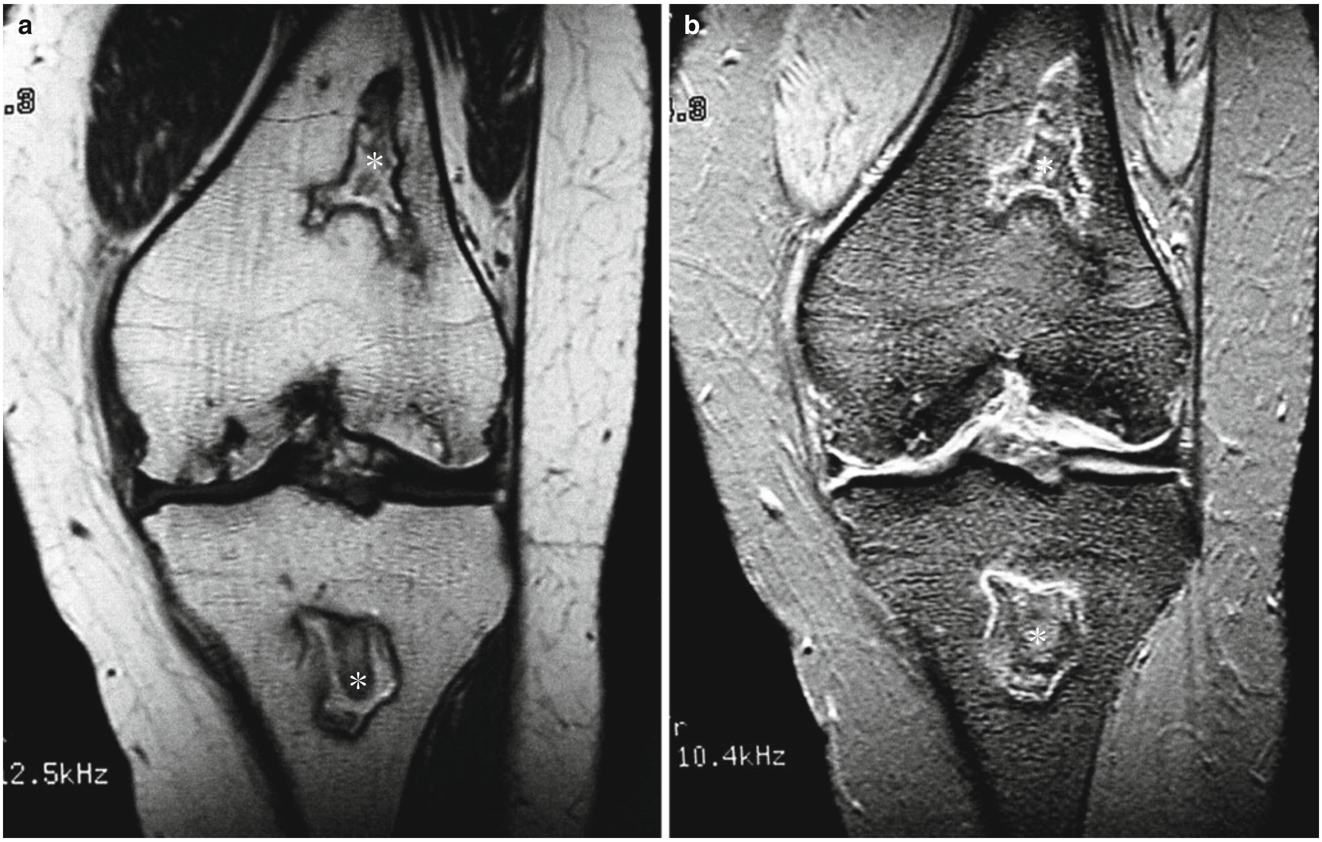

Fig. 10.6 **Steroid-induced osteonecrosis**. A woman in her 20s, receiving systemic steroid therapy to treat systemic lupus erythematosus. (**a**) Coronal T1WI and (**b**) coronal T2*WI. Necrotic foci are present in the medial and lateral condyle of the femur and tibia, suggesting this is a systemic lesion. The lesion has a rim which shows hypointensity on T1WI and hyperintensity on T2WI, and itself shows inhomogeneous hyperintensity on T1WI (*)

Steroid-induced osteonecrosis

- In patients receiving systemic steroid therapy to treat disease such as systemic lupus erythematosus, systemic sclerosis, rheumatoid arthritis, and post-organ transplantation status, characteristic osteonecrosis occurs, which is distinctly different from spontaneous osteonecrosis.
- The lesion may be present bilaterally, more likely in the lateral than the medial condyle of the femur and tibia. Individual lesion may be large, and its shape is irregular.
- On MRI, the lesion has a rim which shows hypointensity on T1-weighted image and hyperintensity on T2-weighted image. The lesion itself shows inhomogeneous hyperintensity on T1-weighted image, suggestive of fatty necrosis (Fig. 10.6).

10.3 Bone Marrow Reconversion

- Bone marrow around the knee converts from the red (hematopoietic) marrow to the yellow (fatty) marrow as ageing occurs.
- Fatty marrow may reconvert to hematopoietic marrow when a person is subjected to an increased need for hematopoiesis due to severe anemia or other conditions.
- Reconversion starts from the proximal to the distal part of a long bone. Conversely, conversion from the distal to the proximal part.
- Faint areas of hypointensity are present within the hyperintense fatty bone marrow on T1-weighted image or T2-weighted FSE image (Fig. 10.7).
- Histologically, this phenomenon is called hematopoietic hyperplasia. This phenomenon can also be seen in marathon runners who are subjected to strenuous exercise.
- Incidental finding on MRI may (unnecessarily) lead to bone marrow biopsy. However, differentiating this from hematological malignancy such as leukemia on the basis of MRI alone is difficult.

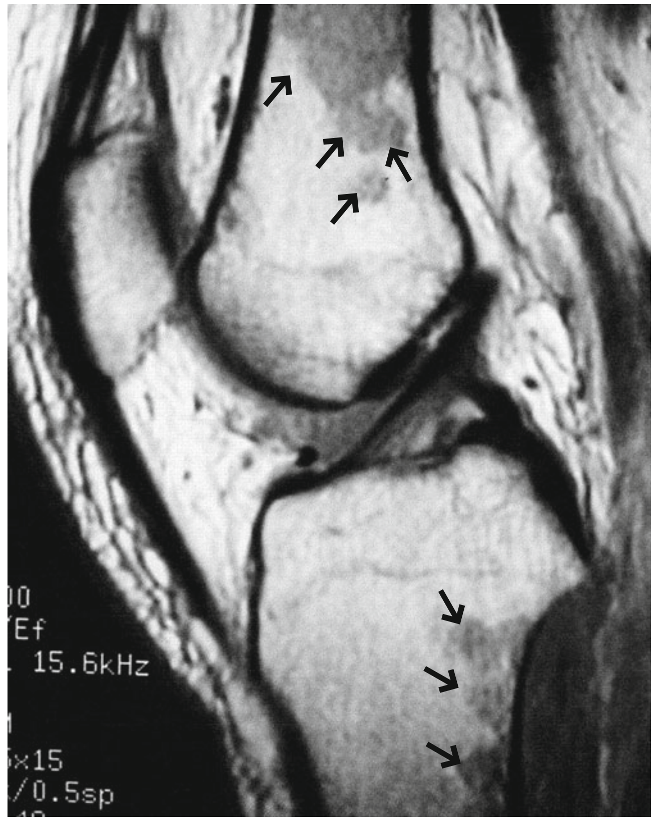

Fig. 10.7 Bone marrow reconversion. A woman in her 40s with a long-term history of severe anemia due to uterine myoma. PDWI shows areas of hypointensity that replace normal fatty marrow (hyperintensity) in the femur and tibia (*arrows*)

References

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Indication of MRI for Imaging of OA

Traditionally, knee MRI has been indicated for imaging diagnosis of trauma such as ligamentous and meniscal injuries in young persons. However, in recent years (in Japan), an increasing number of elderly patients are undergoing knee MRI. This is a result of widespread availability of MR systems in clinical practice. Within the limited amount of examination slots, patients with life-threatening conditions such as cancers and stroke were of course given priorities, and imaging of treatable knee trauma was performed when there were available slots. Nowadays, modern MRI techniques enable improved delineation of articular cartilage, and thus MRI has become increasingly used for imaging of knee OA. Meniscal tear associated with OA can also be diagnosed and treated appropriately, relieving patients of symptoms. Considering the fact that the life expectancy of the Japanese population is rising, use of MRI on elderly patients is expected to rise even further.

11 Disorders of Synovium and Plica

11.1 Pigmented Villonodular Synovitis (PVS)

- Villous and nodular synovial proliferative disease.
- Cause is unknown, but is thought to be related to inflammation and fatty acid metabolism disorder.
- Common in young persons (20–40 years old).
- Commonly affects large joints and the knee is the most common site.
- Usually takes a monoarticular form.
- It can be classified into localized type (Fig. 11.1) in which localized synovial masses form, and diffuse type (Fig. 11.2) in which there is diffuse synovial proliferation with some nodules.
- The lesion may erode into the bone and form a cyst-like lesion.
- Clinically, the disorder is characterized by joint swelling with no known trigger, and joint aspirates contain blood.

Fig. 11.1 Pigmented villonodular synovitis, localized type. A man in his 50s. (**a**) PDWI, (**b**) T2*WI, and (**c**) intraoperative photo. There is a mass lesion eroding into the Hoffa's fat pad (*). Within the joint space, there is synovial proliferation with hemosiderin deposition showing hypointensity (*arrows*). The mass lesion had a *yellowish* color and proliferated synovium contains *black* spots representing bleeding (*arrowheads*)

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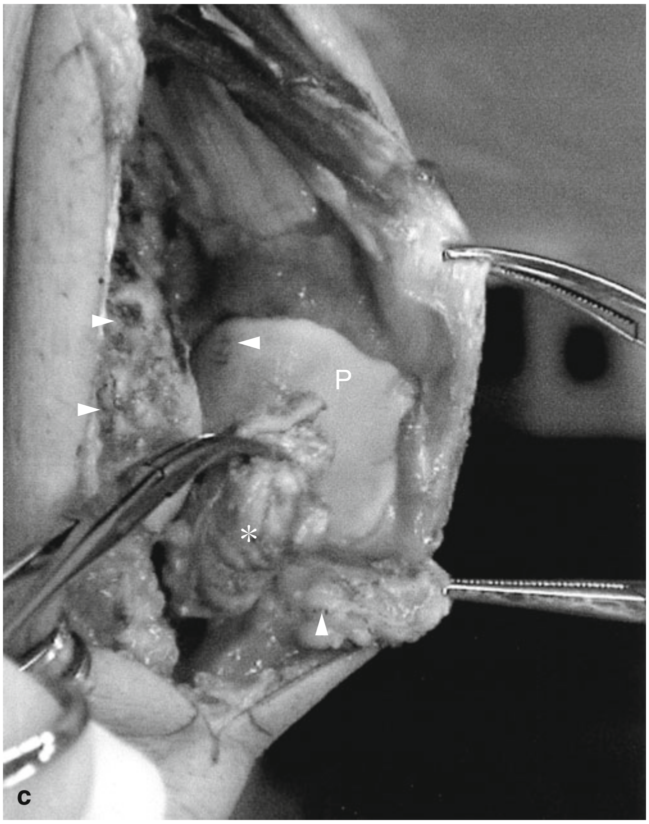

Fig. 11.1 (continued)

- Treatment is surgical removal, but if it is not completely removed, recurrence commonly occurs. It is therefore important to search for the full extent of the lesion on MRI.

Key points for MRI interpretation

- Joint space is filled by soft tissue due to synovial proliferation. Gadolinium contrast-enhanced MRI shows strong enhancement of the proliferated synovium. Due to hemosiderin deposition, the lesion shows hypointensity on T2-weighted image, particularly when gradient echo sequence (which is affected by susceptibility artifact) is used.

Reference

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11.2 Giant Cell Tumor of Tendon Sheath

- This is histologically identical to PVS described in the previous section.
- It mostly arises in the tendon sheath. In the knee joint, it commonly arises adjacent to the joint capsule.
- In old days it was called “xanthoma.”

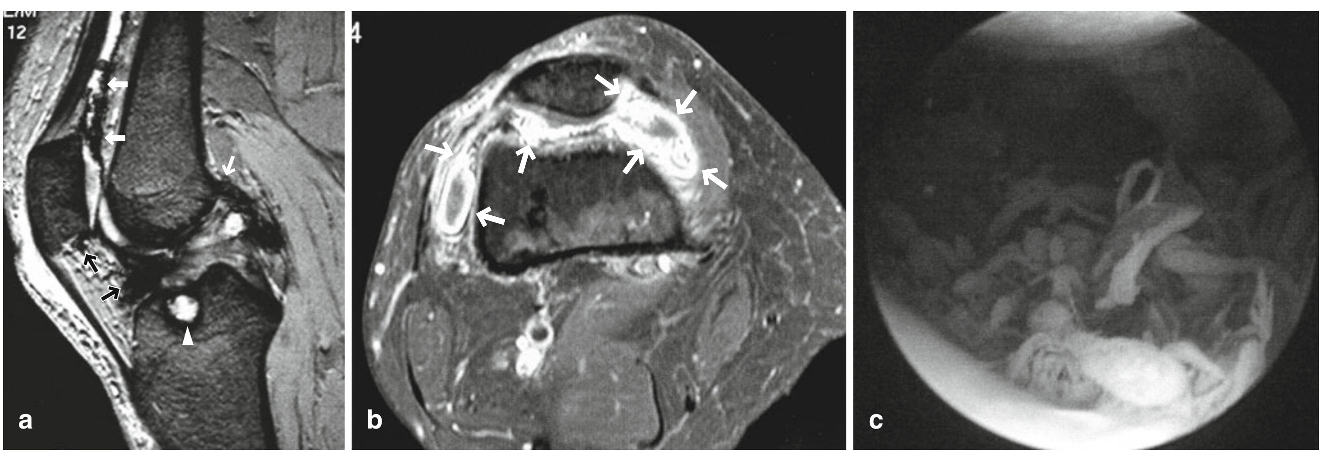

Fig. 11.2 **Pigmented villonodular synovitis, diffuse type**. A woman in her 50s. (**a**) T2*WI, (**b**) axial FS postcontrast T1WI, and (**c**) arthroscopic image. Within the joint space including the posterior joint capsule, there is diffuse synovial proliferation which shows hypointensity on T2*WI (*arrows*). There is a cystic change in the tibial plateau due to erosion of the synovium (*arrowhead*). Proliferated synovium shows strong enhancement after gadolinium injection. Arthroscopically, proliferated synovium has a villous appearance

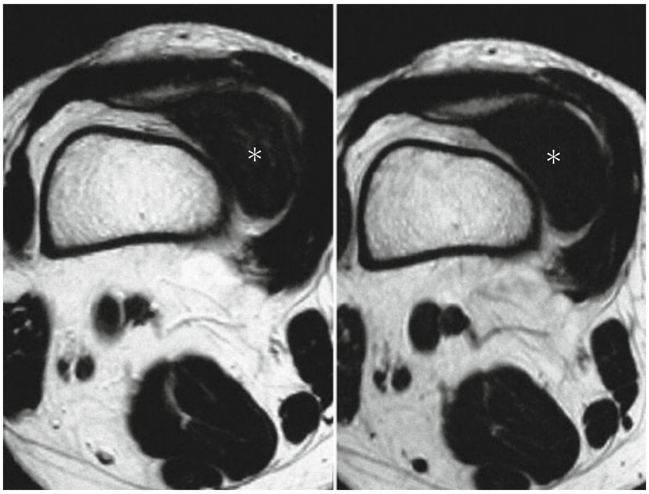

Fig. 11.3 Giant cell tumor of tendon sheath. A woman in her 50s. Axial T2WI (*left*) and T1WI (*right*). There is a mass lesion (*) which generally shows hypointensity with some faint hyperintense component on T2WI adjacent to the suprapatellar bursa. Histologically, it is proliferated synovium, which is identical to that found in PVS

11.3 Synovial Osteochondromatosis

- It is a benign condition of unknown etiology characterized by synovial nodular proliferation containing cartilaginous and osseous components.
- Common in young to middle-aged persons.
- Knee, hip, and elbow joints are most commonly affected.
- Chondroma may grow into the joint space, and fragments may break off from the synovial surface into the joint, where they may enlarge, calcify, or ossify. Appearance of such loose fragments resembles that of rice bodies seen in rheumatoid arthritis.
- Intra-articular proliferation of osteochondroma and multiple loose fragments causes widening of the joint space and overall swelling of the joint.
- Erosion of bone cortex may be seen.
- Usually monoarticular.
- If loose fragments ossify or calcify, they can be visualized on radiograph. However, this is only the case in 30–40% of cases.
- Clinically, patients initially have dull pain and swelling due to joint effusion. When loose fragments drop into the joint space, range of movement of the affected joint becomes limited and may eventually lead to osteoarthritis. Synovial proliferation is said to cease spontaneously.
- Treatment includes excision of proliferated synovium and removal of loose fragments under arthroscopy. If complete removal is not possible arthroscopically, open surgery is required. If actively proliferating synovium is not completely removed, postoperative recurrence may occur, but prognosis is good in general.

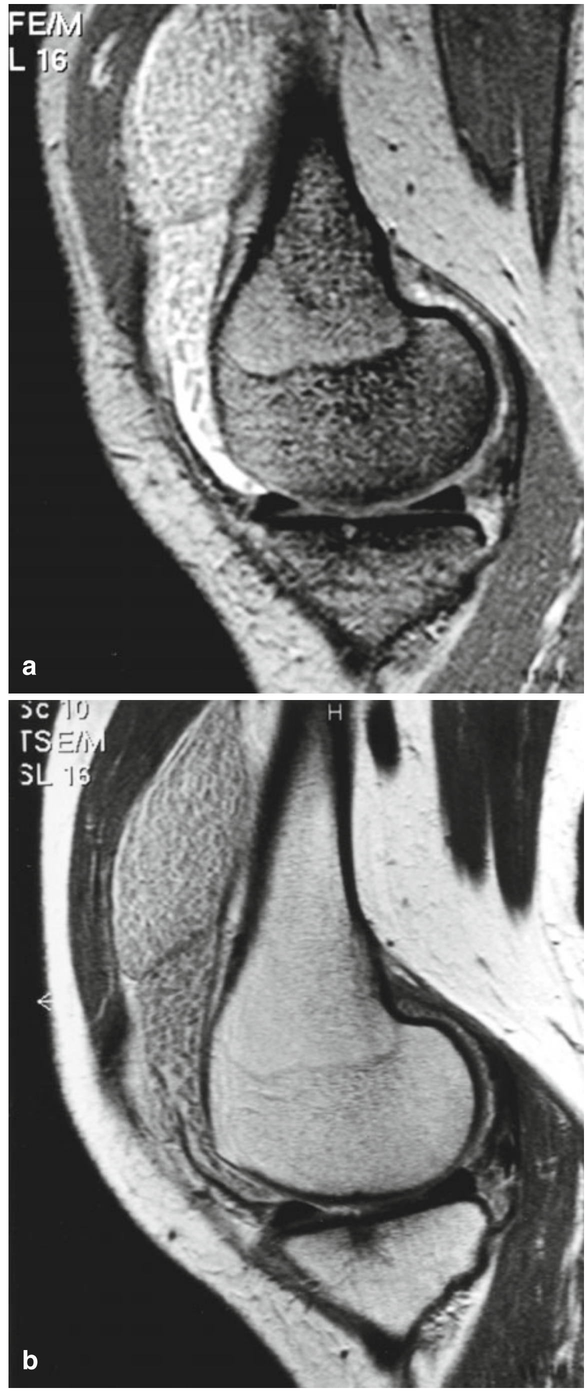

Fig. 11.4 Synovial chondromatosis. A woman in her 30s. T2*WI with MTC, (**b**) sagittal postcontrast T1WI taken 2 h after gadolinium injection, and (**c**) excised surgical specimen. Within the joint capsule, there are numerous micronodules that show signal intensity similar to that of articular cartilage (**a**). Contrast between the nodules and joint fluid can be obtained by using either MTC technique (**a**) or contrast-enhanced MRI (**b**) in which gadolinium diffuses into the joint fluid in a late phase. Proliferating synovium and loose fragments were excised arthroscopically. Numerous rice body-like micronodules (a few millimeters in size) were removed from the joint space. In this case, radiograph and CT did not reveal any ossified components, and diagnosis of synovial chondromatosis was made

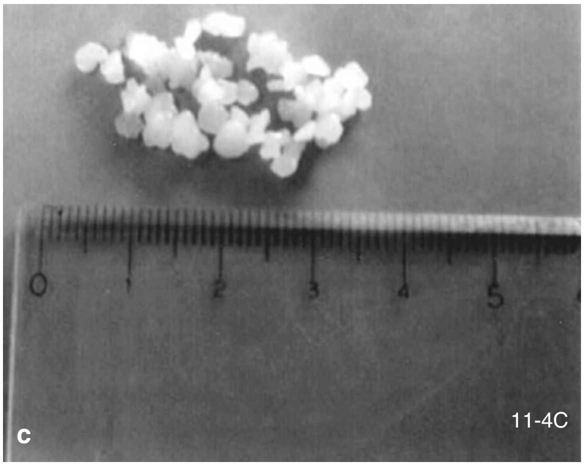

Fig. 11.4 (continued)

Key points for MRI interpretation

- Intra-articular soft tissue due to proliferation of osteochondroma is seen.
- Large osteochondroma may show heterogeneous signal intensities and may include signal void corresponding to ossified component.
- Cartilaginous component shows signal intensity similar to that of articular cartilage.
- If sufficient contrast between the cartilaginous component and joint effusion cannot be obtained, MTC technique should be applied.

Reference

Narváez JA, Narváez J, Ortega R, De Lama E, Roca Y, Vidal N. Hypointense synovial lesions on T2-weighted images: differential diagnosis with pathologic correlation. AJR. 2003;181:761–9.

11.4 Synovial Hemangioma

- Synovial hemangioma arising within the knee joint is rare.
- Histologically, it is commonly a cavernous hemangioma, or a mixture of cavernous and capillary hemangioma.
- Common in young persons.
- Repetitive intra-articular hemorrhage cause knee swelling, pain, and restricted range of motion.
- Radiograph may reveal a phlebolith.

Key points for MRI interpretation

- It shows characteristic of strong hyperintensity on T2-weighted image.
- It shows strong enhancement following gadolinium injection.
- The presence of hypointensity on T2*-weighted image reflects the hemosiderin deposition following repetitive hemarthrosis.

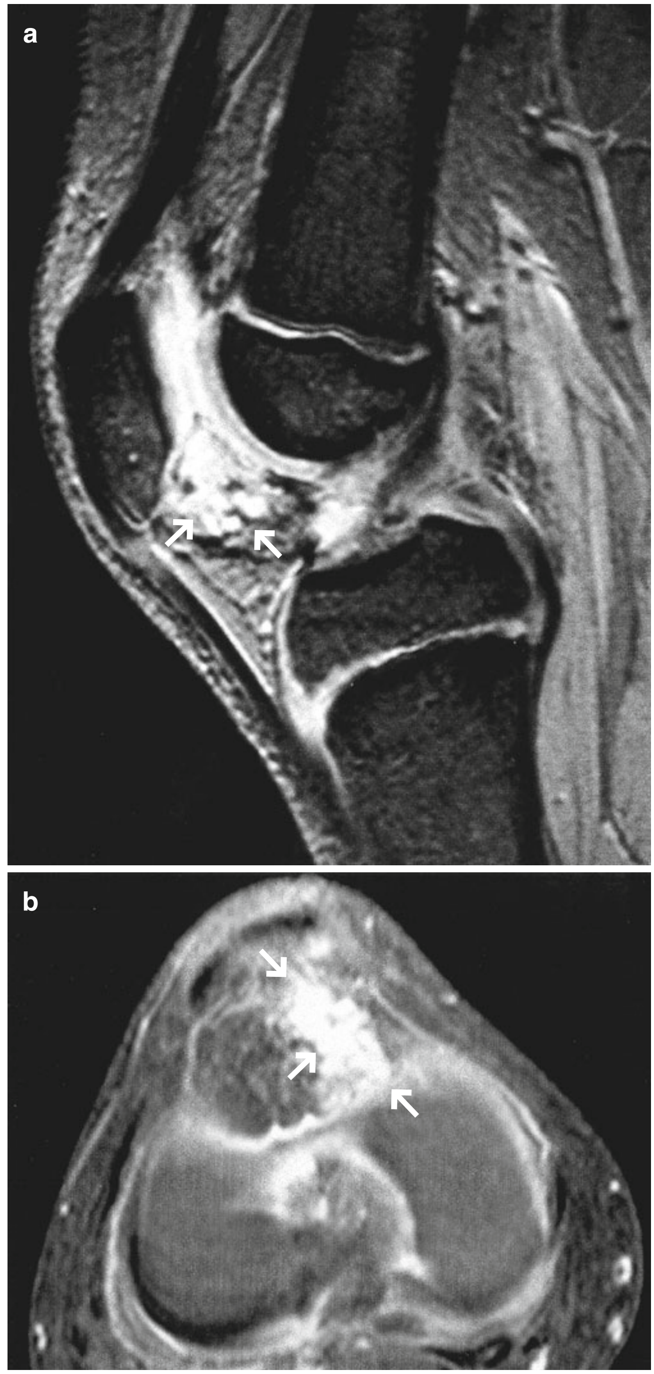

Fig. 11.5 **Synovial hemangioma**. An 8-year-old girl with history of recurrent hemarthrosis. (**a**) T2*WI and (**b**) axial gadolinium-enhanced FS T1WI. There is a multilocular mass showing hyperintensity on T2*WI eroding into Hoffa's fat pad (*arrows*, **a**). The lesion shows strong enhancement after gadolinium injection (*arrows*, **b**)

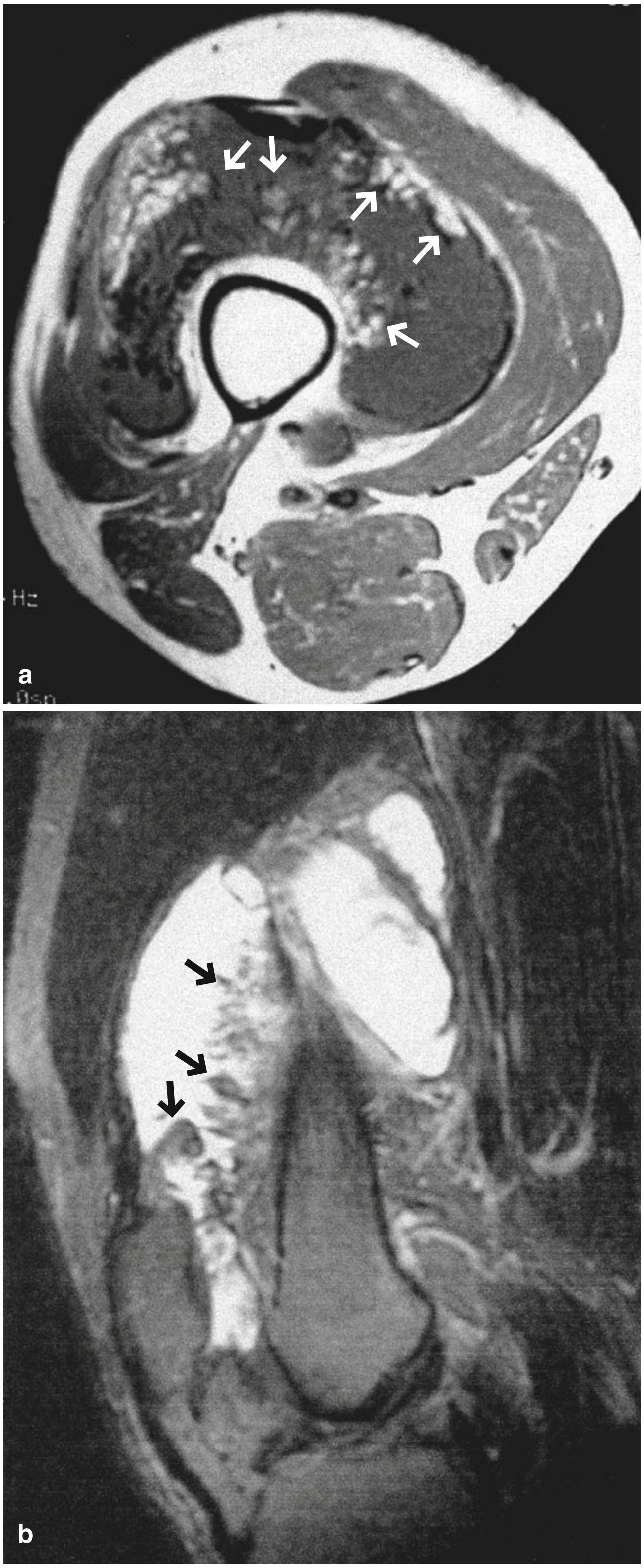

Fig. 11.6 **Lipoma arborescens**. A man in his 30s. (**a**) Axial T1WI and (**b**) FS T2WI. Synovial tissue showing villous proliferation contains numerous microlipomas and shows arborescent architecture (*arrows*). Severe joint effusion is noted (Images courtesy of Dr. Shigeru Ehara, Department of Radiology, Iwate Medical University)

11.5 Lipoma Arborescens

- Lipomatous proliferation of synovium.
- Synovial tissue showing villous proliferation contains numerous microlipomas and shows arborescent architecture.
- Also called diffuse synovial lipoma.
- Most commonly affect the knee unilaterally.
- Suprapatellar bursa is the primary location of this lesion.
- It is said to occur as a reactive change to chronic arthritis.
- It resembles PVS, but it can be differentiated from PVS by the fact that it has mainly lipomatous component, little hemosiderin deposition, and little bone changes such as erosion.
- Rarely, lipoma may arise within Hoffa's fat pad.

Reference

Feller JF, Rishi M, Hughes EC. Lipoma arborescens of the knee: MR demonstration. AJR. 1994;163:162–4.

11.6 Hoffa's Syndrome

- It is a general term referring to diseased state of Hoffa's fat pad due to mechanical stimulus or inflammation.
- Hoffa's disease refers to impingement of the Hoffa's fat pad, which is swollen following traumatic injury including hemorrhage, between the femur and the tibia.
- It is caused by a direct blow to the anterior aspect of the knee or repetitive mechanical stimulus.
- At acute stage, there is swelling due to edema and hematoma and point tenderness (Fig. 11.7). Hematoma shows heterogeneous signal intensity on MRI.
- At chronic stage, fibrous proliferation and limitation in the range of motion are added (Fig. 11.8). Hypointensity on T2-weighted images, representing fibrous changes as well as hemosiderin deposition, may be seen. Cystic changes and calcification of the fibrotic foci may also be seen.
- Hoffa's fat pad ganglion may cause limitation in the range of motion. This is also considered as Hoffa's syndrome (Fig. 11.9). However, it has to be differentiated from meniscal cysts that extend into Hoffa's fat pad (see Chap. 12).

Reference

Jacobson JA, Lenchik L, Ruhoy MK, Schweitzer ME, Resnick D. MR imaging of the infrapatellar fat pad of Hoffa. Radiographics. 1997;17:675–91.

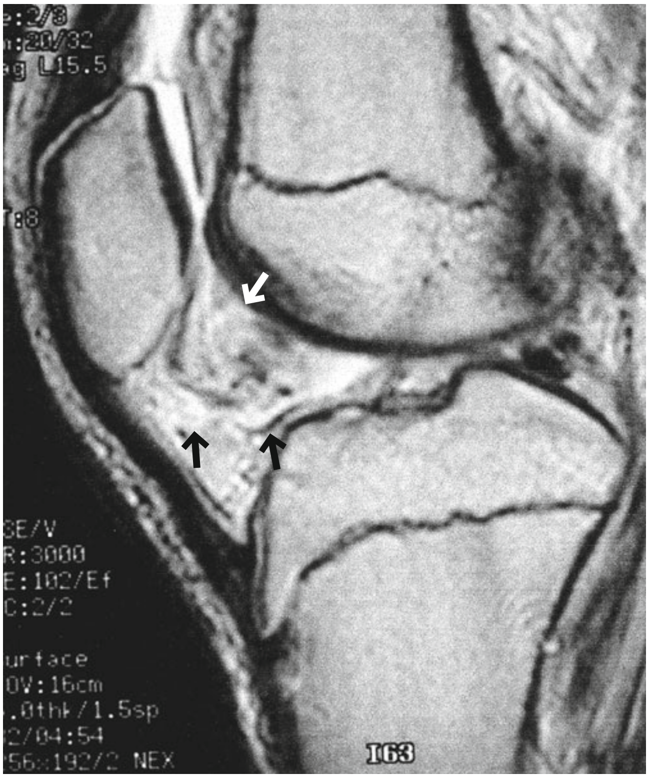

Fig. 11.7 **Hoffa's syndrome**. A 14-year-old boy with Reiter's syndrome. T2WI shows signal abnormality within the Hoffa's fat pad due to inflammation and swelling (Image courtesy of Dr. Shigeru Ehara, Department of Radiology, Iwate Medical University, Japan)

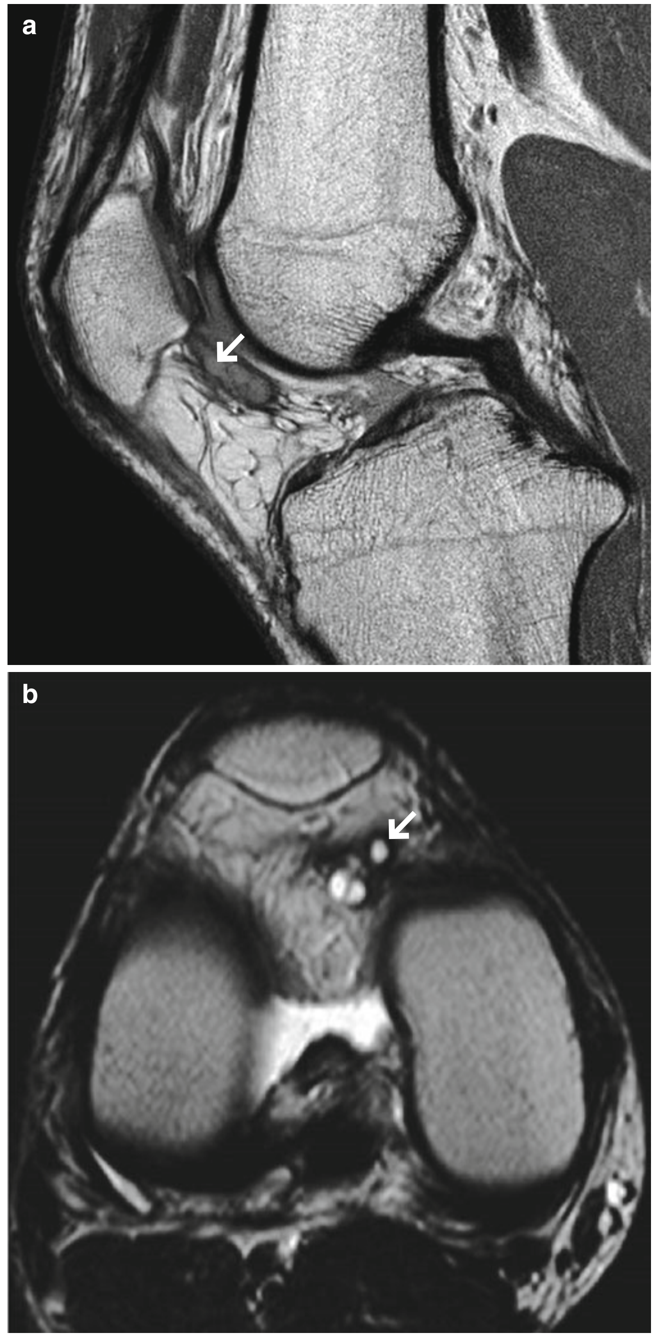

Fig. 11.8 **Hoffa's syndrome**. A man in his twenties, a keen soccer player. (**a**) PDWI and (**b**) axial T2WI. A portion of Hoffa's fat pad immediately posterior to the inferior pole of the patella shows a cystic change together with fibrous proliferation (*arrows*). Similar findings were seen in the contralateral knee

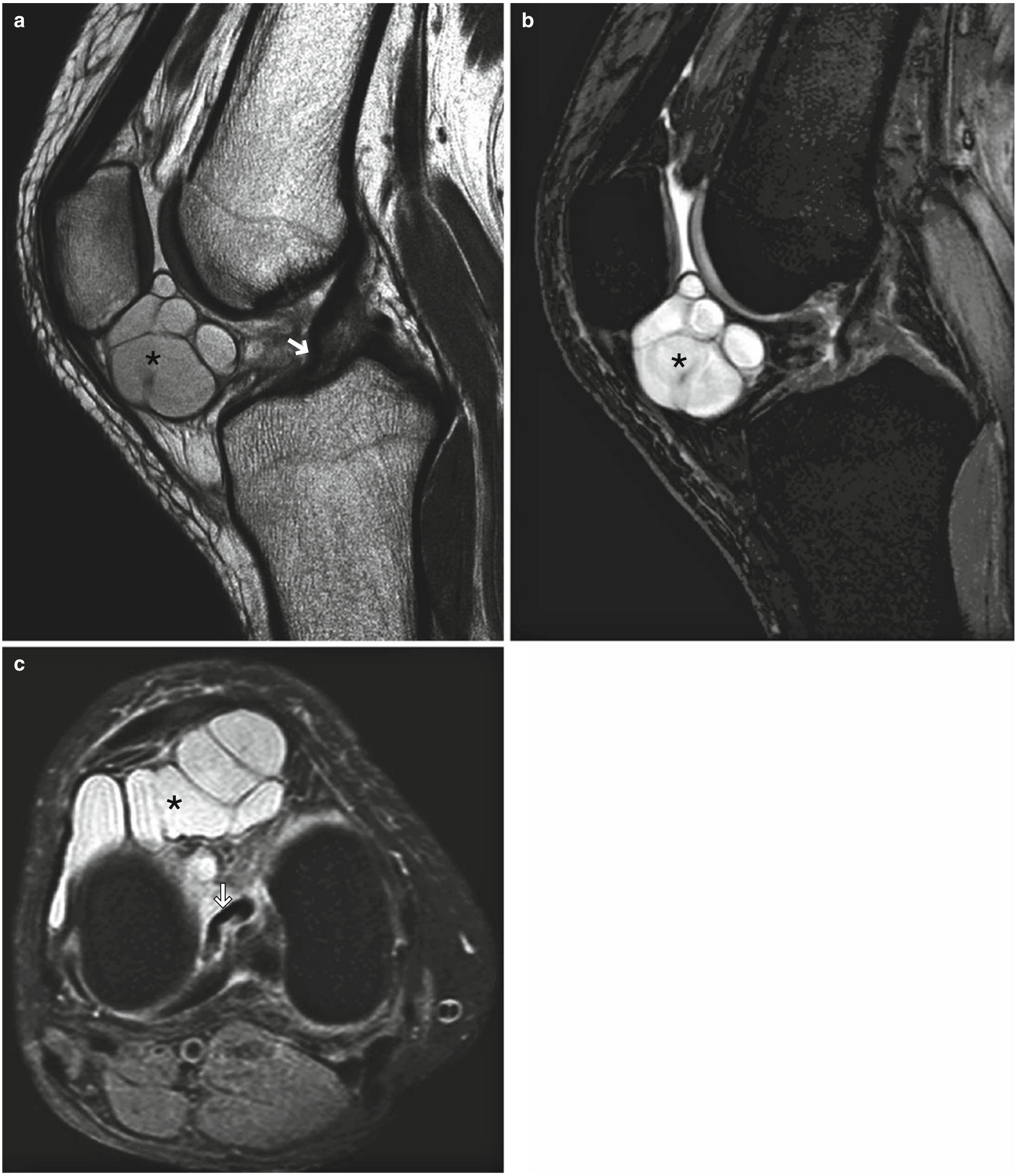

Fig. 11.9 Hoffa's fat pad ganglion. A woman in her 30s presenting with pain on knee extension. (**a**) PDWI, (**b**) FS T2*WI, and (**c**) axial FS PDWI. There is a large septated cystic lesion (*), and ACL is compressed toward posterior direction (*arrow*) (Images courtesy of Dr. Koichi Sato, Sato Orthopaedic Clinic, Japan)

Patellar tendon-lateral femoral condyle friction syndrome

- Localized injury to the superolateral aspect of the Hoffa's fat pad.
- It is said to be caused by impingement between the patellar tendon (patella) and the lateral femoral condyle, but the exact cause is unknown.
- Commonly seen in patients with patella alta and abnormally shaped patella (Wrisberg type III), and thus functional patellofemoral malalignment may be a cause.
- Chronic localized pain in the anterolateral aspect of the knee, which worsens on knee extension.
- Relatively common in young women.
- On MRI, the lesion located in the superolateral aspect of the Hoffa's fat pad shows hypointensity on T1-weighted image and hyperintensity on fat-suppressed T2-weighted image. There may be associated signal abnormalities within the patellar tendon and patella.

What Is Hoffa's Fat Pad?

Fatty tissue that occupies the anterior aspect of the knee just below the patella.

It is an intra-articular, extrasynovial structure (same as ACL and PCL).

It occupies the space created anteriorly by the joint capsule, patellar tendon, and the inferior pole of the patella, and posteriorly synovium-lined joint cavity, femur, and tibia form the posterior.

Infrapatellar plica (ligamentum mucosum) connects the posterior border of Hoffa's fat pad and the intercondylar space.

Inferiorly, it touches the anterior horn of the lateral meniscus and the tibial surface.

Mostly composed of adipose tissue, but also contains fibrous bands and septum-like structures as well as a network of blood vessels.

It is crossed by the transverse ligament which connects the anterior horns of the medial and lateral menisci.

Reference

Chung CB, Skaf A, Roger B, Campos J, Stump X, Resnick D. Patellar tendon-lateral femoral condyle friction syndrome: MR imaging in 42 patients. Skeletal Radiol. 2001;30:694–7.

Fig. 11.10 Patellar tendon-lateral femoral condyle friction syndrome. A man in his 30s who had 10-year history of anterior knee pain. (**a**) FS T2*WI, (**b**) axial T1WI, and (**c**) axial FS PDWI. There is a localized area showing hypointensity on T1WI and hyperintensity on FS T2WI in the superolateral aspect of the Hoffa's fat pad (*arrows*). Mild swelling of the affected part is noted

11.7 Amyloidosis

- Long-term dialysis treatment for renal failure leads to deposition of amyloid in the synovium and articular cartilage in the knee.
- It is mainly composed of β_2-microglobulin.
- Commonly affects the knee, shoulder, hip and wrist.
- Affected joint shows severe swelling because of amyloid deposition.
- Bone erosion and subchondral cysts occur.
- Usually affects bilateral joints.

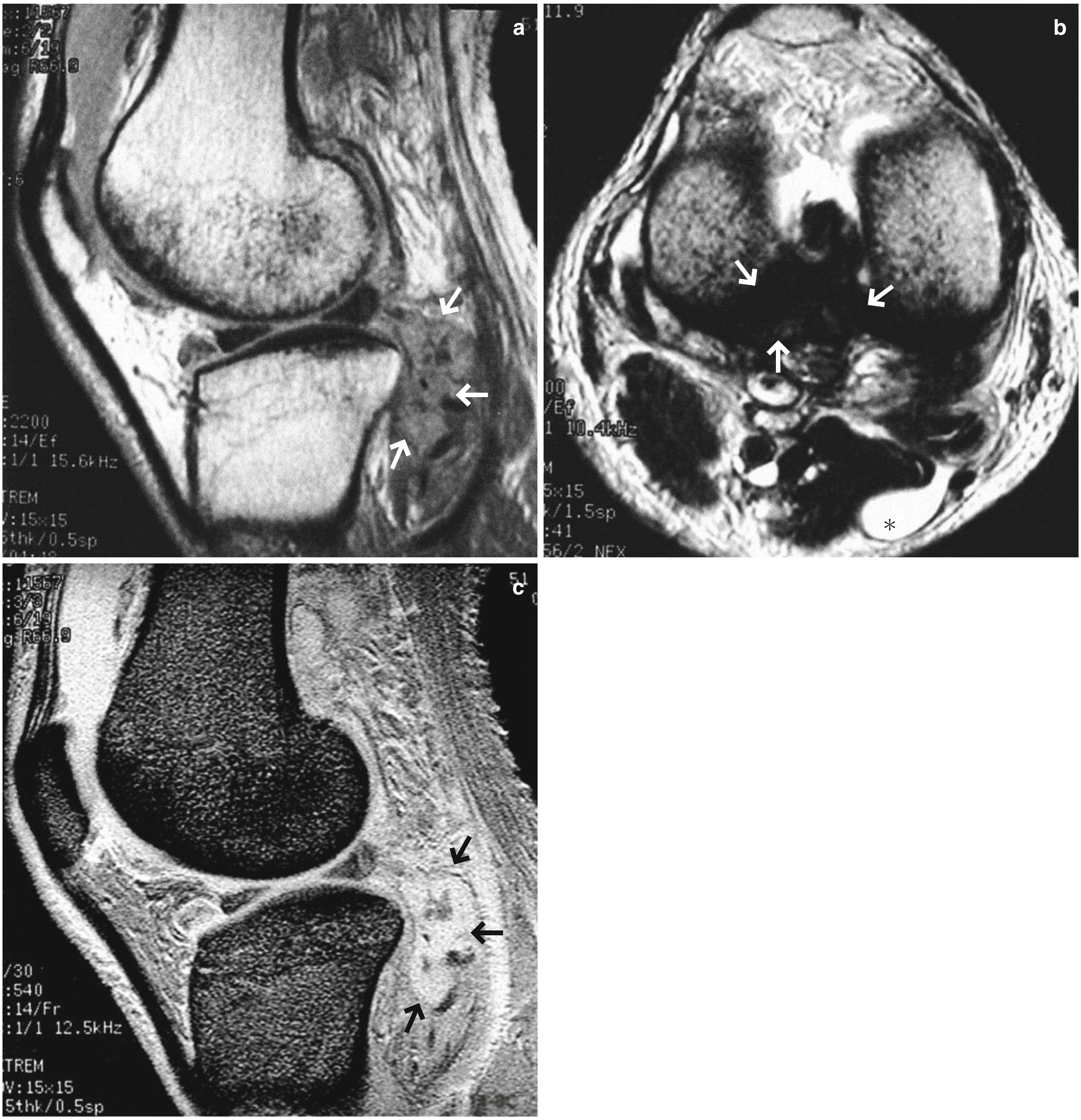

Fig. 11.11 **Amyloidosis**. A man in his 50s who had a long-term dialysis therapy. (**a**) PDWI, (**b**) axial T2WI, and (**c**) T2*WI. Severe joint effusion is noted. In the posteroinferior joint space, there is a mass-like lesion (amyloid deposition) which shows hypointensity on T2WI (*arrows*). However, it does not show strong hypointensity which is characteristic to hemosiderin deposition seen in PVS. * popliteal cyst

Table 11.1 Comparison between PVS and amyloidosis

	PVS	Amyloidosis
Deposition	Hemosiderin	β_2-microglobulin
T1-weighted image	Hypointensity	Hypointensity
T2-weighted image	Hypointensity	Hypointensity
T2*-weighted image (gradient echo)	Hypointensity (close to signal void)	Slightly low to intermediate signal intensity

Key points for MRI interpretation

- Amyloid deposition shows hypointensity on both T1- and T2-weighted image (which is similar to PVS).
- Amyloid deposition contains little hemorrhagic component, and it does not show strong hypointensity on T2*-weighted image which is characteristic of PVS (Table 11.1).

11.8 Plica Syndrome

- A plica is a remnant of an embryonic partition in the knee.
- Suprapatellar plica, mediopatellar plica, and infrapatellar plica are most commonly seen (Fig. 11.12).
- It is a normal structure which is thin and flexible, and thus its presence itself does not cause clinical problems. Arthroscopically, it is seen as a white membrane-like structure. If it is subjected to repeated mechanical stimuli, reactive synovitis may occur, causing thickening and scarring of the plica and clinical symptoms.

Reference

Boles CA, Martin DF. Synovial plicae in the knee. AJR. 2001; 177:221–7.

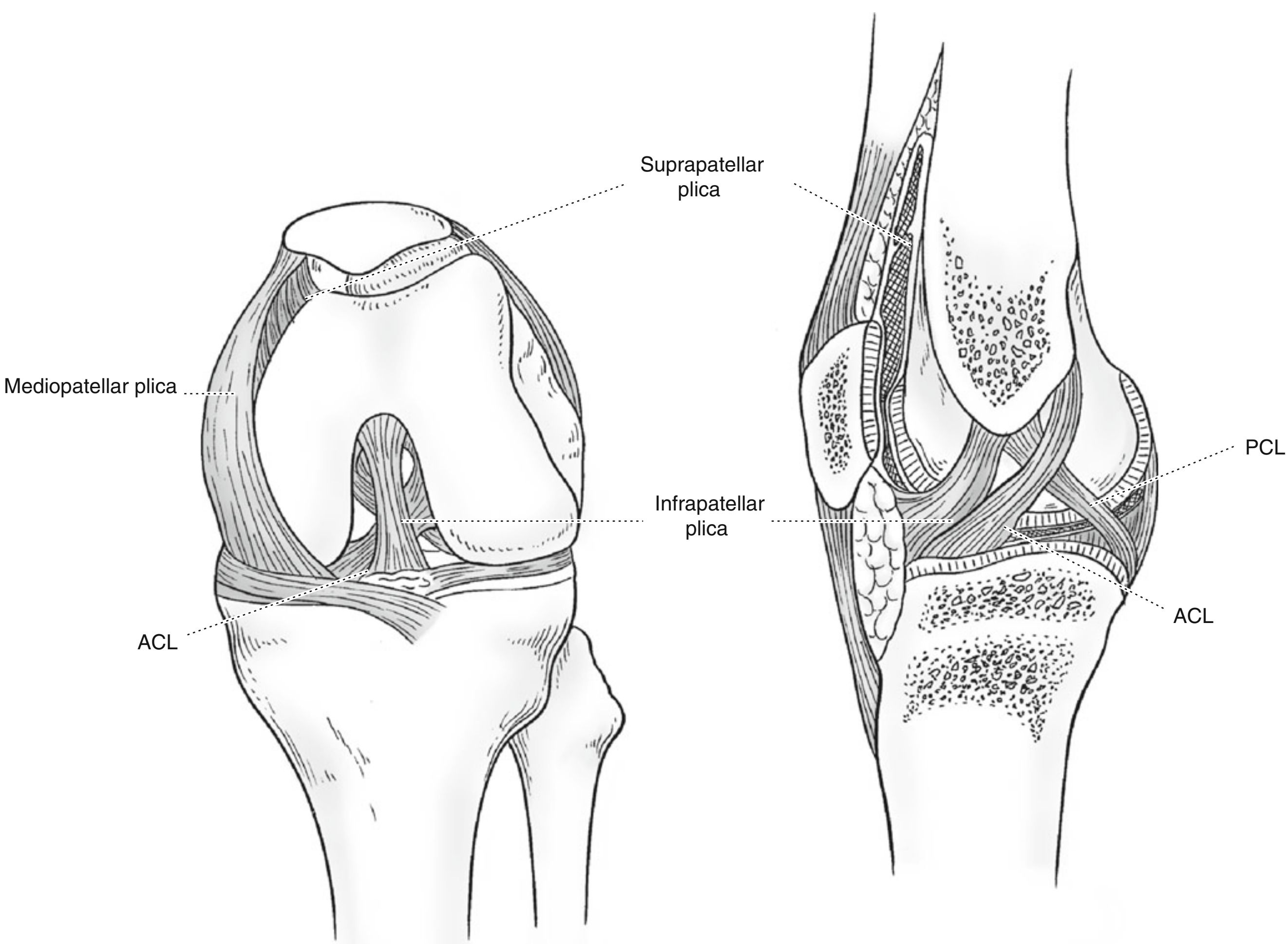

Fig. 11.12 **Knee plica**. Suprapatellar plica, mediopatellar plica, and infrapatellar plica are most commonly seen

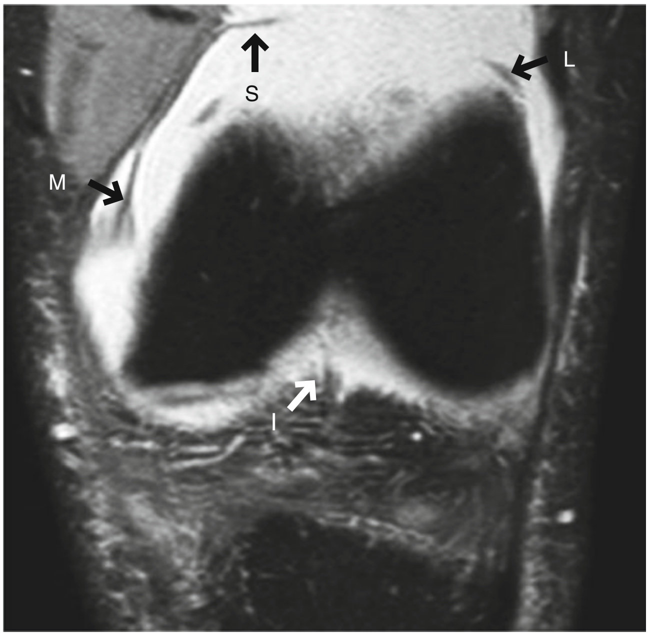

Fig. 11.13 Coronal FS PDWI of knee plicae. The presence of joint effusion enables visualization of suprapatellar plica (*S*), mediopatellar plica (*M*), infrapatellar plica (*I*), and lateropatellar plica (*L*) in this example

11.8.1 Suprapatellar Plica

- It is present in almost all normal knees and separates suprapatellar bursa and the knee joint space (Fig. 11.14).
- If the suprapatellar plica becomes enlarged, it may close off the communication between the suprapatellar bursa and the knee joint space. In this state, if trauma, inflammation, or hemorrhage occurs, fluid collection in the suprapatellar bursa becomes significantly worse and a subcutaneous mass may be palpable just superior to the patella (Fig. 11.15).

Reference

Trout TE, Bock H, Resnick D. Suprapatellar plicae of the knee presenting as a soft-tissue mass. Report of five patients. Clin Imaging. 1996;20:55–9.

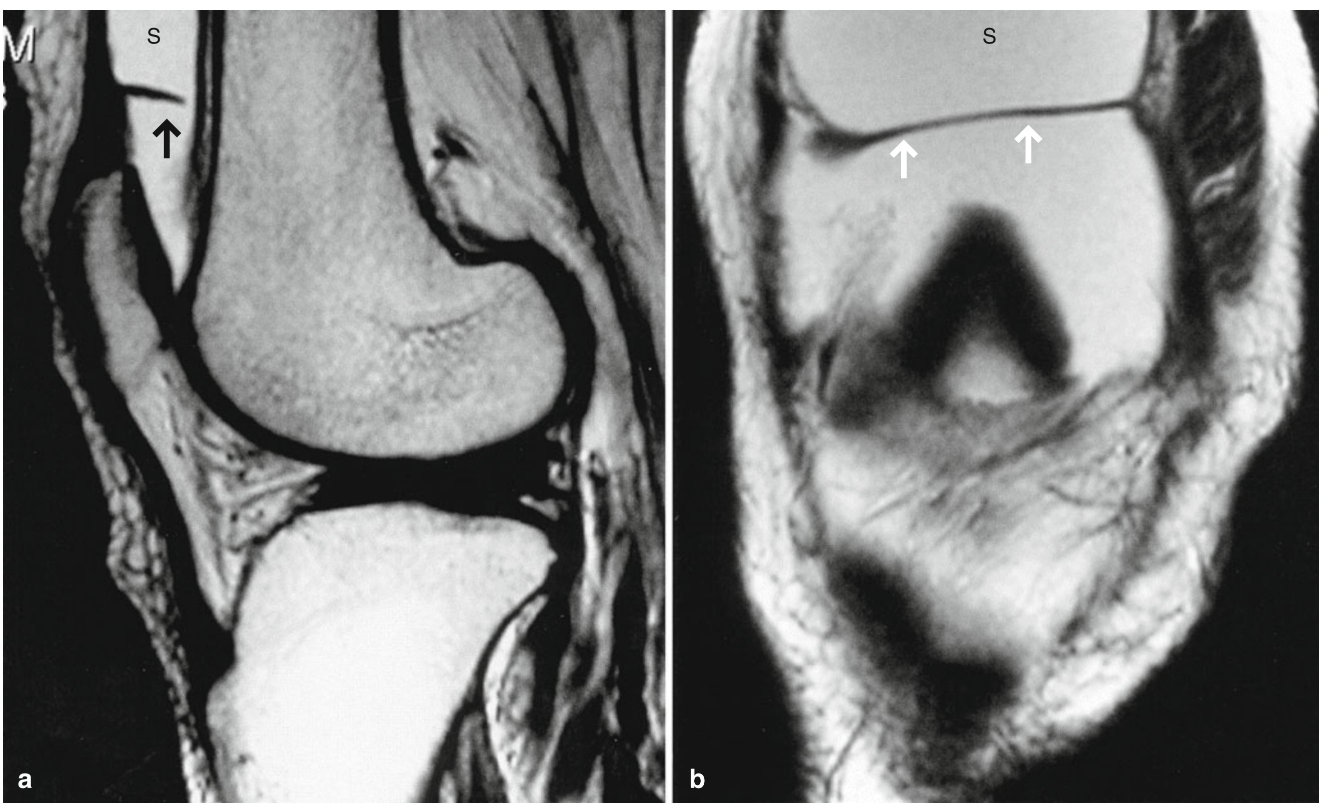

Fig. 11.14 Suprapatellar plica. A woman in her 50s. (**a**) Sagittal and (**b**) coronal T2WI. Suprapatellar plica is the sheet-like structure separating the suprapatellar bursa (S) and the knee joint space (*arrows*)

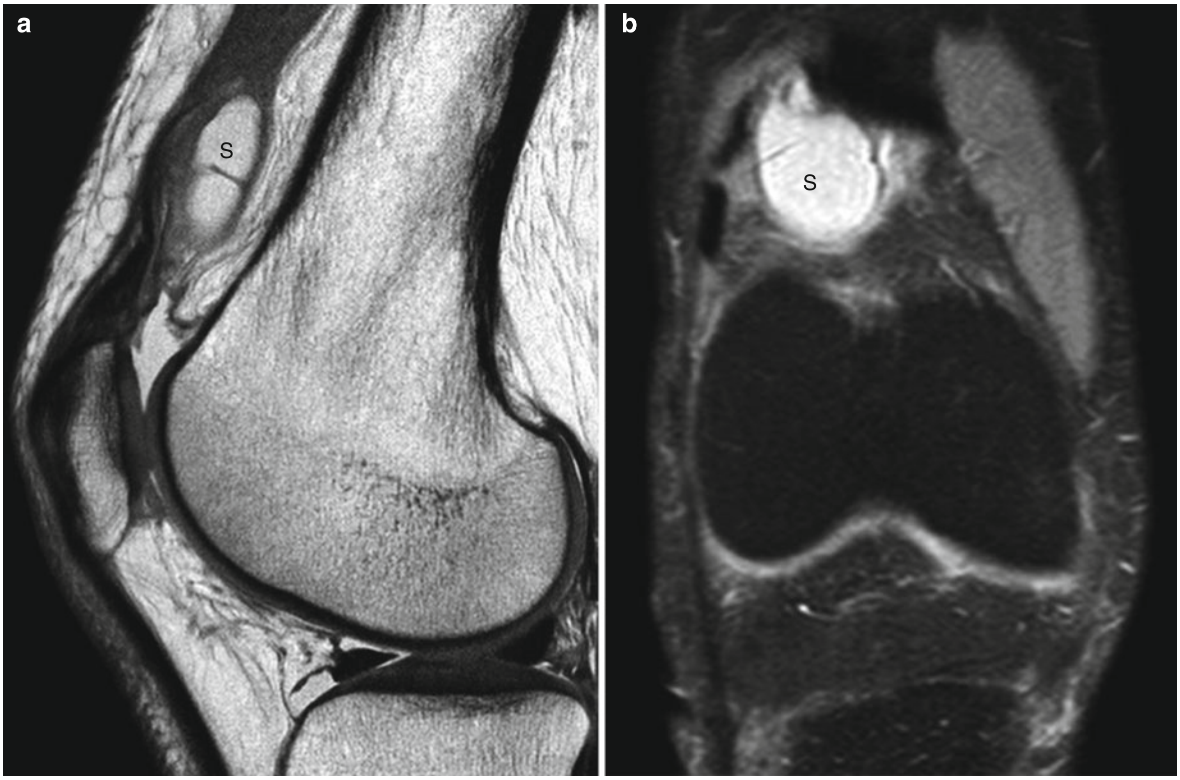

Fig. 11.15 **Suprapatellar bursitis**. A woman in her 50s, presenting with a few months history of suprapatellar swelling. (**a**) PDWl and (**b**) axial FS PDWl. Suprapatellar bursa is swollen due to fluid accumulation (*S*). There is also surrounding edematous swelling

11.8.2 Mediopatellar Plica

- Synovial plica located in the medial aspect of the knee joint space.
- Frequently seen in axial MR images (Fig. 11.16).
- May not be visualized if there is little joint fluid.
- Laterally located plica is rare (Fig. 11.17).
- Large mediopatellar plicae become impinged between the patellofemoral joint, causing pain and "clicking" sound (so-called plica syndrome, Figs. 11.18 and 11.19).

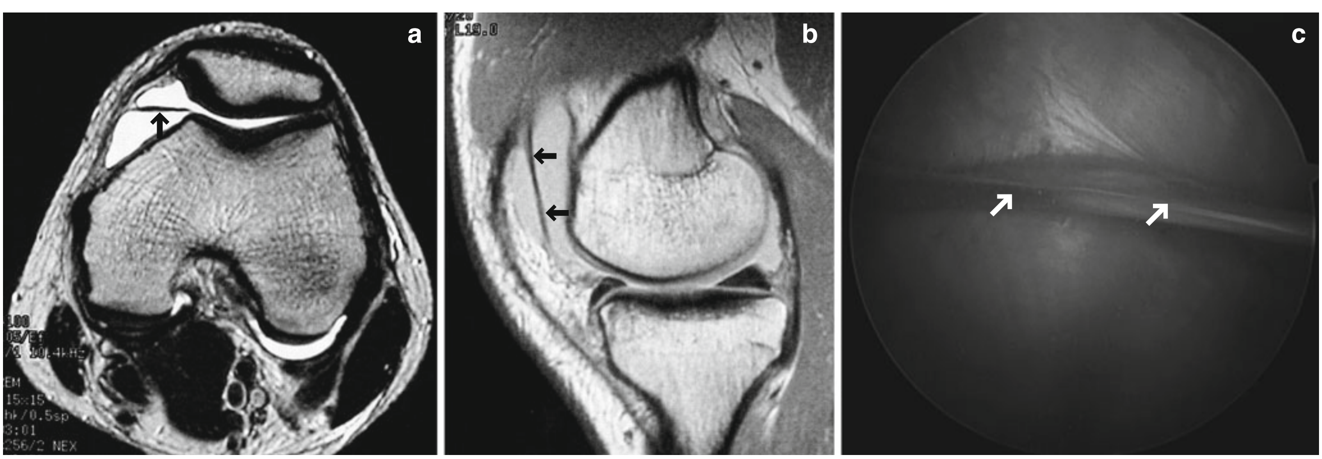

Fig. 11.16 **Mediopatellar plica**. A man in his late teens. (**a**) Axial T2WI, (**b**) PDWI, and (**c**) arthroscopic image. This is a typical example of a mediopatellar plica (*arrow*)

Reference

Nakanishi K, Inoue M, Ishida T, et al. MR evaluation of mediopatellar plica. Acta Radiol. 1996;37:567–71.

Fig. 11.17 **Lateropatellar plica**. A man in his 30s. A lateropatellar plica is rarely seen (*arrows*)

Fig. 11.18 **Plica syndrome due to a large mediopatellar plica**. A man in his 40s. Axial T2WI. There is a large mediopatellar plica (*arrow*)

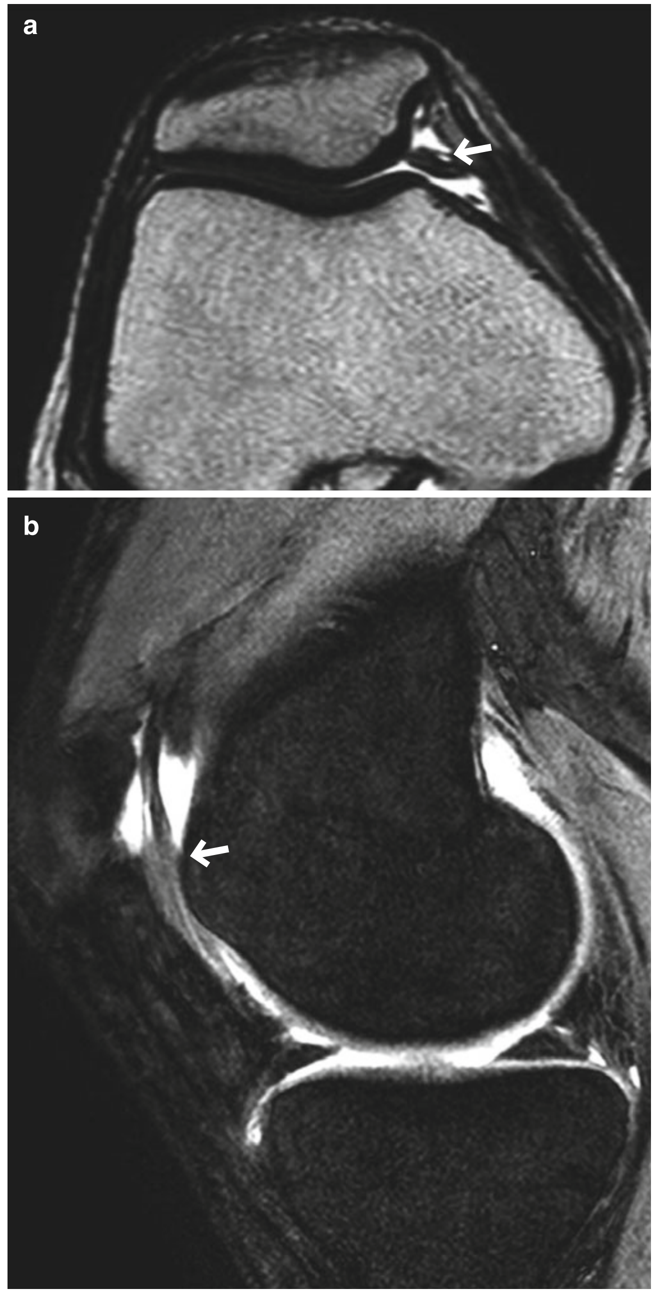

Fig. 11.19 **Plica syndrome due to a large mediopatellar plica**. A man in his 30s, presenting with medial patellar pain. (**a**) Axial T2WI, (**b**) FS T2*WI, and (**c**) arthroscopic image. Mediopatellar plica thickening is seen (*arrows*) (Images courtesy of Dr. Atsushi Tazaki, Department of Orthopaedics, St. Luke's International Hospital, Japan)

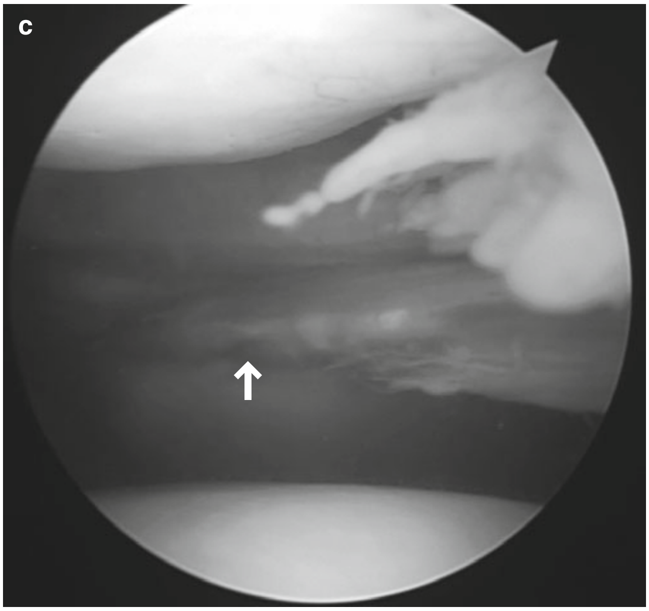

Fig. 11.19 (continued)

11.8.3 Infrapatellar Plica

- It is also known as anterior plica or ligamentum mucosum.
- It is situated anterior to the ACL, connects Hoffa's fat pad and the anterior aspect of the intercondylar space, and divides the tibiofemoral joint space into right and left sides.
- It is said to have a role in lifting Hoffa's fat pad.
- It is commonly seen during arthroscopic examination, and if it obscures the arthroscopic procedure, its resection (or piercing through it) may be required.
- It is less commonly visualized on MRI than suprapatellar or mediopatellar plicae.
- It can be visualized as a thin band-like structure running just anterior to the ACL almost in parallel to it (Fig. 11.20).
- It is rarely clinically significant, but rarely it can swell and cause knee extension disorder.

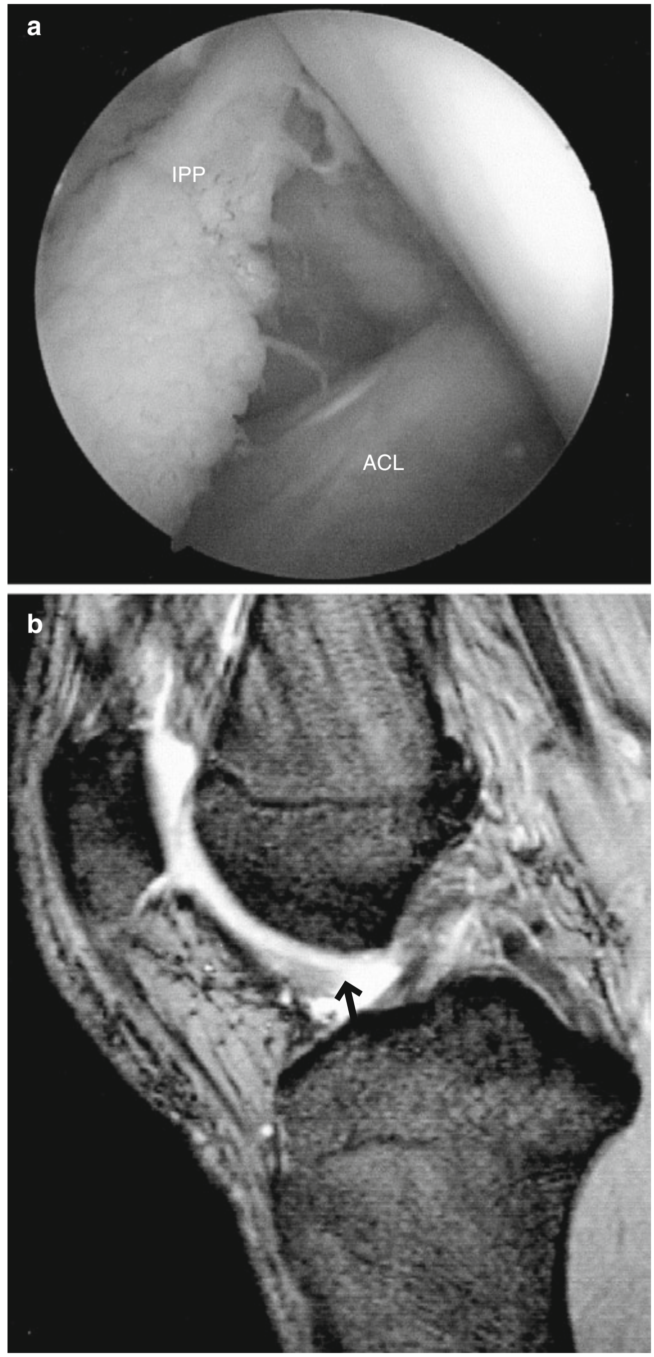

Fig. 11.20 **Infrapatellar plica**. A man in his late teens. (**a**) Arthroscopic image and (**b**) T2WI. There is a band-like structure just anterior to the ACL, representing infrapatellar plica (*IPP*). In sagittal MRI, it can rarely be visualized as a thin band-like structure running in front of ACL in parallel to it (*arrow*)

Reference

Kosarek FJ, Helms CA. The MR appearance of the infrapatellar plica. AJR. 1999;172:481–4.

12 Cystic and Cyst-Like Lesions of the Knee

12.1 Intra-articular Ganglion

- The lesion has a well-defined border, and its wall is lined by spindle shaped cells.
- Contains clear fluid similar to synovial fluid or mucoid material.
- Commonly has multiple cystic chambers due to the presence of septa.
- May cause pain and disorder of knee flexion and extension.
- Commonly seen in the intercondylar space as an ACL ganglion (Fig. 12.1) or a PCL ganglion (Figs. 12.2 and 12.3).

References

Bui-Mansfield LT, Youngberg RA. Intraarticular ganglia of the knee: prevalence, presentation, etiology and management. AJR. 1997;168:123–7.

Marra MD, Crema MD, Chung M, et al. MRI features of cystic lesions around the knee. Knee. 2008;15:423–38.

Ganglia and Bursae

A ganglion is a benign, unilocular, or multilocular cystic mass containing clear and highly viscous fluid within a dense fibrous connective tissue wall without a synovial lining. It does not communicate with the joint capsule. The pathogenesis of ganglia remains controversial. Proposed theories include mucoid cystic degeneration in a collagenous structure near areas under continuous stress and herniation of synovial tissue.

A bursa is lined by synovium and contains synovial fluid, usually representing normal physiologic fluid accumulation. Numerous bursae are present around the knee and have names according their anatomical location.

Ganglia and fluid-filled bursae are commonly seen around the joint and tendon sheath. They are often incidentally found on MRI in asymptomatic persons,

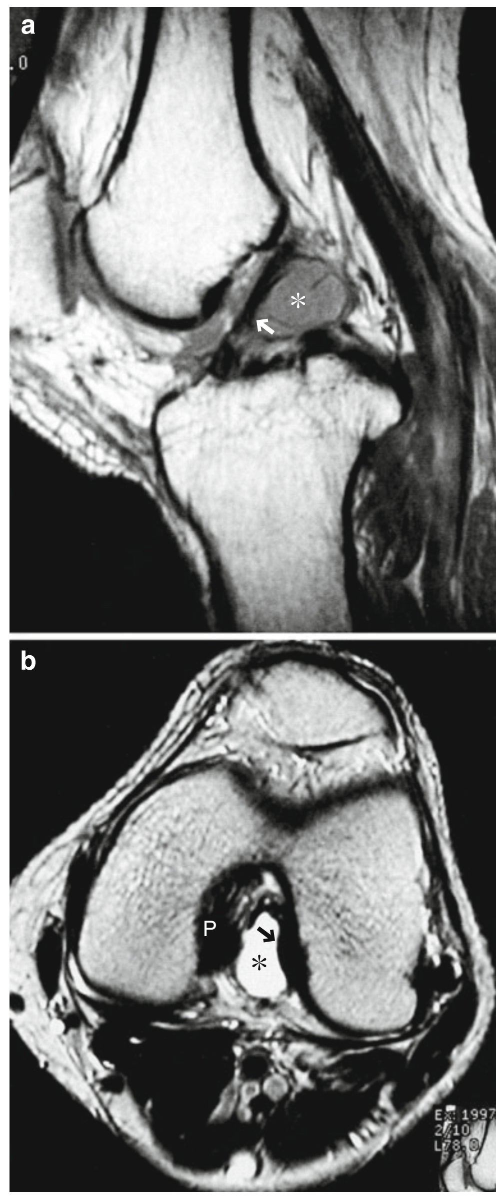

Fig. 12.1 **ACL ganglion**. A man in his 30s. (**a**) PDWI and (**b**) axial T2WI. There is an ACL ganglion (*) which is septated and compresses the ACL from below (*arrow*). *P* PCL

M. Niitsu et al., *Magnetic Resonance Imaging of the Knee*,
DOI 10.1007/978-3-642-17893-1_12, © Springer-Verlag Berlin Heidelberg 2013

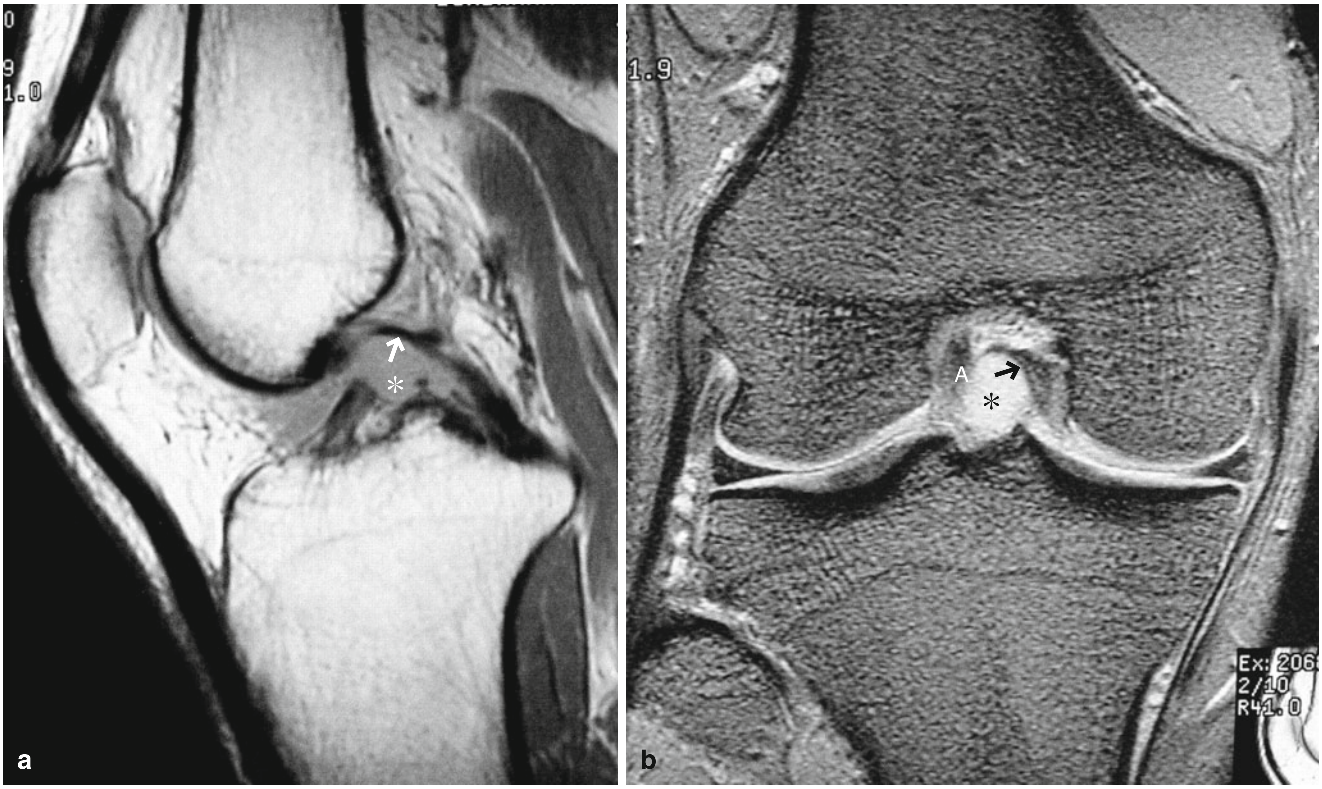

Fig. 12.2 **PCL ganglion**. A man in his 40s. (**a**) PDWI and (**b**) coronal T2*WI. There is a PCL ganglion (*). PCL shows an arc-like shape due to compression by the PCL ganglion (*arrow*). *A* ACL

Fig. 12.3 **ACL and PCL ganglion**. A man in his 40s. (**a**) Coronal T2*WI, (**b**) axial T2*WI, and (**c**) arthroscopic image. There is a cystic lesion (*arrow*) sandwiched between ACL (*A*) and PCL (*P*), both of which are compressed by this lesion. Arthroscopic puncture of the cystic lesions revealed it was filled with yellow jellylike material

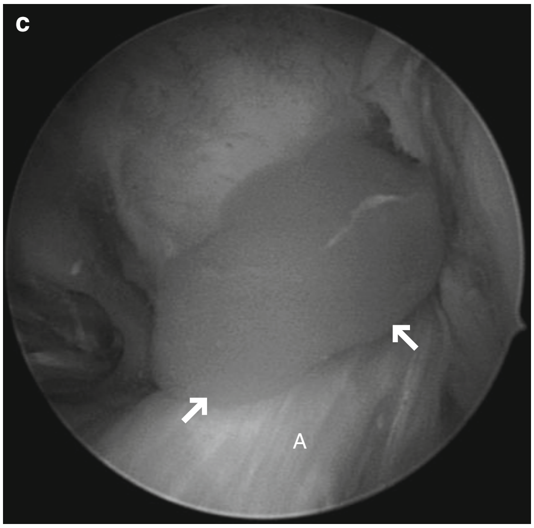

Fig. 12.3 (continued)

but can cause pain and swelling. Ganglia tend to be multilocular, but differentiating between these two entities may be difficult at times on the basis of MRI alone.

12.2 Meniscal Cyst

- It is a focal collection of synovial fluid located within or adjacent to the meniscus.
- Parameniscal cysts are thought to form when there is fluid extravasation through a meniscal tear into the parameniscal soft tissue.
- Large meniscal cysts may protrude laterally and may become palpable at the level of knee joint space as a subcutaneous mass (especially on the lateral side of the knee). Meniscal cysts may cause pain, tenderness, and swelling. Medial meniscal cysts are more likely to be painless.
- Prevalence of the lateral meniscal cysts is 3–4 times higher than that of the medial meniscal cysts (Fig. 12.4). Meniscal cysts are particularly common around the anterior horn.
- Medical meniscal cysts tend to enlarge into the posterior direction (Fig. 12.5).
- Because the bond between the superficial layer of the MCL and the joint capsule is strong, it is rare for a cystic lesion to form at this location (see Fig. 5.3). However, in the event that fluid accumulates here, it may cause symptoms.
- Meniscal cysts can be treated by surgical excision, but to prevent recurrence, meniscectomy may be necessary if the meniscal tear is present (Fig. 12.6).

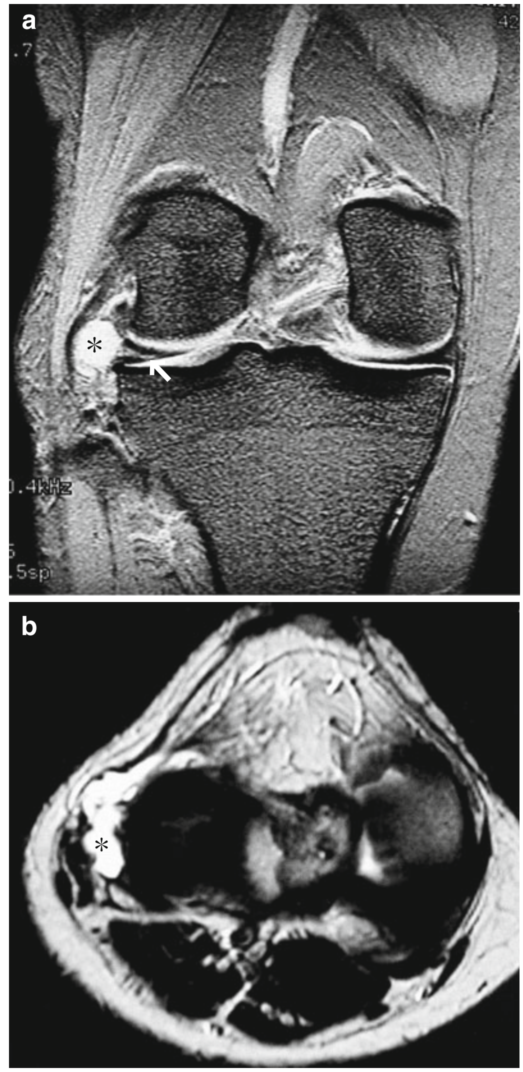

Fig. 12.4 **Lateral meniscal cyst**. A woman in her 40s. (**a**) Coronal T2*WI and (**b**) axial T2WI. There is a degenerative horizontal tear of the middle segment of the lateral meniscus (*arrow*) and a cystic lesion that is continuous with the tear (*)

References

Jansen DL, Peterfy CG, Forbus JR, et al. Cystic lesions around the knee joint. MR imaging findings. AJR. 1994;163:155–61.

Tschirch FTC, Schmid MR, Pfirrmann CWA, Romero J, Hodler J, Zanetti M. Prevalence and size of meniscal cysts, ganglionic cysts, synovial cysts of the popliteal space, fluid-filled bursae, and other fluid collections in asymptomatic knees on MR imaging. AJR. 2003;180:1431–6.

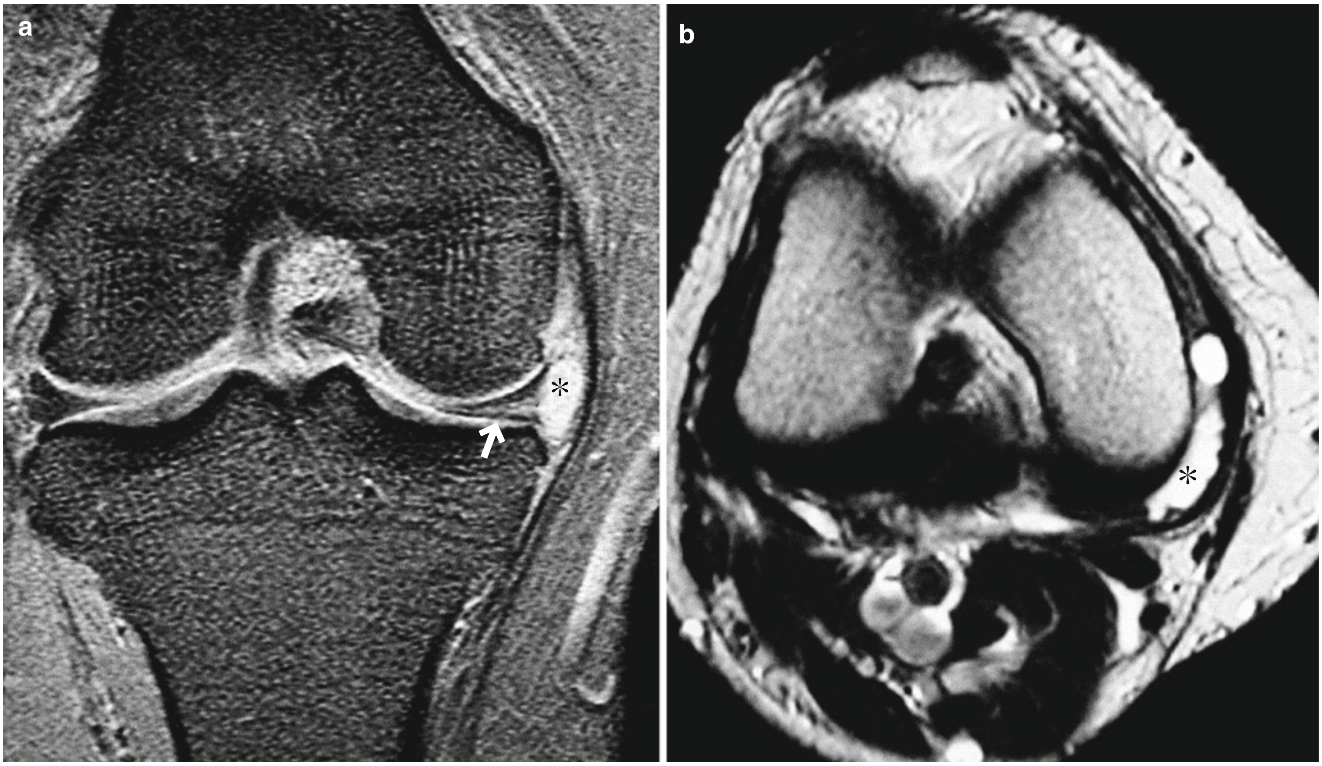

Fig. 12.5 **Medial meniscal cyst**. A woman in her 50s. (**a**) Coronal T2*WI and (**b**) axial T2WI. There is a degenerative horizontal tear of the medial meniscus (*arrow*) and a cystic lesion that is continuous with the tear and extends posteriorly (*)

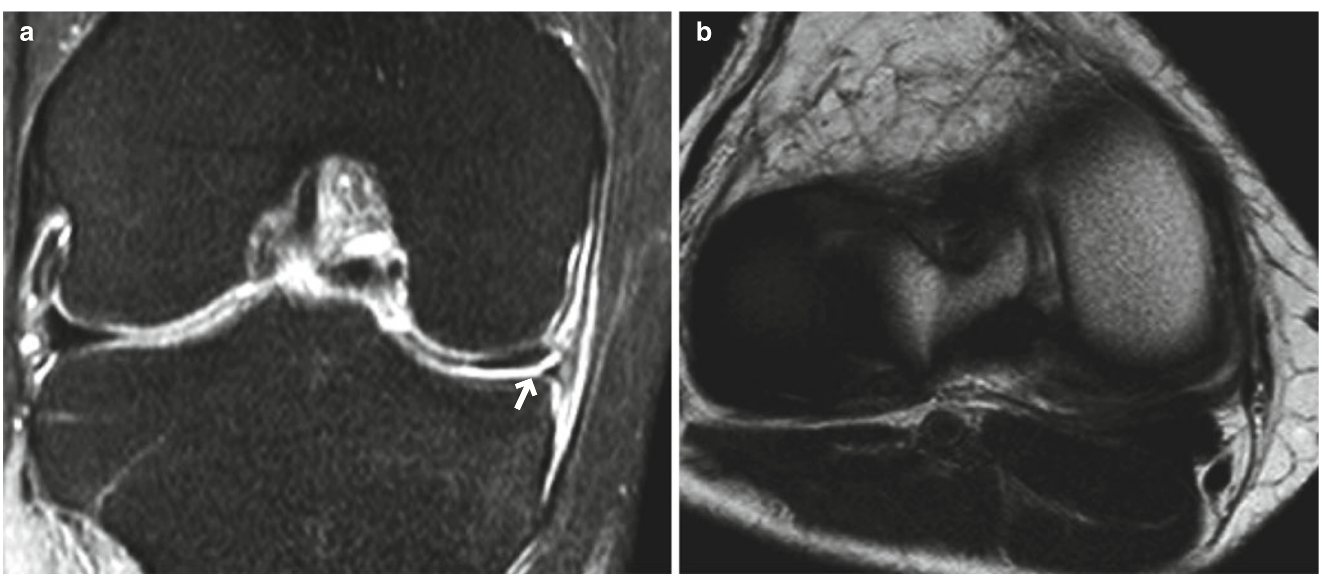

Fig. 12.6 **Medial meniscal cyst that occurred 2 years after meniscal tear**. A woman in her 40s. (**a**) Coronal T2*WI and (**b**) axial T2WI at the time of meniscal tear. (**c**, **d**) Respective sequences taken 2 years later. A medial meniscal tear is noted (*arrow*, **a**), but no cysts are seen. Two years later, there is a cystic lesion connected to the medial meniscal tear (*arrows*, **c**, **d**). This lesion was palpable

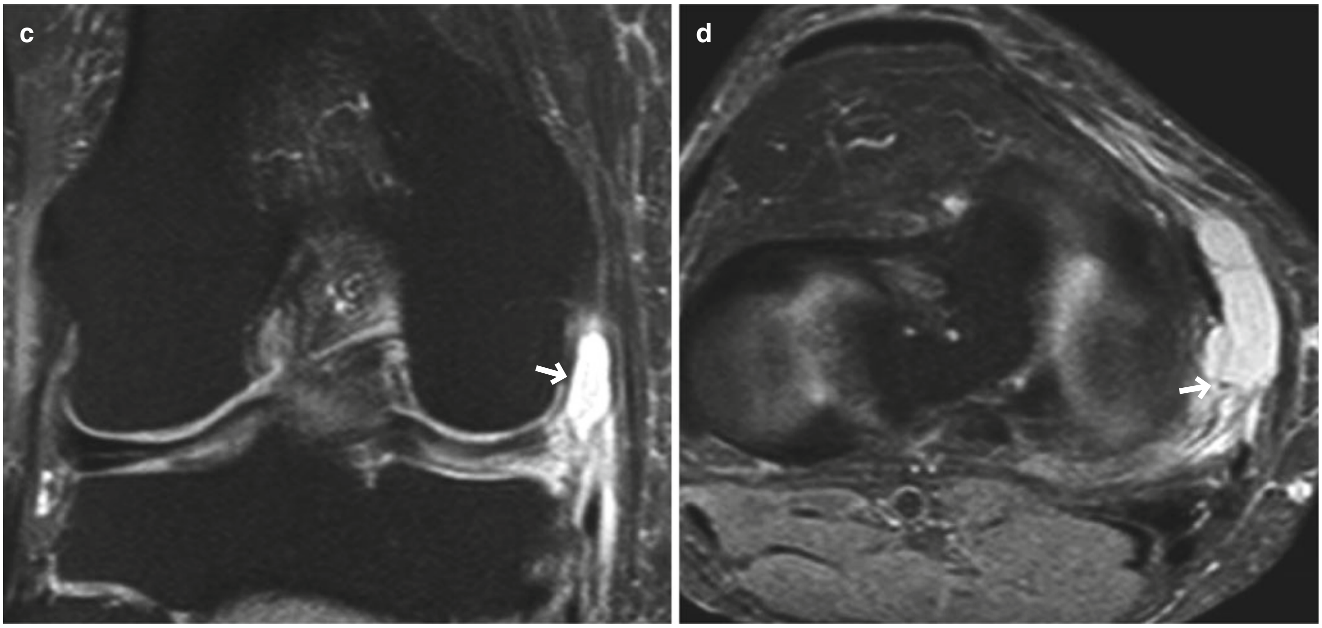

Fig. 12.6 (continued)

12.3 Popliteal Cyst (Baker's Cyst)

- Popliteal cysts are not true cysts and represent fluid accumulation in the semimembranosus-medial gastrocnemius bursa (Figs. 12.7 and 12.8).
- It commonly communicates with the joint capsule.
- Most commonly seen cystic lesion in the whole body and the knee (about 40%).
- On T2-weighted MRI, it shows homogeneous hyperintensity, but rarely it may appear heterogeneous if it contains hemorrhagic components or debris.
- Increased intra-articular pressure due to joint effusion or other factors (e.g., meniscal tear, ACL tear, inflammatory arthritis) causes the extravasation of joint fluid through the posteromedial joint capsule posteriorly into the bursa, leading to gradual formation of an enlarging popliteal cyst.
- It has a teardrop shape between the medial head of gastrocnemius and the semimembranosus tendon.
- Rarely seen in children and becomes more common as the age increases.
- Commonly painless if the size is less than 30 mm.
- Rarely it can rupture (Fig. 12.9), causing extravasation of fluid into muscle interstitium and symptoms that are similar to those of thrombophlebitis.

References

Steiner E, Steinbach LS, Schnarkowski P, et al. Ganglia and cysts around joints. Radiol Clin North Am. 1996;34:395–425.

Miller TT, Staron RB, Koenigsberg T, Levin TL, Feldman F. MR imaging of Baker cysts: association with internal derangement, effusion and degenerative arthropathy. Radiology. 1996;201:247–50.

Hayashi D, Roemer FW, Dhina Z, et al. Longitudinal assessment of cyst-like lesions of the knee and their relation to radiographic osteoarthritis and MRI-detected effusion and synovitis in patients with knee pain. Arthritis Res Ther. 2010;12:R172.

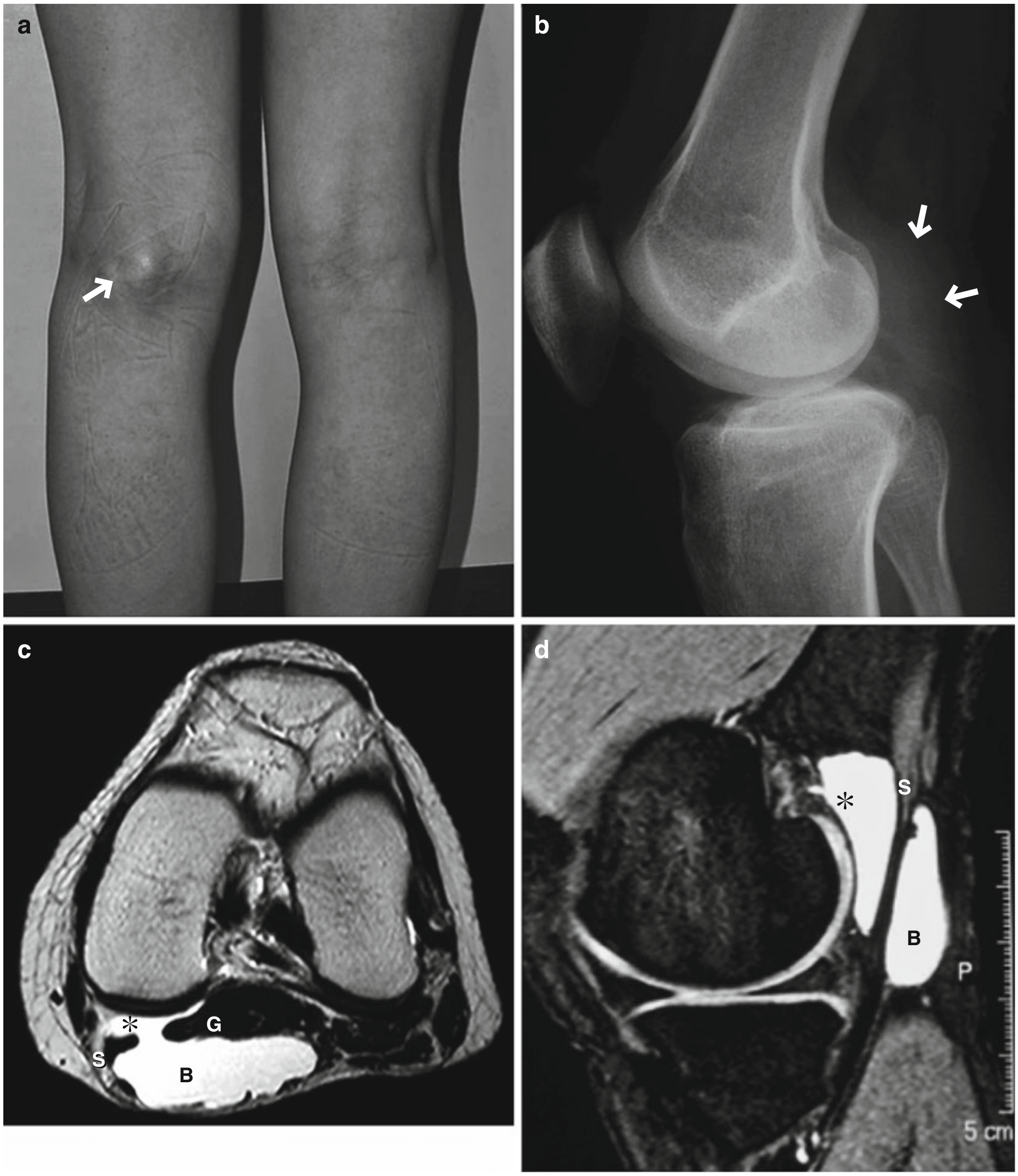

Fig. 12.7 **Popliteal cyst**. A man in her 20s. (**a**) Posterior view of the knee, (**b**) lateral radiograph, (**c**) axial T2WI, and (**d**) FS T2*WI. A swelling in the popliteal fossa (*arrow*, **a**) is noted. On radiograph, there is a soft tissue density in the corresponding location of the posterior knee (*arrows*, **b**). MRI shows the subgastrocnemius bursa (*) extending posteriorly between the medial head of gastrocnemius (*G*) and semimembranosus tendon (*S*) into the Baker's cyst (*B*). The subgastrocnemius bursa and the Baker's cyst are connected by a communication, and thus the entire lesion is generally considered to be a popliteal cyst, or simply "the Baker's cyst". (also see Sect. 12.4)

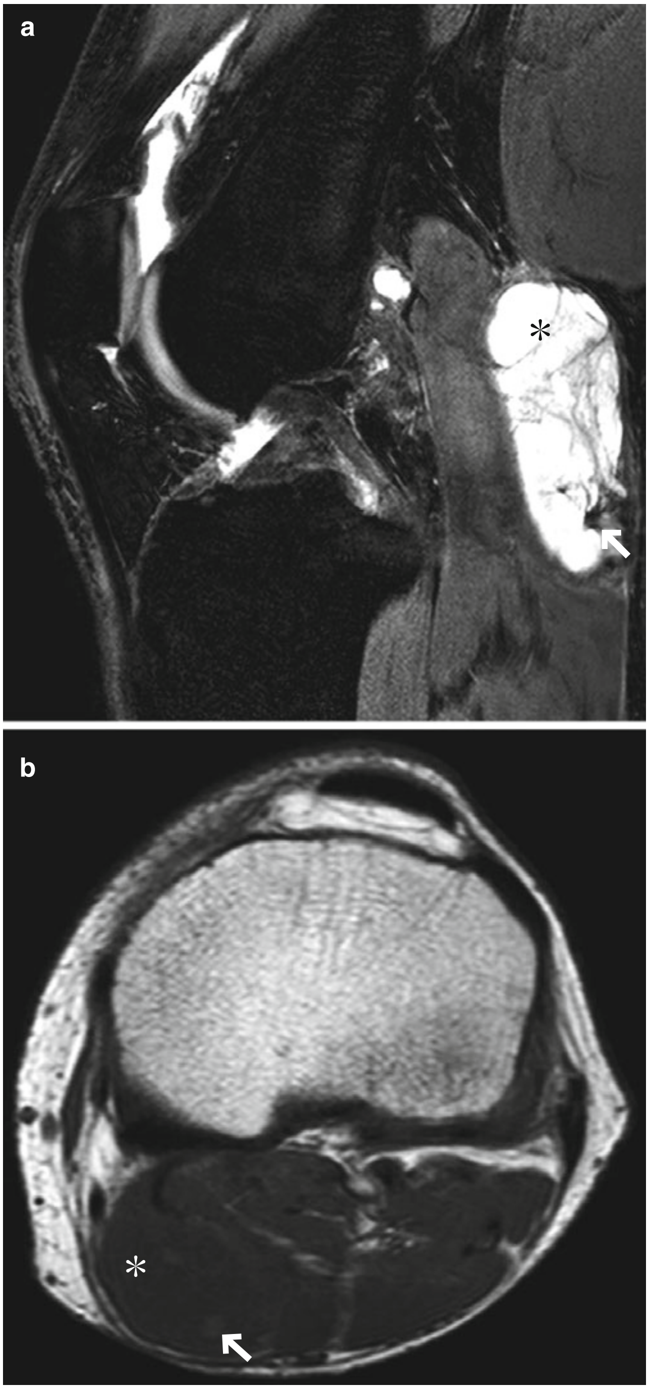

Fig. 12.8 Popliteal cyst showing heterogeneous MR signal intensity. A man in his thirties. (**a**) FS T2*WI and (**b**) axial T1WI. Popliteal cyst (*) shows heterogeneous signal intensity due to the presence of septum-like structures and small amount of bleeding (*arrow*)

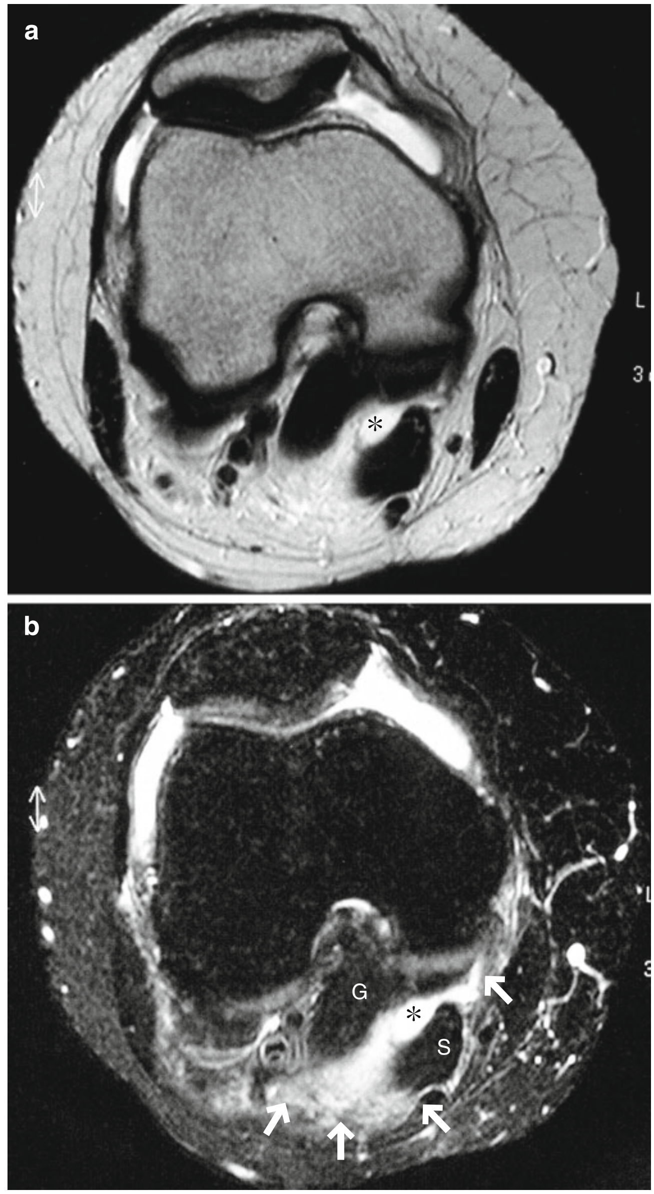

Fig. 12.9 Ruptured popliteal cyst. A woman in her 40s. (**a**) Axial T2WI and (**b**) axial FS T2*WI. The popliteal cyst (*) has ruptured and extensive edema is seen in the surrounding interstitium (*arrows*). *G* medial head of gastrocnemius, *S* semimembranosus tendon

12.4 Posterior Capsular Area of the Knee

- Posterior capsular area of the knee can be separated into medial, middle, and lateral compartments. In this section, mainly the medial posterior capsule is described in relation to the popliteal cyst.
- Medial posterior capsule extends above and below the posterior root/segment of the medial meniscus (Fig. 12.10). It extends superiorly by more than several centimeters.
- Medial posterior capsule runs below the tendon sheath of the medial head of gastrocnemius (this space is called subgastrocnemius bursa), fuses with the tendon sheath, and eventually attaches to the cortical bone of the medial femoral condyle.
- Semimembranosus tendon runs immediately posterior to these structures, which can be confirmed on axial MRI.
- Accumulation of fluid will make it easier to visualize these structures on MRI.
- Injury of medial posterior capsule commonly leads to its separation from the gastrocnemius (Fig. 12.11).
- Joint capsule and subgastrocnemius bursa communicate through a small opening at the site where the medial posterior capsule and gastrocnemius fuse together, even in

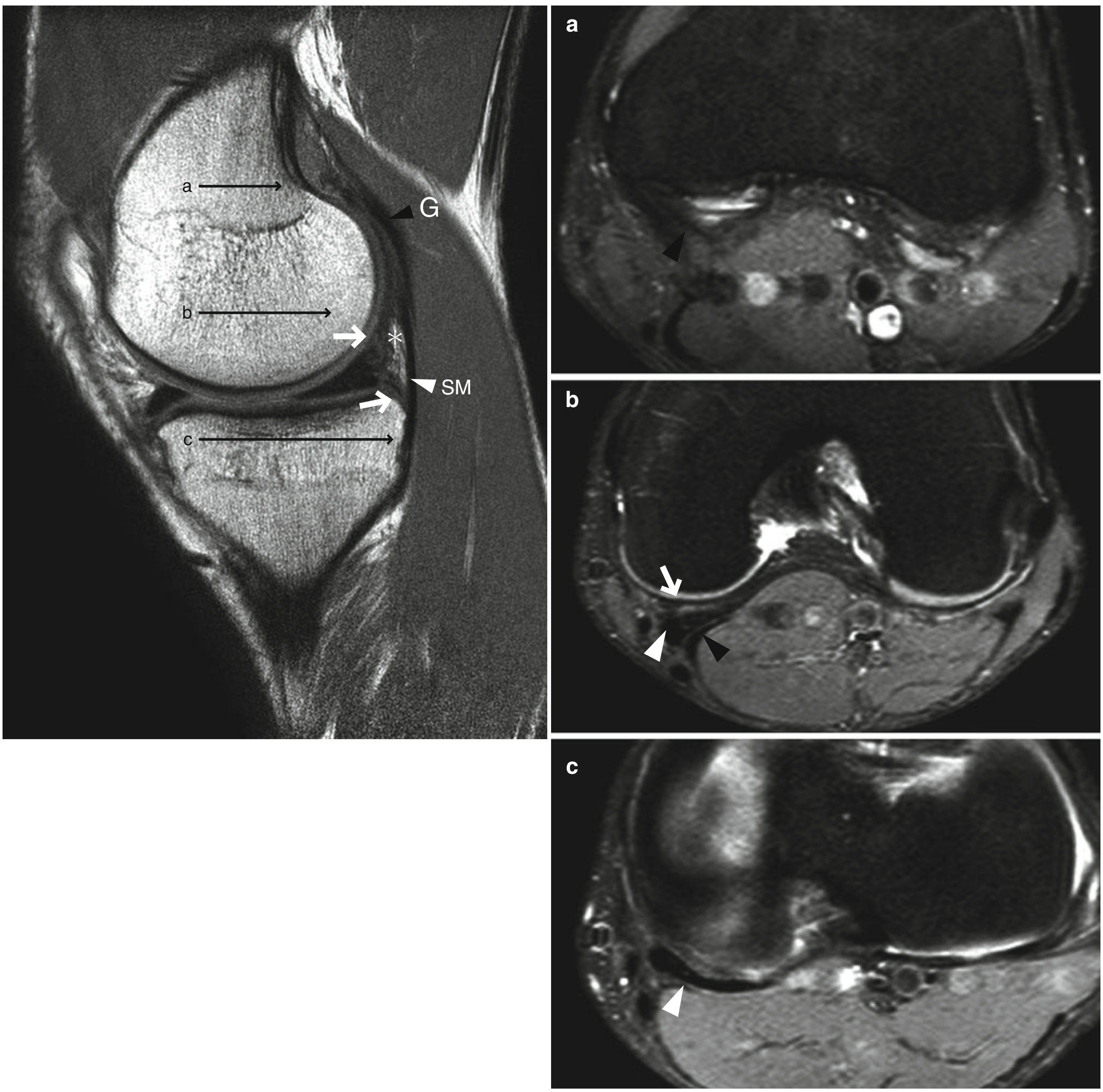

Fig. 12.10 Normal anatomy of the medial posterior capsule. Sagittal image (*left*) and axial images through the horizontal levels annotated in the sagittal image (**a–c**). Please refer to the texts for detailed explanation of the anatomy. Medial posterior capsule: arrow, medial head of gastrocnemius (*G*): *black arrowhead*, semimembranosus tendon (*SM*): *white arrowhead*, subgastrocnemius bursa: *

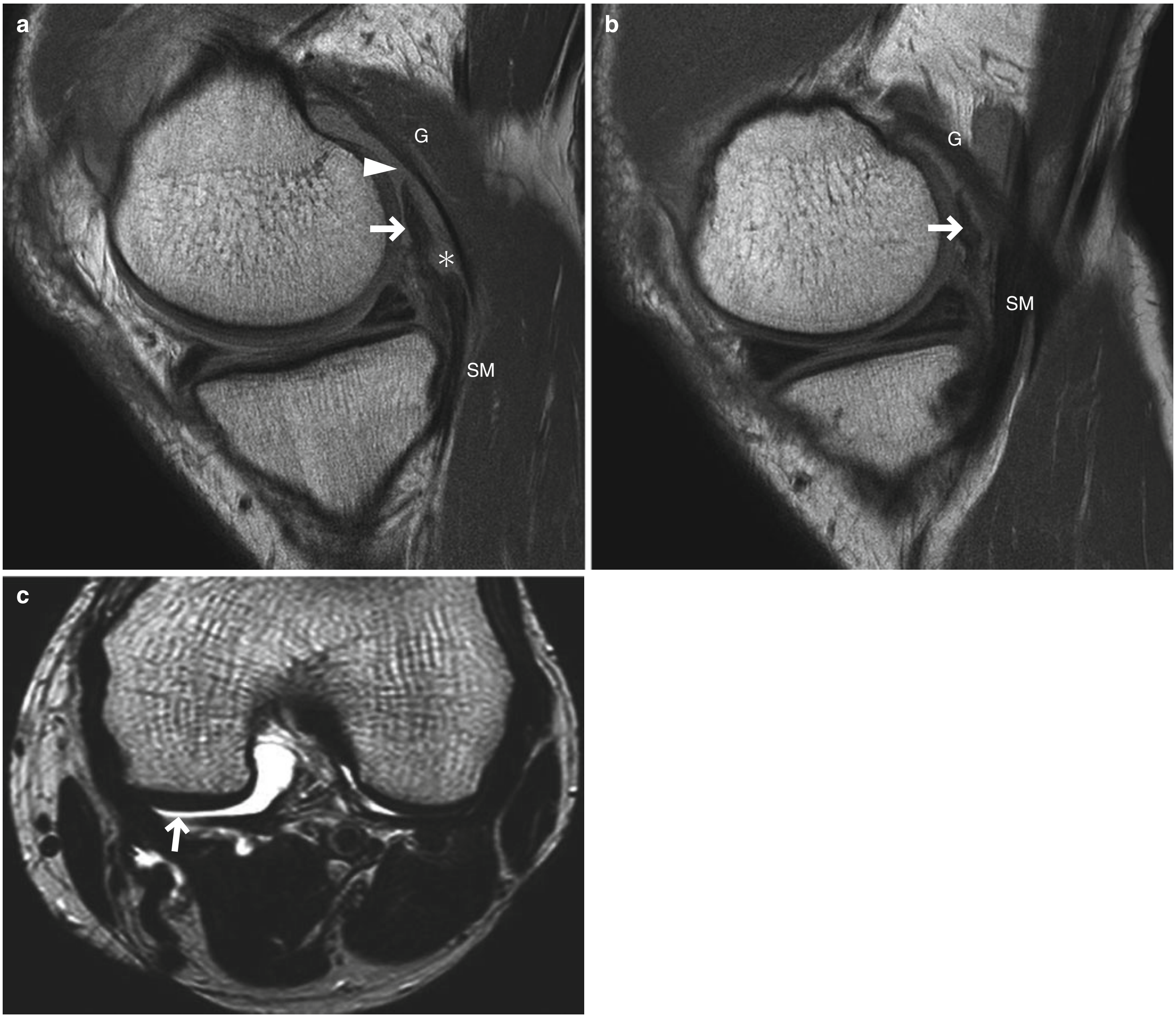

Fig. 12.11 Injury to medial posterior capsule. A man in his 50s with PCL tear. (**a**, **b**) PDWI and (**c**) axial T2WI. There is an injury to the medial posterior capsule (*arrow*), showing abnormal hyperintensity, kinky appearance of fibers, and separation of the fusion site with the gastrocnemius (*arrowheads*, **a**). There is also fluid accumulation within the subgastrocnemius bursa (*). *G* medial head of gastrocnemius, *SM* semimembranosus tendon

a normal state. Because subgastrocnemius bursa communicates with the popliteal cyst through an opening between the medial head of gastrocnemius and the semimembranosus tendon (Fig. 12.7c), consequently the joint capsule itself communicates with the popliteal cyst.

- Popliteal cyst becomes enlarged if there is pathologic accumulation of fluid.
- If there are loose bodies or hemorrhagic component in the joint capsule, they may move into the popliteal cyst through the communication (Fig. 12.12).
- Posterior capsule has a gap at the middle portion, and lymphatic vessels and nerves enter from the popliteal fossa into the intra-articular space through this opening (Fig. 12.13).

Reference

De Maeseneer M, Van Roy P, Shahabpour M, Gosselin R, De Ridder F, Osteaux M. Normal anatomy and pathology of the posterior capsular area of the knee: findings in cadaveric specimens and in patients. AJR. 2004; 182:955–62.

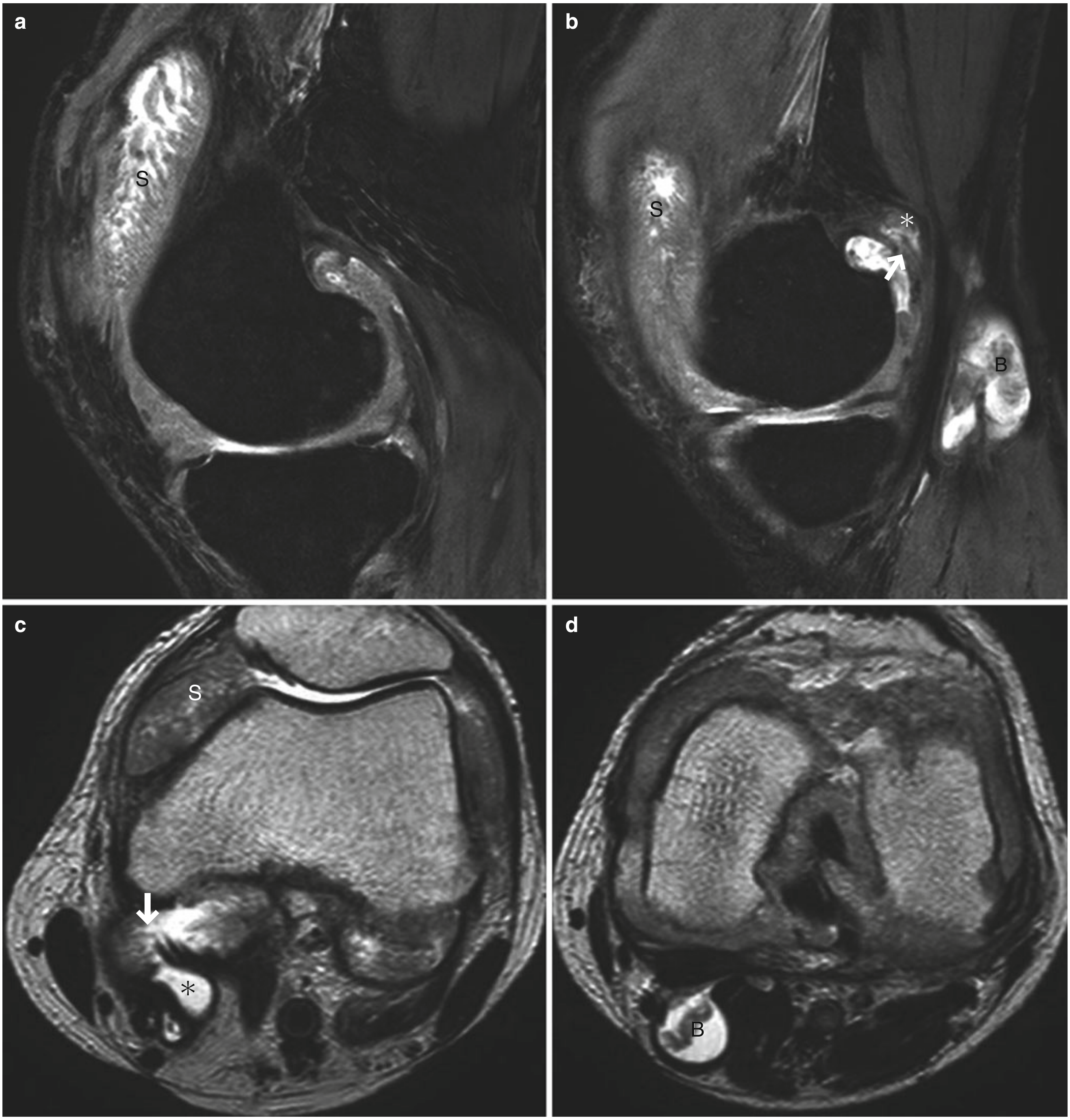

Fig. 12.12 **Synovial osteochondromatosis and the popliteal cyst**. A man in his 60s. (**a**, **b**) FS T2*WI and (**c**, **d**) axial T2WI. The patient has synovial osteochondromatosis, which is mainly seen in the suprapatellar bursa (S). Proliferated synovium and chondromas are also seen in the suprapatellar bursa (**S**). and the popliteal cyst (**b**) (In this study alone, it is impossible to tell if these lesions arose within these locations from the beginning or they moved from other locations.) Knee joint space communicates with the subgastrocnemius bursa through the opening (*arrow*) between the joint capsule and the gastrocnemius (*arrow*)

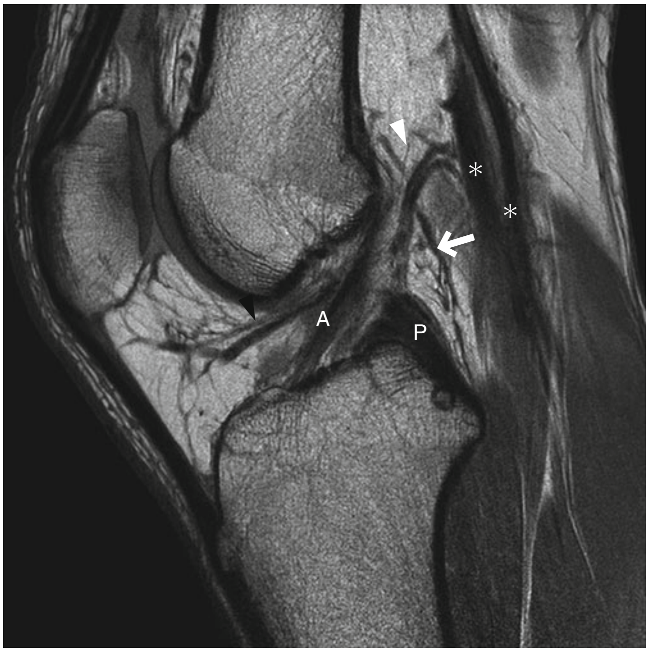

Fig. 12.13 Entry of the vessels through the gap at the middle portion of the posterior capsule. Vessels from the popliteal artery/vein (*white arrowhead*) enter into the intra-articular space piercing through the gap of the posterior capsule. A hypointense linear structure running in front of ACL is a blood vessel (*black arrowhead*), not an infrapatellar plica (see Sect. 11.8.3)

12.5 Bursa and Bursitis

- Naming of bursae is variable, and details can be found in anatomical textbooks. In this book, we will focus on major bursae that are relevant to our clinical practice (Fig. 12.14). If the bursae are subjected to repetitive mechanical stress, infection, or bleeding, the amount of fluid inside them increases, causing swelling and pain (bursitis).

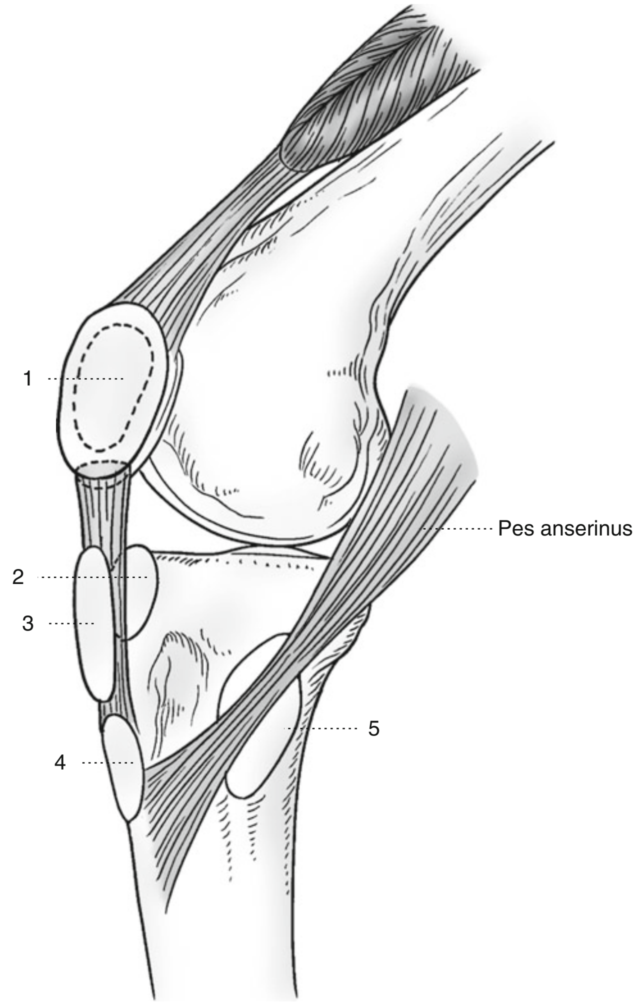

Fig. 12.14 Major bursae around the knee. (*1*) Prepatellar bursa. (*2*) Deep infrapatellar bursa. (*3*) Superficial infrapatellar bursa. (*4*) Pretibial bursa. (*5*) Pes anserine bursa

Reference

Tschirch FTC, Schmid MR, Pfirrmann CWA, Romero J, Hodler J, Zanetti M. Prevalence and size of meniscal cysts, ganglionic cysts, synovial cysts of the popliteal space, fluid-filled bursae, and other fluid collections in asymptomatic knees on MR imaging. AJR. 2003;180:1431–6.

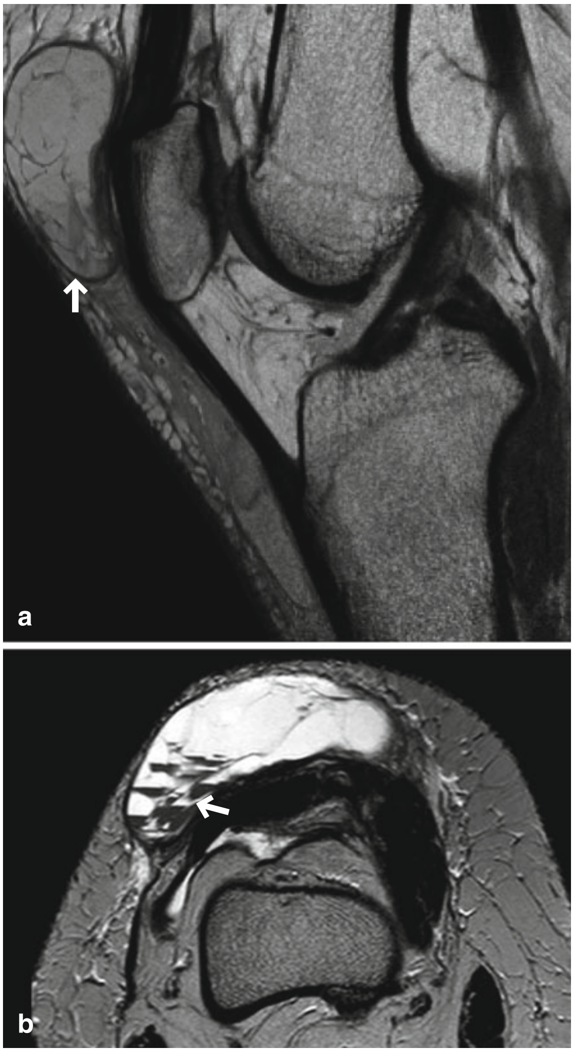

Fig. 12.15 **Prepatellar bursitis with bleeding**. A woman in her 40s. (**a**) PDWI and (**b**) axial FS T2WI. There is a cystic lesion showing fluid-fluid levels (*arrows*) within the subcutaneous tissue anterior to the patella. These are suggestive of prepatellar bursitis with associated bleeding

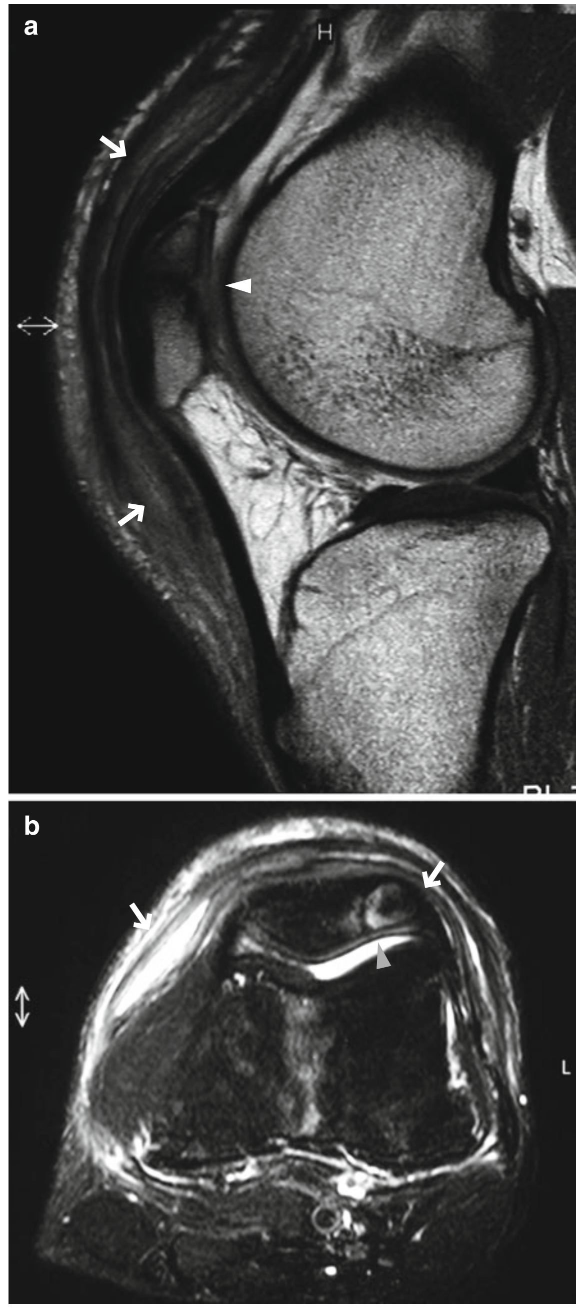

Fig. 12.16 **Extensive prepatellar bursitis**. A male wrestler in his late teens. (**a**) PDWl and (**b**) axial FS PDWl. There is an extensive fluid-containing space (*arrows*) within the subcutaneous tissue anterior to the patella. Note the patella bipartita (*arrowheads*)

12.5.1 Prepatellar Bursa

- Located anteriorly between the patella and the subcutaneous tissues.
- Bursitis results from overuse injury or chronic trauma, often due to frequent kneeling and crawling, and is usually referred to as “housemaid’s knee” or “carpet-layer’s knee.” Also common in sports such as judo and wrestling.
- Effusion and hematoma are common (Fig. 12.15).
- Effusion and the surrounding edematous swelling may spread extensively. It may later form a scar tissue (Figs. 12.16 and 12.17).
- It may communicate with superficial infrapatellar bursa or pretibial bursa.

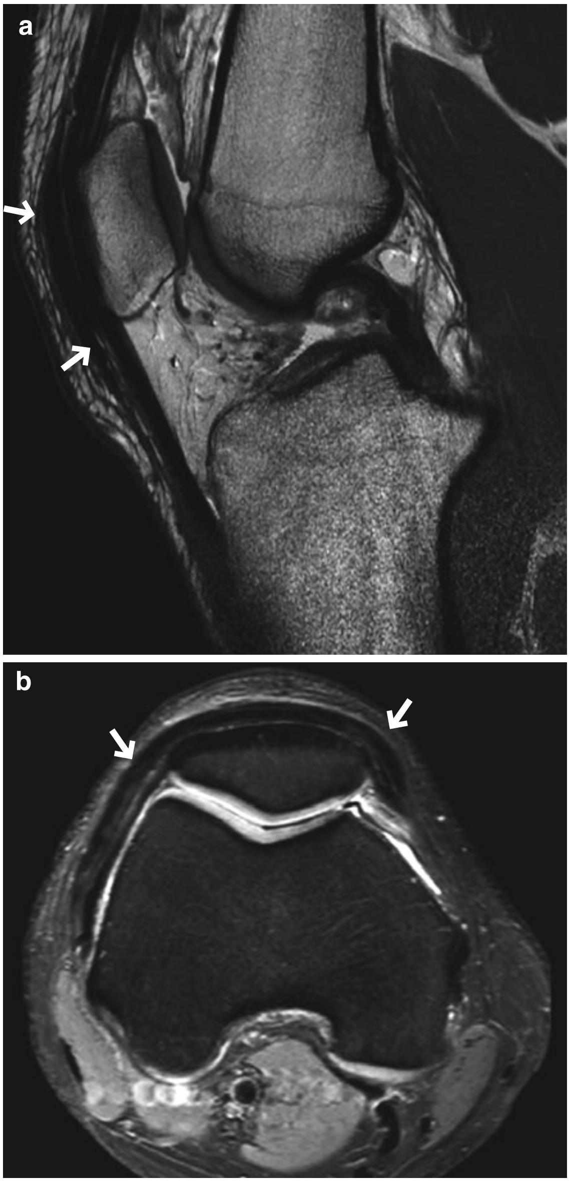

Fig. 12.17 **Scar tissue following prepatellar bursitis**. A male judo wrestler in his 20s. (**a**) PDWl and (**b**) axial FS PDWl. There is an extensive hypointense band (*arrows*) within the subcutaneous tissue anterior to the patella, suggestive of scar tissue following prepatellar bursitis

12.5.2 Superficial Infrapatellar Bursa

- Located between the patellar tendon and the overlying skin (Fig. 12.18).
- It may communicate with prepatellar bursa superiorly and with pretibial bursa inferiorly.

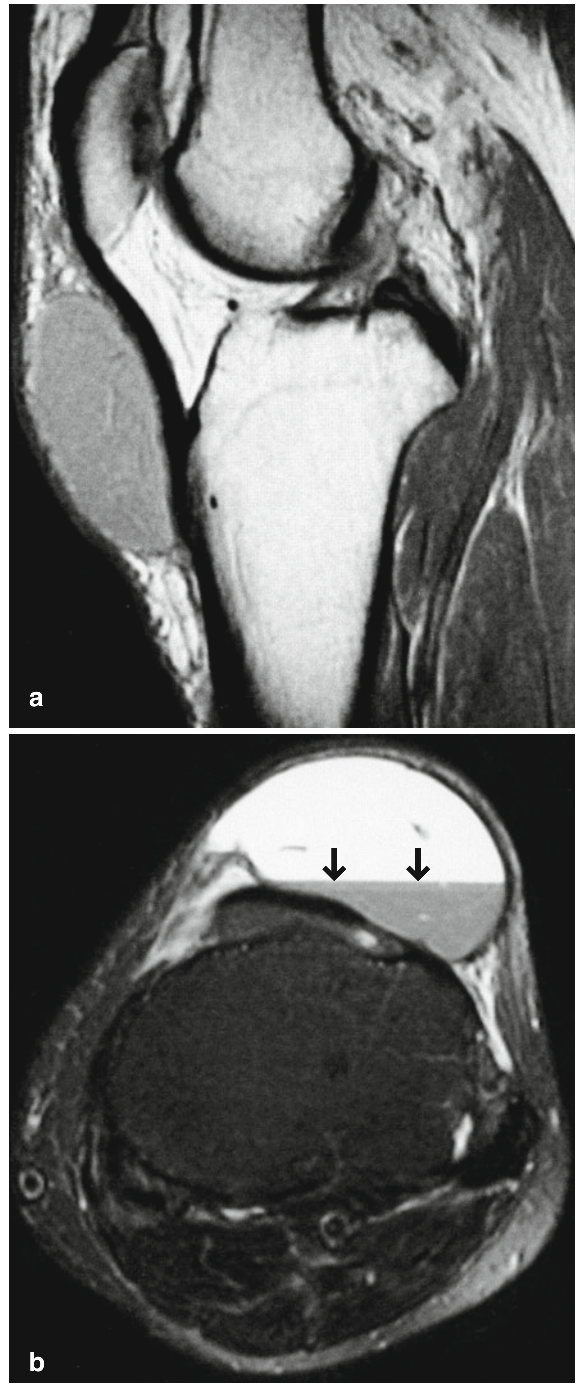

Fig. 12.18 **Superficial infrapatellar bursa**. A woman in her 50s. (**a**) PDWI and (**b**) axial FS T2WI. There is a fluid-containing space within the subcutaneous tissue below the patella. Bleeding inside the lesion creates the fluid-fluid level (*arrows*)

Fig. 12.19 **Deep infrapatellar bursa (nonpathologic)**. A man in his 60s. T2*WI shows a small bursa between the patellar tendon and the tibial tuberosity (*arrow*). This is a common finding in a normal knee

Fig. 12.20 **Deep infrapatellar bursitis**. A woman in her 70s with knee osteoarthritis. T2*WI. A large amount of fluid is seen in the deep infrapatellar bursa (*arrows*), suggesting bursitis. The lateral tibiofemoral joint space is narrowed (*arrowhead*). There is extensive joint effusion

12.5.3 Deep Infrapatellar Bursa

- Located between the posterior margin of the distal part of the patellar tendon and the anterior tibia.
- Commonly seen in normal knees on MRI (Fig. 12.19).
- Deep infrapatellar bursitis may be part of overuse syndrome seen in jumpers and runners.

12.5.4 Pretibial Bursa (Fig. 12.21)

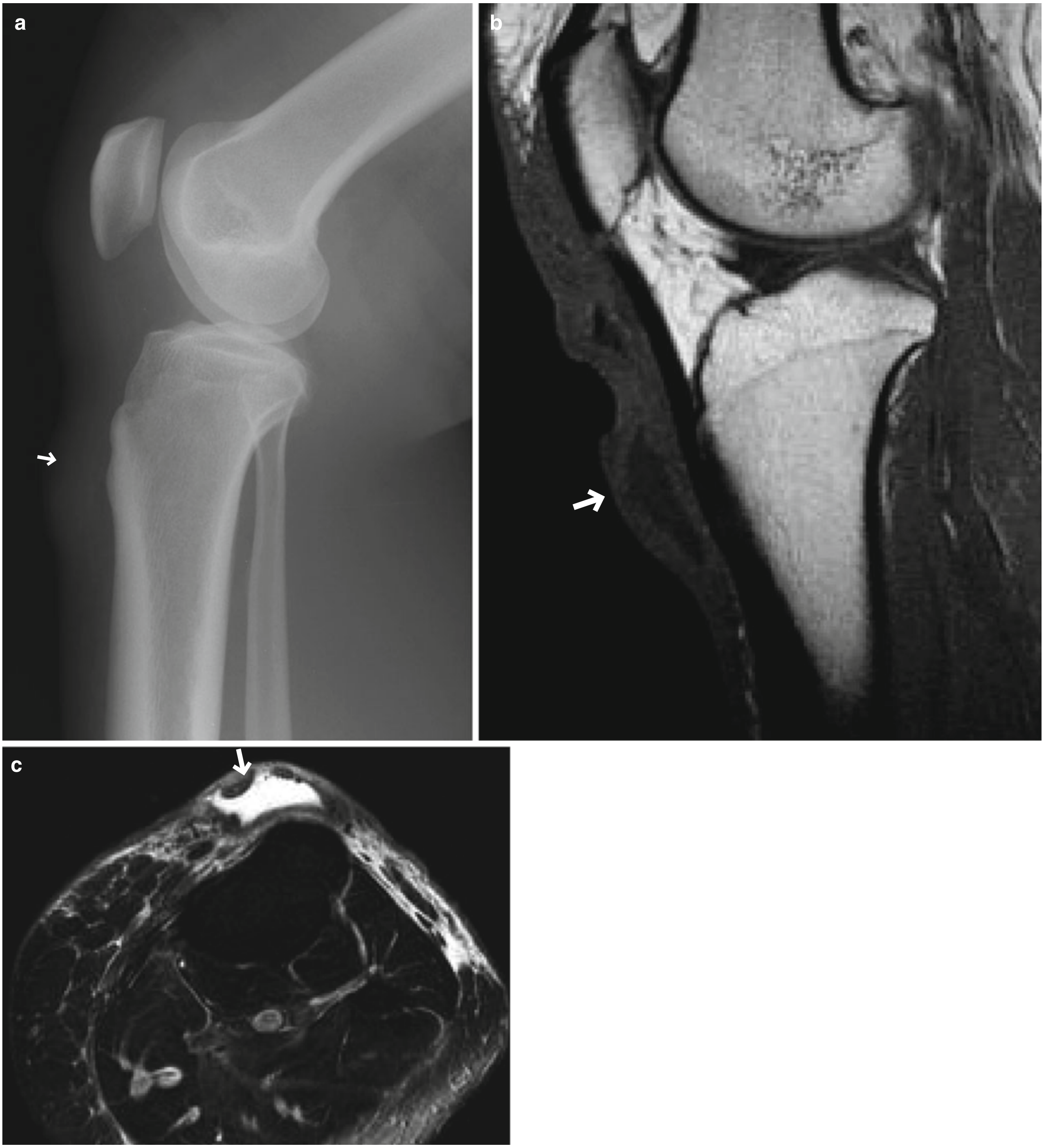

Fig. 12.21 **Pretibial bursitis**. A woman in her 30s. (**a**) Lateral radiograph, (**b**) PDWI, and (**c**) axial FS T2WI. There is extensive swelling and fluid accumulation (*arrows*) within the subcutaneous tissue anterior to the tibia

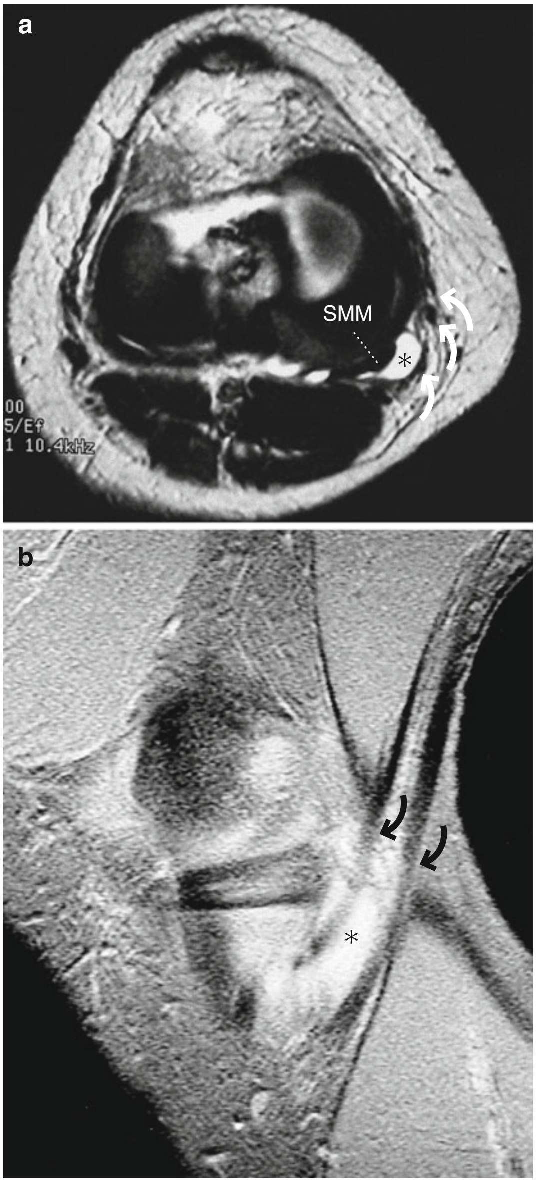

Fig. 12.22 **Pes anserine bursa (nonpathologic)**. A woman in her 40s. Axial T2WI (**a**) and (**b**) T2*WI. There is a small bursa (*) deep to the pes anserinus (*curved arrows*). *SMM* semimembranosus tendon

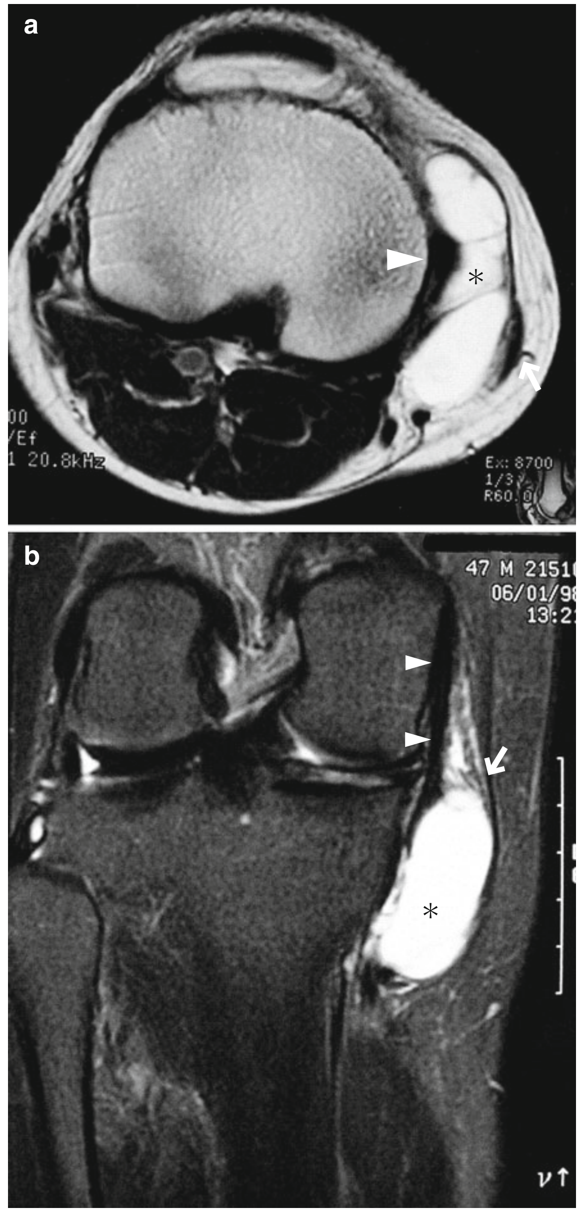

Fig. 12.23 **Pes anserine bursitis**. A man in his 40s. (**a**) Axial T2WI and (**b**) coronal FS T2WI. There is a multiloculated cystic lesion (*) between the pes anserinus (*arrow*) and MCL (*arrowheads*)

12.5.5 Pes Anserine Bursa

- Located along the medial aspect of the tibia separating the pes anserinus from the tibial insertion of the medial collateral ligament and the bony surface of the medial tibial condyle (Fig. 12.22). The pes anserinus is formed by the conjoined tendons of the sartorius, gracilis, and semitendinosus muscle and inserts along the anteromedial surface of the tibia. (Also see Chap. 5.)
- Relatively common in obese persons and athletes.
- If traumatized or inflamed, it becomes swollen and palpable (Fig. 12.23).
- May occur following a MCL injury.
- Posterior to the pes anserine bursa lies semimembranosus-MCL bursa, which wraps the semimembranosus from anterior direction showing a “reverse U” shape.

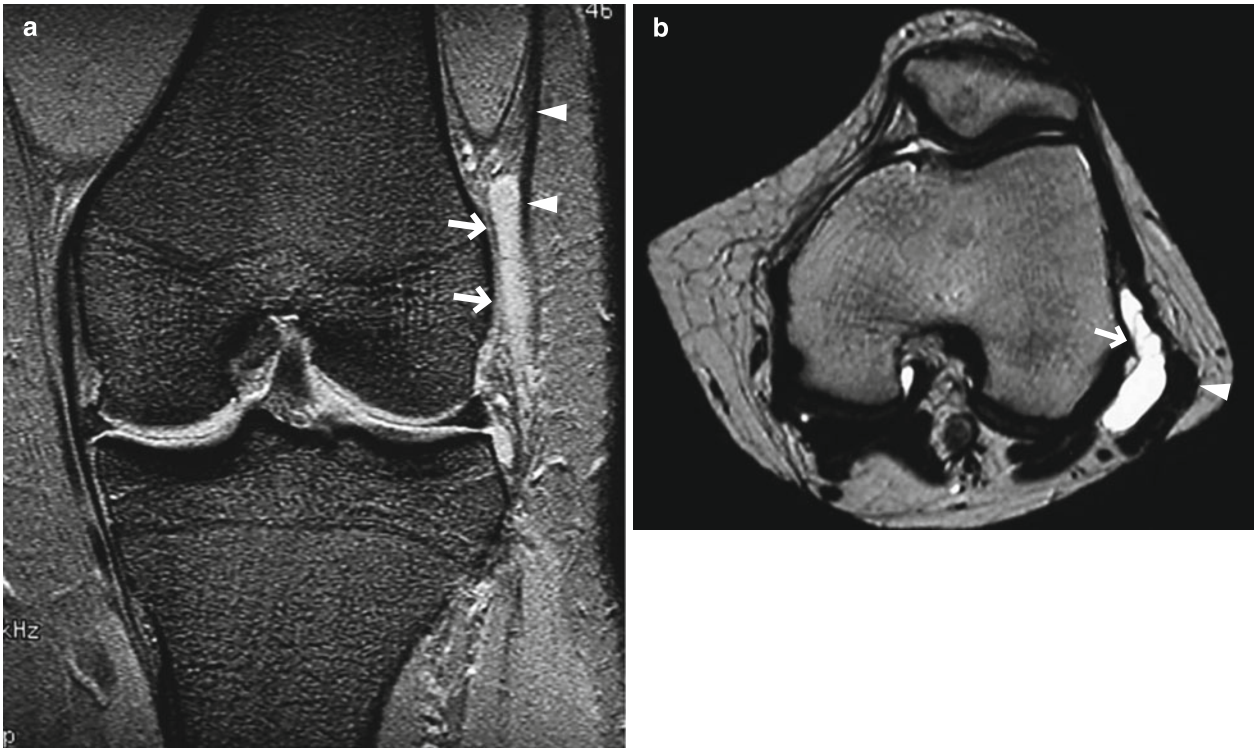

Fig. 12.24 **Iliotibial bursitis**. A woman in her 40s. (**a**) Axial T2*WI and (**b**) axial T2WI. There is a cystic lesion (*arrows*) between the iliotibial band (*arrowhead*) and the lateral femoral condyle

12.5.6 Iliotibial Bursa

- Located between the distal part of the iliotibial band proximal to its insertion on Gerdy's tubercle and the adjacent tibial surface.
- Iliotibial bursitis (Fig. 12.24) is usually caused by overuse injury and varus stress of the knee, commonly in the long-distance runners. Pathogenesis is similar to that of iliotibial band friction syndrome (see Chap. 6).

12.6 Periarticular Ganglion

- Ganglionic cysts may be present within periarticular muscles and the surrounding interstitium (Fig. 12.25). Unlike the aforementioned bursae, these ganglionic cysts usually show multiloculated appearance, but it is difficult to differentiate them from fluid-containing bursae on the basis of MRI alone. Moreover, there is little clinical significance in doing so.

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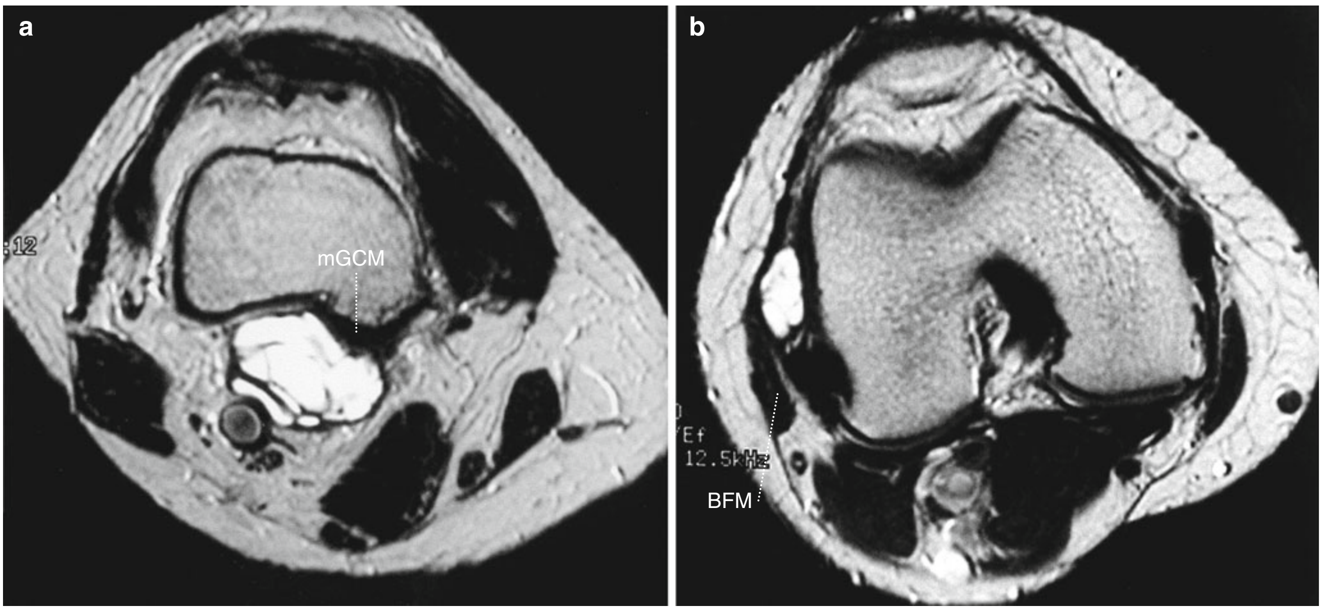

Fig. 12.25 **Periarticular ganglion**. (**a**) A woman in her 50s. There is a multiloculated cystic lesion behind the distal femur. (**b**) A woman in her 30s. There is a multiloculated cystic lesion deep to the biceps femoris tendon. *mGCM* medial head of gastrocnemius, *BFM* biceps femoris muscle

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