2 Imaging Following Knee Injury

Tina Zahel and Heike Einhellig

2.1 Plain Imaging

2.1.1 Introduction

Plain imaging of the knee in an acute knee trauma is one of the most frequently performed radiological examinations in emergency departments [1, 2]. In spite of newer technologies, plain imaging sustains its position. It is readily available, faster, and cheaper compared to computed tomography. In addition, it enables an easy overview for therapy planning and helps to avoid delayed diagnoses, which may result in a poorer clinical outcome. Routinely performed two views [anterior posterior (ap) view, lateral view] are the minimum for initial evaluation of acute injuries of the knee.

In some cases, even for specialists, it is quite difficult or even impossible to detect subtle fractures on radiographs. Undislocated fractures can be missed, e.g. depression fracture of the tibia, stress, or insufficiency fractures. Additional views such as skyline patellar and tunnel view, oblique views, or ap views with varus and valgus stress can be helpful to increase sensitivity of fracture diagnostics [3–6]. Fractures can be missed due to insufficient positioning of the patient (dislocation, pain). It was proven that 15% of patients, especially those with multiple fractures, show an insufficient positioning, which may prohibit an accurate fracture diagnosis or fracture exclusion [7]. It has been suggested that four views (e.g. obliques) instead of two standard views (ap and lateral) show a higher sensitivity in fracture detection [5].

In daily emergency routine, two radiographs perpendicular to each other are the initial diagnostic procedure. Special views can be performed to improve evaluation of superimposed structures such as intercondylar area or patella (Fig. 2.1).

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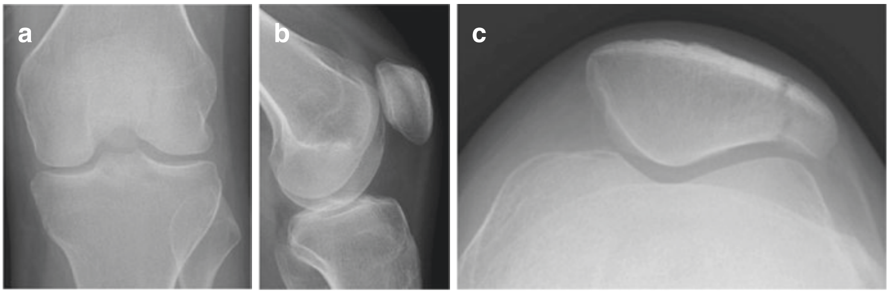


Fig. 2.1 Vertical patella fracture. Almost invisible in standard views. Best seen in axial view. (**a**) ap view (**b**) lateral view (**c**) axial view

The ossification of the patella starts between 3 and 5 years and normally ends in adolescence. Incomplete ossification with remaining ossification centres can mimic patella. The epiphyses of the distal femur and the proximal tibia and proximal fibula are present until 17–19 years [8].

2.1.2 Technique

For all views the patient has to undress his/her knee. Woman need to negate pregnancy. Gonadal protection or lead gown must be attached.

The average effective dose of the knee is approximately 0.01 mSv for radiography [9].

2.1.2.1 Standard Views

Knee Anteroposterior (AP) View

The main indication for knee radiography is fracture diagnosis in emergency departments. Most of the times, fractures of the femoral condyles or tibia plateau can easily be seen on ap views, especially in cases with dislocation. But a closer look is necessary to evaluate other osseous injuries such as Segond fracture, intercondylar tubercles fracture, or luxation (displacement of the tibia with respect to the femur). Also (lipo-)hemarthrosis (joint effusion arranged in layers in the recessus patellaris) is a good indirect sign in serious knee injuries in case of joint involvement of the fracture. Beyond that, knee radiography is also performed in non-acute situations, e.g. for tumours, infections, degeneration, osteochondritis dissecans, or Osgood-Schlatter.

Patella fractures or non-dislocated tibia plateau fractures are often missed in standard ap views.

For an ap view, supine position of the patient with stretched legs (sometimes minimal flexion in the joint) is necessary. The leg is normally rotated inwards by placing femoral epicondyles parallel with a centred patella. The central ray must be orthogonal on the joint space (about 1 cm below the lower patella apex) with passing x-rays from anterior to posterior. In some cases, the tube is angled to the patella apex in an angle of 5°–7° cephalad (Fig. 2.2).

Quality criteria for ap views of the knee are an open femorotibial joint space, symmetrical located femoral condyles with a centred patella, a line appearance of the lateral tibia plateau, and a slightly oval appearance of the medial tibia plateau. The fibula head is partially superimposed by the tibia. The patella is completely superimposed.

Potential mistakes are made if (1) the knee is not in the centre of the radiograph; (2) the knee is not stretched enough (the lower patella pole covers the eminentia intercondylaris and the lateral tibial plateau gets an oval shape); and (3) the patella is not medial enough [fibula head projects itself on the tibial head and the distal part of the patella protrudes the distal femur. Or the patella protrudes the medial side of the femoral edge and the fibula head is almost completely visible if the central ray is displaced (results in an oval shape of the medial and lateral tibia plateau)].

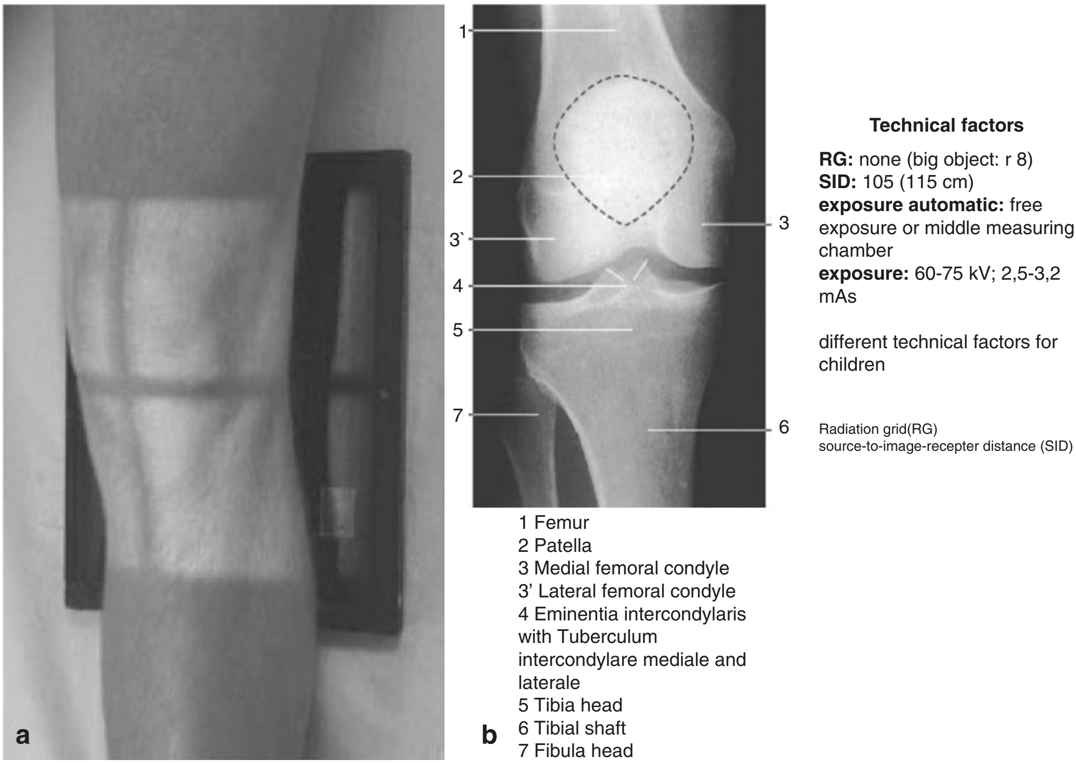


Fig. 2.2 (**a**) Positioning for ap view (**b**) anatomy of ap view

Shortcomings of an ap view of the knee especially apply to the patella and the tibial head. In an ap view of the knee, it is often hard to distinguish a true patella fracture from a patella bipartite (upper outer quadrant affection) or other osseous variants. For this reason, additional views may be necessary.

Some fractures, e.g. depression fractures of the tibia, can also be subtle in an ap view. For preventing an overlook of a tibia fracture, it can be helpful to follow the osseous tibial joint contour for interruptions or irregularity. Also the tibiofemoral alignment should be correct (shift less than 5 mm). If hemarthrosis is visible, further investigation is indispensable, even if no osseous injury can be seen on radiographs.

Valgus and varus stress views are options for evaluation of collateral ligaments.

Further imaging techniques such as ap weight-bearing (Rosenberg) or ap weight bearing radiographs are meant for evaluation of joint space narrowing and are not meant for fracture evaluation.

Knee Lateral

The lateral view is part of standard knee diagnostics. It enables an uncovered look on the patella in a lateral profile. Also the distal part of the femur, the proximal ends of the fibula and tibia, and the adjacent soft tissues (quadriceps and patellar tendon and suprapatellar pouch) can be assessed. This view is the optimal choice to look for lipohemarthrosis. Moreover, suspicions of luxation, osteoarthritis, or Osgood-Schlatter are typical indications.

The patient lies in an exact lateral position on his/her affected side. The affected knee is slightly flexed (30°–45° flexion; relaxation of the muscles with view on the maximum volume of the joint space) and brought forwards to bring the knee into a lateral position on the image receiver (IR). The unaffected leg is almost stretched and far in front of the affected knee. Immobile patients can put the healthy leg behind the x-rayed knee. The foot of the affected knee is positioned with a wedge-shaped bolster. The epicondyles and the patella must be vertical to the plane of the underlay and congruent with each other. Sometimes fixation of the healthy side with bolsters is necessary to avoid overrotation of the body. The central ray is focused, perpendicular mediolateral to the knee joint space, and 2 cm below the apex of the patella. The x-ray tube can be slightly angulated for a perpendicular central ray to the joint space (5° angle cephalad) (Fig. 2.3).

Another highly preferred option for lateral radiographics for severely injured or immobile patients is the horizontal beam view (cross lateral view). Patients lie on their back. The affected and slightly flexed (ca. 30°) knee is supported with bolsters. The patella is oriented frontwards. The image receiver is positioned medial with a lateromedial central beam.

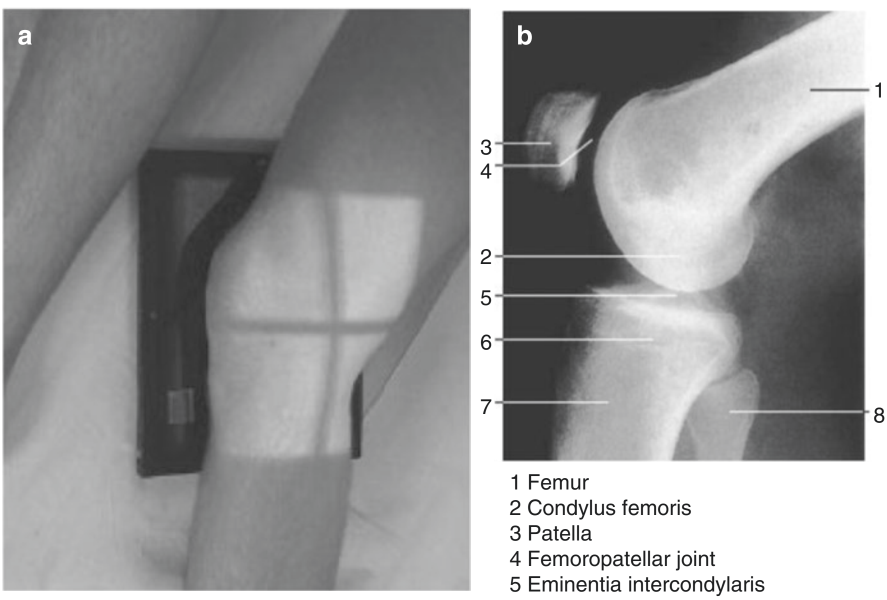
Quality criteria are congruent femoral condyles to each other, an open retropatellar space, and a plane-parallel appearance of the tibial bearing area. The patella shows a lateral profile. The fibular head is hidden in the posterior part of the tibia.

Low quality is performed with nonmatching condyles. Either the leg is overturned too much or too little. If so, one can see the full fibula head with an overlain patella or you can find an overlain fibula head and an overlain patella. If the femur condyles show a double contour, the lower leg is not in the same height as the thigh.

Lateral views are often better for evaluation of anterior or posterior depression of the tibia plateau. But even in the lateral view, it is often hard or even impossible to evaluate the posterior portion of the tibial head [6, 10]. Here the tibial plateau view can be helpful (15° view with tangential central beam to the tibia plateau). Lateral views can also be helpful to exclude undisplaced fractures of the eminentia intercondylaris [11].

Evaluation of discontinuity of the cortical margin of the distal femur (especially supracondylar) is possible. Tibia plateau fractures can be seen as discontinuity or sclerosis due to impaction. The patella for horizontal fractures can be evaluated (but vertical fractures are often invisible in the lateral view).

Dependent on the clinical findings and the result of the standard views, further views are



1 Femur
2 Condylus femoris
3 Patella
4 Femoropatellar joint
5 Eminentia intercondylaris mediale and laterale
6 Tibia head
7 Tuberositas tibiae
8 Fibula head

Technical factors

See ap view

Fig. 2.3 (**a**) Positioning for lateral view, (**b**) anatomy of lateral view required. Joint effusion can be an indirect sign for meniscal tears and appears as soft tissue density extending behind the quadriceps and prepatellar tendon. The patella can be displaced anteriorly or inferiorly due to large effusions.

For evaluation of ligamentary injuries of the ACL or PCL, stress radiography is possible (Fig. 2.4).

2.1.2.2 Additionals

Patella Axial View

Main indications are vertical fractures, luxations, and degeneration with focus on the patellofemoral joint.

The axial view is the main view in suspicion of patella fracture [7].

Never initiate a patella axial view in cases of transverse or fixed patella fractures.

Several techniques to perform an axial image of the patella exist. The sunrise patella view with a patient in a prone position is the most commonly used projection. Maximum flexion of the preferred knee is necessary for this projection. The ideal positioning shows contact between the thigh and lower leg and a vertical orientation of the patella to the image receiver. The leg can be fixed with a band (Fig. 2.5).

The central ray is angled on the femoropatellar joint and the middle of the image receiver. If

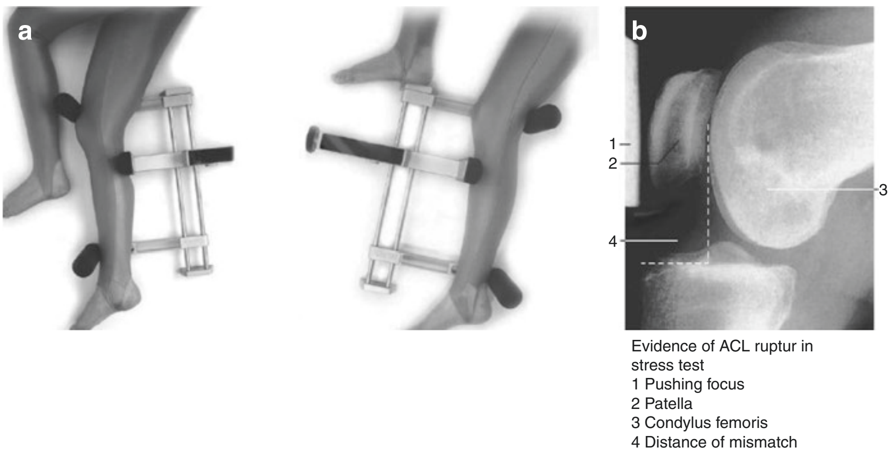


Fig. 2.4 (**a**) Positioning and pressure points for ACL and PCL with Telos device. (**b**) Evidence of ACL rupture in stress test

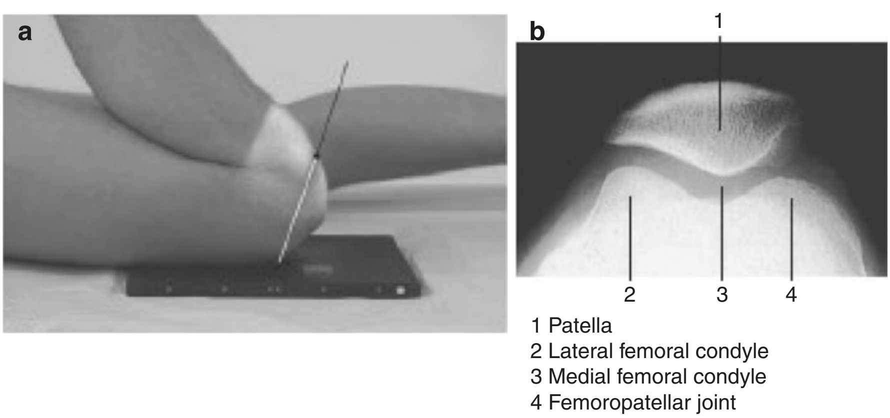


Fig. 2.5 (**a**) Positioning for axial view in mobile patients, (**b**) anatomy of axial view

the joint is not perpendicular, an angulation of the central beam of 15–20% is necessary.

Well-performed axial views provide insight into an open femoropatellar joint.

It can be difficult to reproduce the axial view in prone position due to knee mobility dependent on pain.

In cases of immobile patients, the patella view is also possible for sitting or lying patients. But radiographs in a sitting position are associated with a higher radiation exposure.

The patient sits or lies with a flexed (about 45°) knee. Stabilization of the knee with wedge-shaped bolster is necessary. The patient holds the x-ray plate with his hands and positions the image receiver above the knee perpendicular to the longitudinal axis of the patella (image receptor distance 115 cm). The central ray is focused axial on the femoropatellar joint/perpendicular to the lower patella pole perpendicular to the image receiver. The beam path enters horizontal from caudal (if necessary 5°–10°).

Mistakes are made in case of quadriceps tension (shifted patella) or non-visible femoropatellar joint (beam path incorrect).

For further evaluation of the femoropatellar joint or patella luxation, the so-called en-défilé series (30°, 60°, 90° knee flexion) are possible with increasing knee flexion angle and increasing x-ray tube angulation for tangential horizontal central beam on the femoropatellar joint.

Tunnel View

Loose bodies, degeneration, and fractures with joint involvement in the area of the femur condyles (posteroinferior surface), intercondylar fossa, and intercondylar eminence are typical indications for tunnel view.

Supine position of the patient with an angled knee (45°; fixation of the knee with sandbags). Leg with a slight internal rotation. The patella is centred between the femur condyles. The central ray is zoomed in on the joint space (beneath lower patella pole) in vertical direction to the axis of the lower limb. The image receiver is underneath the knee lying on the examination table. Alternative the patient is in prone position with a flexed knee (45°) and a patella resting on the IR (Fig. 2.6).

Adequate tunnel views offer an open fossa intercondylaris with a line-like lateral tibia plateau and non-covered femoral condyles.

Failed tunnel views show a covered tunnel due to external leg rotation or non-vertical central ray.

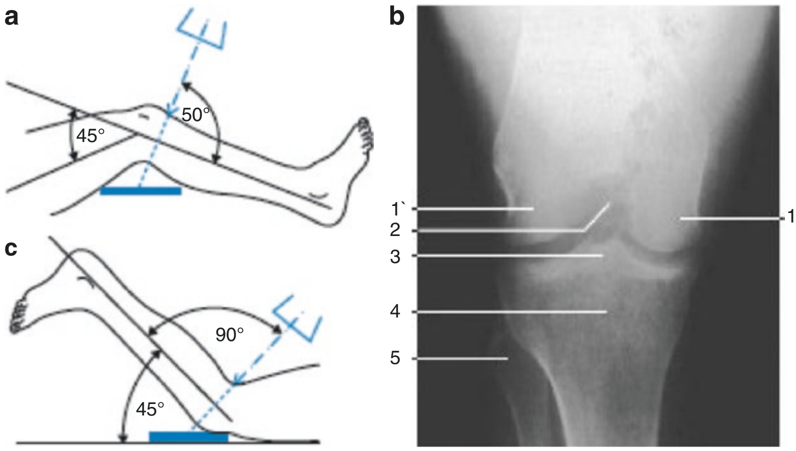
Oblique (Internal or External Rotation)

Oblique fractures of the femur condyles, fibula head fractures, epiphysial injuries, or small avulsion fractures or non-dislocated fractures especially of the tibia often need additional imaging, because they can be easily diagnosed in an oblique view radiograph. However, limitation is found by mobilization of injured patients. Further tumours or inflammatory joint changes or fracture of the fibula head can be assessed.

Supine position with a stretched knee. Foot and leg show an internal *or* external rotation (foot/lower limb rotation of 45° inwards *or* outwards); fixation with wedge-shaped bolster). The central beam is orthogonal on the knee joint space from ventrodorsal and latermedial *or* ventrodorsal and mediolateral (Fig. 2.7).

Criteria for a well-performed oblique radiograph are an open knee joint space and a partially non-covered patella. The fibula head is completely free by 45° internal rotation (fibula head view).

Most of the other known knee imaging projections are not used for emergency diagnostics, but they may be used for other clinical indications, e.g. osteoarthritis.



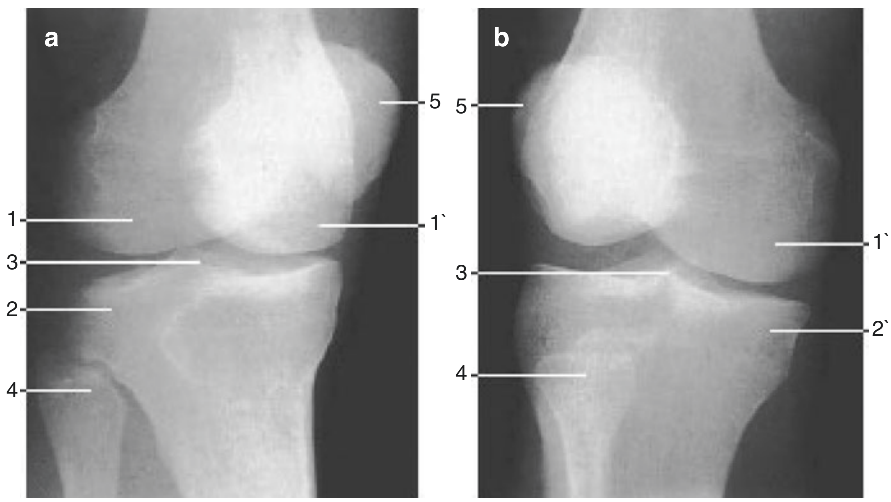
Technical factors

RG: no
Filter: no
SID: 105 cm
Exposure: 60-75 kV; 3,2 mAs
IR: 18x24 cm, landscape
Collimation: centre

different technical factors for children

1 Medial femoral condyle
1‘ Lateral femoral condyle
2 Fossa intercondylaris (tunnel)
3 Eminentia intercondylaris
4 Tibia head
5 Fibula head

Fig. 2.6 (**a**) Possibilities of positioning for tunnel view, (**b**) anatomy of tunnel view



45° internal rotation

45° external rotation

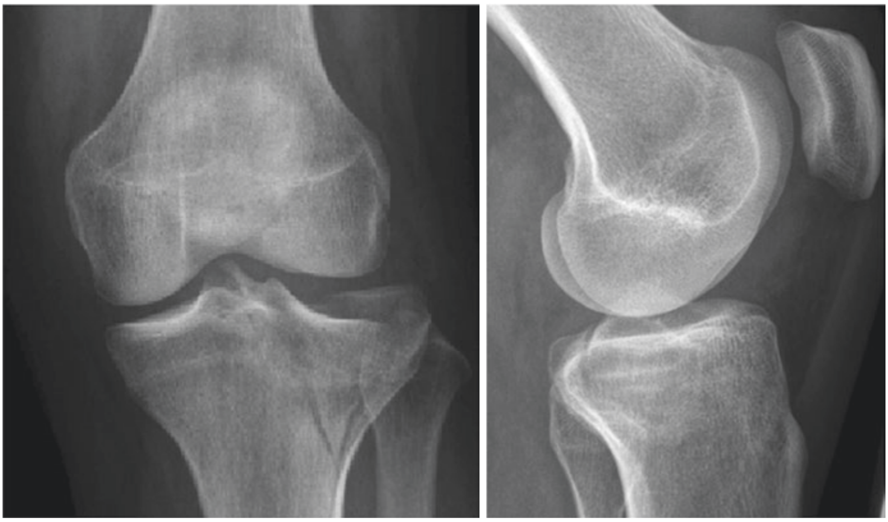
1 Lateral femoral condyle
1‘ Medial femoral condyle
2 Lateral Tibia plateau
2‘ Medial Tibia plateau
3 Eminentina intercondylaris
4 Fibula head
5 Patella

Fig. 2.7 Anatomy of (**a**) internal or (**b**) external rotation

2.1.3 Examples and Catches to Avoid

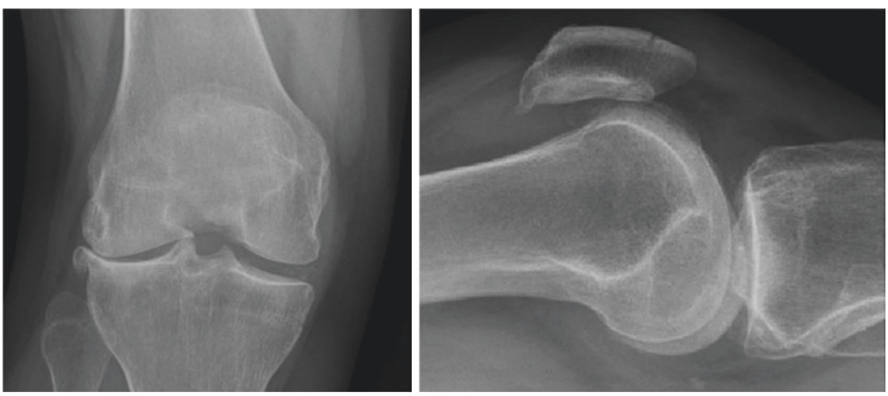
(Courtesy of Klinikum recht der Isar, Munich, Germany, Institute of Radiology)

Lateral Tibia Plateau Fracture



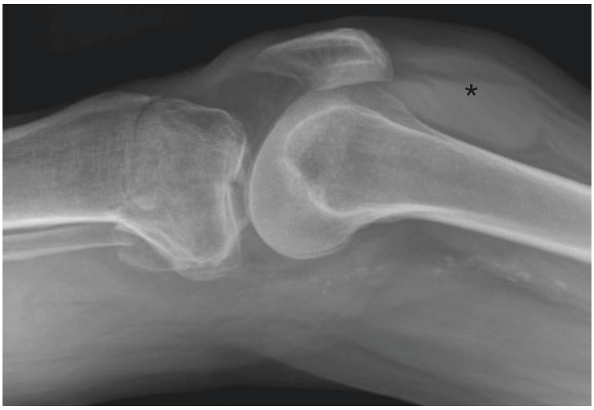
Multifragmentary fracture of the tibia head with impression of the lateral tibia plateau

Patella Fracture



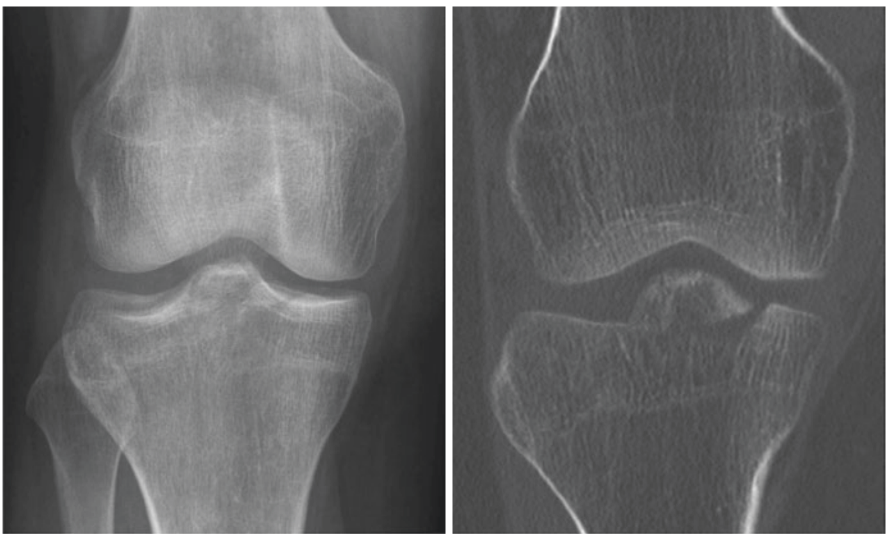
Almost invisible fracture line of the patella fracture in ap view

(Lipo-)hemarthrosis



Fat-blood fluid level (*) (lipohemarthrosis) in a patient with multifragmentary fracture of the tibia head. Best seen in lateral view

Intercondylar Eminence Fracture



Intercondylar eminence fracture with involvement of the medial tibia plateau. Additional impression fracture of the dorsal part of the lateral tibia plateau

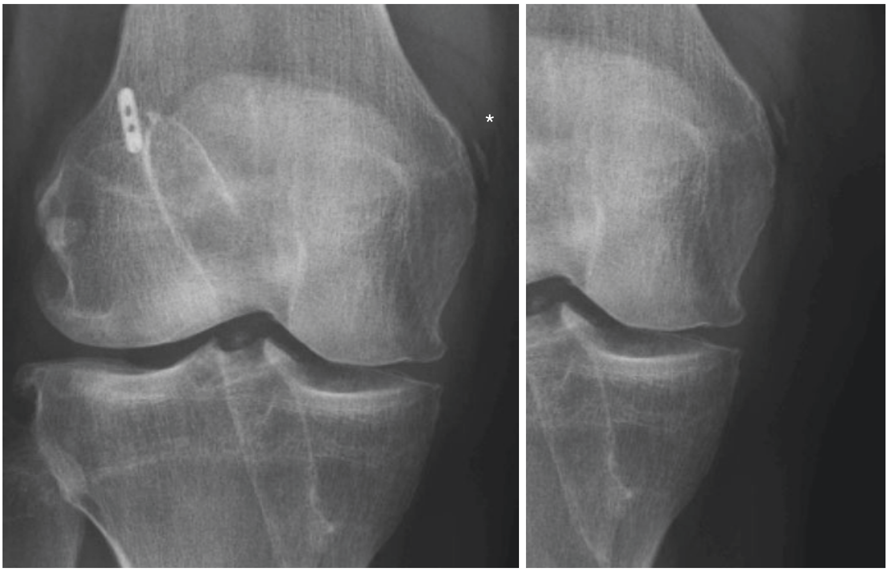
Segond Fracture

Avulsion fracture of the lateral tibia head. Further MRI evaluation with special focus on ACL is essential

Osgood-Schlatter Disease

Osgood-Schlatter with bony rest

Pellegrini-Stieda Disease

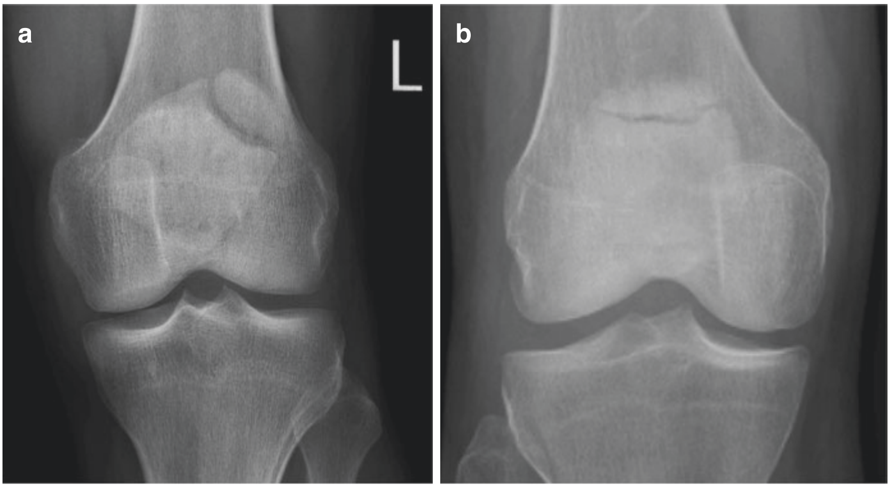


Posttraumatic ossification (*) of the medial collateral ligament adjacent to femoral margin in a patient with reconstructed ACL

Fabella

Common sesamoid bone in the lateral head of the m. gastrocnemius in a knee with osteoarthritis

Patella Bipartite



(**a**) Patella bipartita with non-ossification superolateral (loco typico) and non-sharp fragments, (**b**) Horizontal patella fracture with sharp fragments

2.2 Special Imaging

2.2.1 Introduction

The knee is an anatomically complex joint. Various ligamentous, tendinous, and meniscal structures attaching to the bone are prone to injury. In trauma patient workup, it is crucial to detect, visualize, and classify even small fractures.

Availability and quality of modern imaging techniques aside from plain radiography have rapidly developed in the last decade. Nowadays, it is unthinkable in many clinical issues to abstain from cross-sectional imaging techniques like computed tomography (CT) or magnetic resonance imaging (MRI).

2.2.2 Imaging Modalities

2.2.2.1 Computed Tomography (CT)

Two-plane radiography still is the gold standard in fracture diagnosis. Most special projections in plain radiography, however, have become obsolete. They have been replaced by CT. If clinical findings are suggestive of fracture, even though standard projections in plain radiography are negative, additional CT imaging is advisable [12].

The first prototype CT scanner, developed by Godfrey Newbold Hounsfield, was used 1971 in London, England. Cross-sectional CT images are based on the radiodensity of different human tissues. Density measurements are documented in Hounsfield units. It was in the early 1970s that CT was first used in hospitals. Since then, technology has rapidly developed. In the early 1990s, the introduction of spiral CT scanners allowed for a continuous movement of the patient through the CT scanner. Instead of acquiring single slices, volumetric data could now be collected. Thus, multiplanar reconstructions were possible. Soon the introduction of multidetector scanners (MDCT) followed. Acquisition of multiple slices at the same time was now feasible in a short time. Thinner slides could be scanned in a much shorter time. In 2005, the first dual-source CT scanner was introduced. Dual-energy CT scanners have two x-ray sources with different energy levels rotating at the same time. They allow for a more precise tissue characterization.

Postprocessing methods include multiplanar reformation (MPR), maximum intensity projection (MIP), and volume rendering techniques (VPR). MPR and MIP are two-dimensional reconstructed images in any optional plane, the standard being axial, coronal, and sagittal. MIP images reconstruct highest density objects, e.g. contrast agent in vessels. VPR are three-dimensional images. The latter may be used for a better visual understanding in clinical demonstrations or for the patient [13].

In the acute polytrauma setting, computed tomography has become indispensible. It has been shown that whole-body CT increases the probability of survival in these patients. Whole-body CT scans, however, are associated with high radiation exposure (10–20 mSv). Particularly in the non-acute setting, it is reasonable to keep radiation dose low [14]. To reduce radiation exposure, it is important to apply radiation according to the ALARA (= as low as reasonably achievable) principle. This principle most importantly implies that examinations should be targeted to selective organs or anatomic regions and that the potentially harmful effects of radiation have to be weighed against good quality images. Effective radiation exposure for plain radiography series of the knee is estimated with 0.02 mSv, while it is approximately tenfold higher for a computed tomography.

Specifically designed imaging protocols and modern data processing techniques, e.g. iterative reconstruction algorithms, allow for considerable dose reduction as well as image quality improvement [15].

In general, CT aids in the clinical decision-making process for conservative or surgical measures of knee fractures. It is important to depict the full extent of the fracture and the fracture pattern. This is particularly true for fractures that involve the joint (Fig. 2.8). Classification systems like the Schatzker classification have been useful to assess initial fracture patterns, plan operative management, and predict prognosis [16].

Furthermore, CT scans may visualize certain types of fractures of the knee joint better compared to plain imaging. CT can reveal radiographically occult fractures—e.g. of the posteromedial corner [17]. Simple patella fractures are usually diagnosed in plain radiography; however, in certain cases, e.g. patella bipartita, complex fractures, or suspicion of osteochondral lesions, additional CT scan may be useful [18]. Tibial plateau fractures generally involve cortical interruption and depression or dislocation of the articular surfaces. Dislocated fractures are associated with a higher risk of ligamentous injuries, which may need further treatment. Compared to

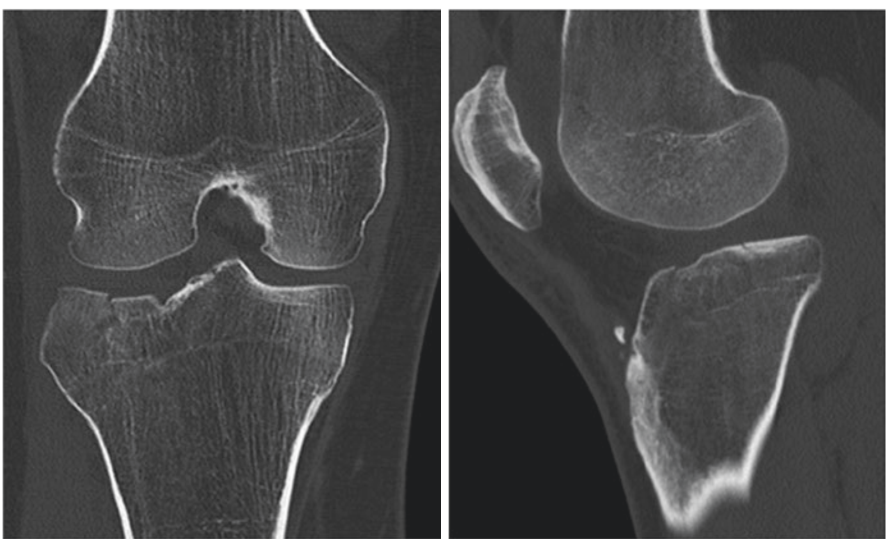


Fig. 2.8 Fracture of the lateral tibia plateau (left: coronar image; right: sagittal image). CT depicts cortical fracture lines with minor displacement and lipohemarthrosis

plain radiography, in complex cases, CT scans render a more accurate visualization of the articular surface. They can also give a diagnostic clue to ligamentous or other soft tissue injuries. It has been shown that initial treatment strategies (based on plain radiography) were modified after exact fracture depiction on CT scans [16].

Knee fracture surgeries, particularly of the tibial plateau, can be very challenging. To result in optimal function of this weight-bearing joint and to avoid early postoperative osteoarthritis, it is necessary to adapt fractures correctly. Congruency of the articular surface needs to be achieved and ligamentous stability needs to be restored. Thus, it is vital to know fracture depression and displacement. CT gives the surgeon important information (fracture depiction, fracture classification, etc.), which facilitates preoperative planning, including operative access or material choice [19].

In addition, volume rendering techniques with 3D pictures can better visualize fracture extent. These pictures are also used in clinical routine to inform the patient about the planned procedure.

CT scans are used on a routine basis to check for the postoperative status, including extraneous material positioning, fracture adaptation, or healing process. Furthermore, in the follow-up, CT aids in the analysis of femoral torsion, especially in patients with chronic instability of the patella or knee osteoarthritis [20].

If needed, application of intravenous iodinated contrast media can better depict potential vessel injury or vessel status. This is particularly true for majorly displaced fractures, lack of pulse in the distal joint, and in suspicion of bleeding (Fig. 2.9). For vessel depiction in knee injuries, CT angiography (CTA) has replaced conventional angiography for the most part [16].

2.2.2.2 Magnetic Resonance Imaging (MRI)

The basis for magnetic resonance imaging (MRI) is the magnetic field, to which the patient is subjected when placed in the scanner. A radiofrequency pulse is applied by a transmitter. This causes changes in magnetization alignment of molecules in the human body. These molecule alignment changes are captured as a signal by a receiver. Additional magnetic fields (gradients) are applied to the patient to allow for selective slice selection in the human body. The data of collected signals can then be used for further image processing, much like image processing in CT scans.

In contrast to other imaging techniques like CT, in MRI more than one tissue-specific parameter determines the contrast of the image. These are proton density, T1, and T2 relaxation times of tissue [21].

A standard protocol for evaluating knee injuries should include water-sensitive pulse sequences in three different planes (axial, coronal, sagittal). Furthermore, an additional T1-weighted image should be included in the protocol. Evaluation of cartilage requires high spatial resolution; thus, 3D gradient echo sequences can additionally be performed [22]. In the postoperative patient, it may be useful to adapt MR protocols to avoid susceptibility artefacts by metallic implants. Intermediate-weighted TSE sequences with fat suppression are suitable. In suspicion of infection, additional intravenous contrast agents may be used with T1-weighted images. For further diagnostic workup, MR arthrography may be useful. For this examination, a gadolinium-based contrast agent is directly administered to the knee joint [23].

In the past, clinicians have mostly relied on physical examination and arthroscopy for ligamentous injuries. Nowadays, MRI may be a good addition or alternative in many cases. The advantage of MRI compared to other imaging techniques is its good soft tissue contrast. While CT delivers mostly indirect signs for soft tissue injuries, MRI can directly depict ligamentous and meniscal structures and surrounding soft tissue including muscle (Fig. 2.10). Furthermore, it can depict cartilage and osteochondral lesions. The disadvantages of MRI are prolonged examination times, costs, and availability.

For a simple bony depiction, CT scans are sufficient and more precise, particularly in shatter fractures. CT can better show the number and dislocation of fragments. These types of fractures are usually prone to open repair, and conse-

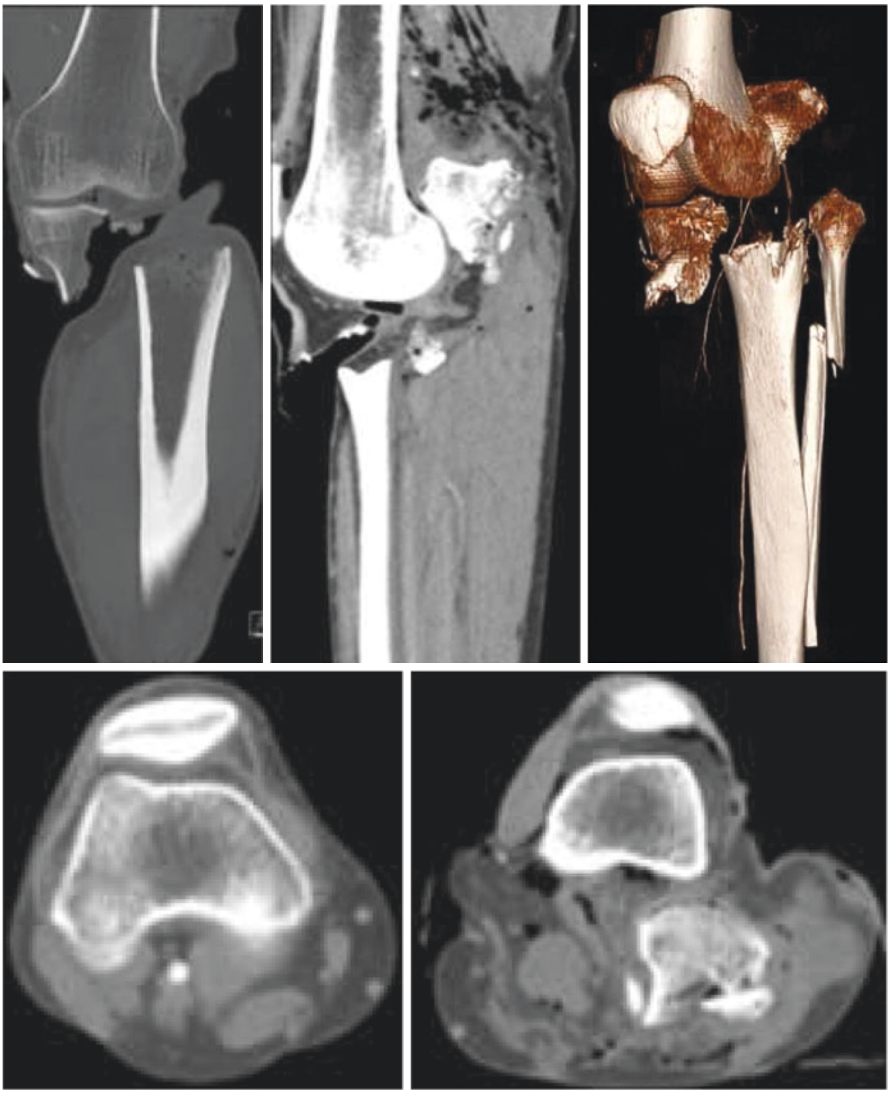


Fig. 2.9 III° complex, open fracture of the knee joint with extensive soft tissue injuries. CT after application of iodinized contrast media depicts not only the fracture displacement and soft-tissue derangements, but also vessel involvement. A reconstructed 3-D image (upper right) shows the complexity of the fracture with multiple fragments

quently soft tissue will be looked at intraoperatively [24].

In the pain-driven trauma patient, clinical examination can be challenging. Prokop et al. describe 63% soft tissue injuries in patients with tibial plateau fractures. To result in the best outcome, it is important to detect tissue injuries early to plan the best therapeutic concept [24].

MRI has become an alternative to diagnostic knee arthroscopy in the primary assessment of the knee in many trauma patients. It has shown a high sensitivity to detect internal derangements. Preoperative planning based on MRI images may facilitate and thus shorten surgical procedures [16]. Furthermore, MRI is excellent for the evaluation of knee cartilage. Friemert et al. could show that MRI

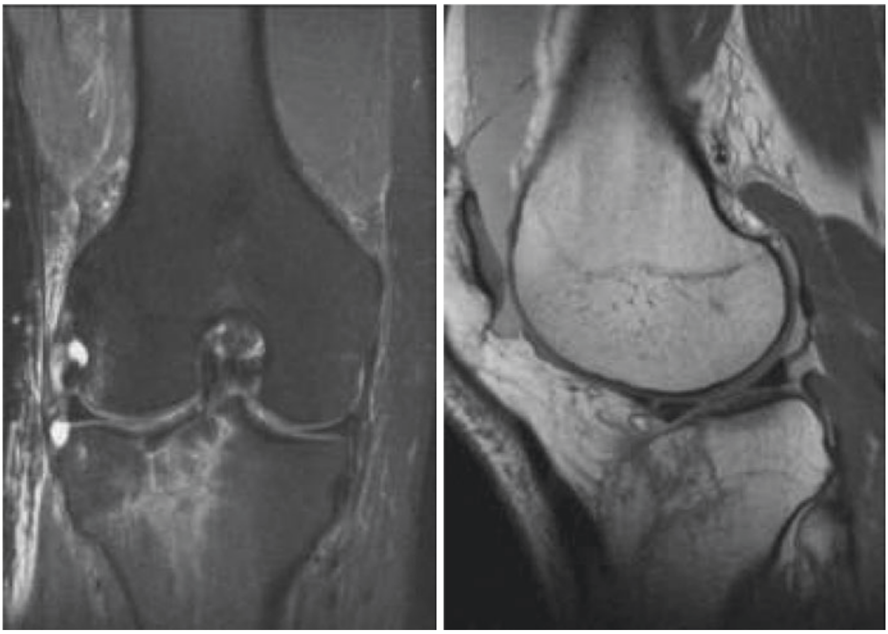


Fig. 2.10 Fracture of the lateral tibia plateau with typical bone marrow edema. Fracture lines extent to the cortex. Tibial cartilage shows a small fissure. MRI also depicts rupture of the lateral collateral ligament (left: PD fatsat weighted coronar image) and lipohemarthrosis (right: T1 weighted sagittal image)

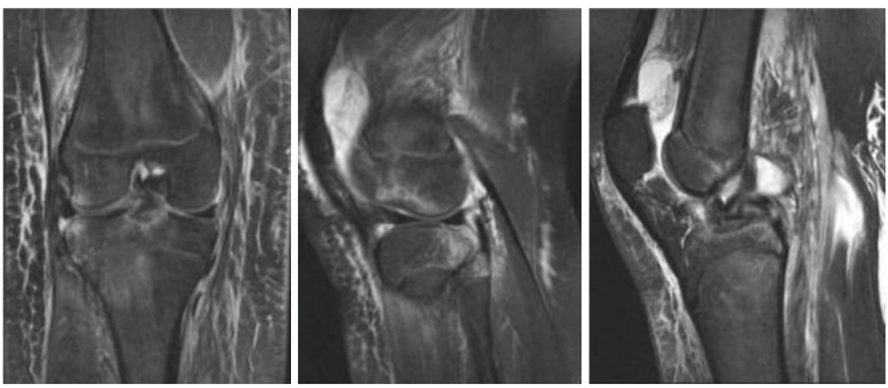


Fig. 2.11 Bony avulsion fracture of the anterior cruciate ligament. Typical bone marrow edema after contusion of the lateral femoral condyle, lateral tibia plateau and fibula head in a pivot-shift injury. PD fatsat weighted images depict the bone marrow edema and accompanying soft tissue injuries

imaging has a very high specificity (97–99%) for cartilage lesions in tibial plateau fractures [25].

MRI is very sensitive in the detection of bone marrow oedema resulting from injury (Fig. 2.11). The location of the marrow oedema in the femur or tibia gives a clue to the injury mechanism. In pivot shift injuries, marrow oedema is usually found in the posterior aspect of the lateral tibial plateau and the lateral femur condyle. In this type of trauma, accompanying soft tissue injuries including cruciate ligaments, menisci, and posterolateral corner structures are common. Marrow oedema located medially in the patella and/or the lateral femur condyle, or large effusion, and soft tissue oedema at the knee joint are suggestive of recent dislocation [12].

Furthermore, MRI may be useful in the detection of fractures that are occult even in CT scans.

Stress and insufficiency fractures can easily be detected in MRI because of bone marrow oedema. MRI also depicts underlying degenerative changes like osteonecrosis, cysts, or even malignant lesions, which need to be differentiated from acute traumatic lesions [26].

MRI may be used in the follow-up of patients after surgery, particularly to visualize soft tissue structures or to detect posttraumatic changes, e.g. chronic osteomyelitis. Transplant failure of cruciate ligaments, reruptures, graft impingement, arthrofibrosis, ganglionic degeneration, and infection are typical postoperative complications that can be detected on MRI scans.

Although MRI seems to be indispensable in the pre- and postoperative workup of knee injuries, standard guidelines for the use of MRI in these injuries are still lacking.

2.2.2.3 Ultrasound

The most readily accessible, cost-efficient imaging method remains ultrasound (US). US neither requires ionizing radiation like plain radiography or CT nor long examination times as in MRI.

Ultrasound aids in the detection of muscle tears. These are usually detected through hypoechoic changes (fresh blood) without the typical ripple of muscle. In knee trauma, ultrasound is used to look at the quadriceps tendon, the ligamentum patellae, and collateral ligaments. Tears in tendons usually also show hypoechoic changes. Cruciate ligaments and menisci are not a domain of ultrasound [26].

When using ultrasound to look for fractures, it is advisable to search for the normal continuous hyperechoic interface between bone and soft tissue. If this layer is disrupted, a fracture is likely. The most important indirect sign for fracture is the detection of lipohemarthrosis. It is usually seen on ultrasound as either a heterogeneous collection with two (hyperechoic fat and anechoic blood) or three layers (fat, anechoic serum, blood). Only infrapatellar fat pad rupture is a differential diagnosis to lipohemarthrosis. Using direct and indirect signs, sensitivity for fracture detection in ultrasound has been described to be 94%. In addition, colour Doppler ultrasound (colour Doppler) can be used to look for vascular trauma or reduced blood flow.

Nevertheless, ultrasound is time-consuming, observer dependent, and the extent and direction of the fracture line or displaced fractures are not sufficiently depictable [27].

2.2.2.4 Arthrography

Arthrography of the knee joint is an invasive procedure, which can be combined with cross-sectional images, both CT and MRI. Contrast media needs to be injected directly into the joint, usually using fluoroscopic guidance. Cross-sectional images should be acquired promptly after injection [28].

CT arthrography may be used to further evaluate the knee after trauma. In patients with contraindications for MRI, it may be used as an alternative. In the acute fracture, CT arthrography is used to evaluate underlying degenerative changes including meniscal and ligament tears, cartilage loss, subchondral cysts, sclerosis, and osteophytes [29].

Direct MR arthrography can also be used for further evaluation after knee trauma. It is particularly useful in the postoperative setting to evaluate menisci and cartilage. It may help to differentiate a meniscal tear or insufficient stitching from degenerative meniscal changes [23].

2.2.3 Summary

In acute knee trauma, accurate diagnosis and visualization of knee fractures are vital for optimal treatment strategies. While plain radiography still remains the most important imaging modality in the primary diagnosis, cross-sectional imaging techniques including CT and MRI have become indispensable.

In the emergency department setting, CT is usually easily accessible and images are rapidly acquired. However, radiation dose needs to be limited to a minimum. CT facilitates preoperative planning in more complex cases. It is particularly advisable to perform CT scans in complex tibial plateau fractures to minimize postoperative complications. CT is also helpful in the postoperative follow-up of patients with knee fractures. Additional application of contrast media can depict vessel status in severe cases.

In contrast to CT, MRI is much more time-consuming, often not readily accessible, and expensive. Nevertheless, MRI has great advantages in the depiction of soft tissue structures and cartilage. Thus, it has often become a good alternative to diagnostic knee arthroscopy in the primary assessment of knee trauma. MRI can also give a clue to the injury mechanism by evaluation of the marrow oedema. Knowledge of the injury mechanism aids in the detection of accompanying soft tissue injuries, e.g. rupture of the cruciate ligaments. MRI may also detect fractures that are occult even in CT scans. Furthermore, MRI is needed in the postoperative follow-up of patients, particularly in search of postoperative complications.

In special cases, cross-sectional imaging techniques (CT and MRI) may be complemented by arthrography. Direct application of contrast media into the joint aids in the primary detection of meniscal and ligament tears and also in the postoperative follow-up.

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