

Department of Diagnostic Radiology
Helsinki University Central Hospital
University of Helsinki, Finland

IMAGING OF KNEE INJURIES WITH SPECIAL FOCUS ON TIBIAL PLATEAU FRACTURES

Antti Mustonen

Academic Dissertation

To be presented with the permission of
the Faculty of Medicine of the University of Helsinki,
for public discussion in Auditorium I, Töölö Hospital

On 6 June 2009 at 12 noon

Helsinki 2009

Supervised by

Docent Seppo Koskinen

Helsinki Medical Imaging Center, Töölö Hospital

Helsinki University Central Hospital

Department of Diagnostic Radiology, University of Helsinki

Helsinki, Finland

Docent Martti Kiuru

Terveystalo Healthcare Ltd.

Helsinki, Finland

Reviewed by

Professor Osmo Tervonen

Department of Diagnostic Radiology, Oulu University Hospital

Oulu, Finland

Docent Arsi Harilainen

Orton Orthopaedic Hospital

Helsinki, Finland

To be discussed with

Docent Kimmo Mattila

Medical Imaging Centre of Southwest Finland

Turku University Hospital and Department of Diagnostic Radiology

University of Turku

Turku, Finland

ISBN 978-952-92-5567-2 (paperback)

ISBN 978-952-10-5575-1 (PDF)

Helsinki University Print

Helsinki 2009

TABLE OF CONTENTS

ORIGINAL PUBLICATIONS.....	6
ABBREVIATIONS.....	7
ABSTRACT.....	8
REVIEW OF THE LITERATURE.....	11
Pertinent knee anatomy and biomechanics	11
Bony structures.....	11
Articular cartilage.....	12
Soft tissue structures.....	13
Posterolateral corner.....	16
Knee injury.....	16
Tibial plateau fractures.....	17
Femur, patella and fibula fractures.....	17
Meniscal injury.....	18
Ligament injuries.....	18
Posterolateral corner.....	19
Imaging of knee injury	19
Radiography	19
Computed tomography.....	21
Multi-detector computed tomography (MDCT)	22
Magnetic resonance imaging (MRI)	24
Arthrography	27
Ultrasonography	28
Treatment options.....	28
Femur	28

Tibial plateau.....	28
Patella.....	29
Menisci.....	29
Cruciate ligaments.....	30
Collateral ligaments.....	31
Posterolateral corner.....	31
AIMS OF THE STUDY.....	32
PATIENTS AND METHODS.....	33
Study I — Knee fractures in radiography and MDCT.....	33
Study II — Cruciate ligaments in MDCT.....	34
Study III — Meniscal injury in MRI.....	35
Study IV — Meniscal repair in MRI.....	37
Study V — Postoperative tibial plateau fractures in MDCT.....	38
STATISTICAL ANALYSIS.....	40
IMAGING METHODS.....	41
RESULTS.....	43
Study I — Knee fractures in radiography and MDCT.....	43
Study II — Cruciate ligaments in MDCT.....	45
Study III — Meniscal injury in MRI.....	45
Study IV — Meniscal repair in MRI.....	46
Study V — Postoperative tibial plateau fractures in MDCT.....	47
DISCUSSION.....	49
Study I — Knee fractures in radiography and MDCT.....	51
Study II — Cruciate ligaments in MDCT.....	52
Study III — Meniscal injury in MRI.....	54

Study IV — Meniscal repair in MRI.....	55
Study V — Postoperative tibial plateau fractures in MDCT	56
Future aspect of the knee trauma imaging	57
CONCLUSIONS.....	59
ACKNOWLEDGEMENTS	60
APPENDIX.....	62
REFERENCES.....	67

ORIGINAL PUBLICATIONS

This thesis is based on the following publications which are referred to in the text by Roman numerals I – V.

- I Antti O. Mustonen, Seppo K. Koskinen, Martti J. Kiuru: Acute knee trauma: Analysis of multidetector computed tomography findings and comparison to conventional radiography. *Acta Radiol* 46:866–874, 2005
- II Antti O. Mustonen, Mika P. Koivikko, Ville V. Haapamäki, Martti J. Kiuru, Antti E. Lamminen, Seppo K. Koskinen. MDCT in acute knee injuries – assessment of cruciate ligaments with MRI correlation. *Acta Radiol* 48:104–11, 2007
- III Antti O. Mustonen, Mika P. Koivikko, Jan Lindahl, Seppo K. Koskinen: MRI of acute meniscal injury associated with tibial plateau fractures: Prevalence, type, and location. *AJR Am J Roentgenol* 191:1002–1009, 2008
- IV Antti O. Mustonen, Laura Tielinen, Jan Lindahl, Eero Hirvensalo, Martti J. Kiuru, Seppo K. Koskinen: MRI of menisci repaired with bioabsorbable arrows. *Skeletal Radiol* 35:515–521, 2006
- V Antti O. Mustonen, Mika P. Koivikko, Martti J. Kiuru, Jari Salo, Seppo K. Koskinen: The postoperative use of MDCT in tibial plateau fractures: Indications, findings, and clinical impact. *AJR Am J Roentgenol*, in press

Reprinted here with the permission of the publishers.

ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
ACL	Anterior Cruciate Ligament
AO/OTA	Arbeitsgemeinschaft für Osteosynthesefragen-Orthopedic Trauma Association
AP	Anterior-Posterior
CR	Computed Radiography
CT	Computed Tomography
DR	Digital Radiography
FOV	Field of View
FSE	Fast Spin Echo
GRE	Gradient Echo
LCL	Lateral Collateral Ligament
MCL	Medial Collateral Ligament
MDCT	Multi-Detector Computed Tomography
MPR	Multi-Planar Reconstruction
MR	Magnetic Resonance
MRI	Magnetic Resonance Imaging
NPV	Negative Predictive Value
PACS	Picture Archiving and Communication System
PCL	Posterior Cruciate Ligament
PD	Proton Density
PLC	Posterolateral Corner
POA	Proportion of Agreement
PPV	Positive Predictive Value
SE	Spin Echo
T	Tesla
US	Ultrasonography

ABSTRACT

Acute knee injury is a common event throughout life often affecting people during their most productive years. A knee injury is usually the result of a traffic accident, simple fall, or twisting injury. Over 90% of patients with acute knee injury undergo radiography, and knee radiography is one of the most commonly performed radiology examinations in emergency rooms. An overlooked fracture or delayed diagnosis can lead to poor patient outcome.

The major aim of this thesis was retrospectively to study imaging of knee injury with a special focus on tibial plateau fractures in patients referred to a level-one trauma center. Multi-detector computed tomography (MDCT) findings of acute knee trauma were studied and compared to radiography, as well as whether non-contrast MDCT can detect cruciate ligaments with reasonable accuracy. The prevalence, type, and location of meniscal injuries in magnetic resonance imaging (MRI) were evaluated, particularly in order to assess the prevalence of unstable meniscal tears in acute knee trauma with tibial plateau fractures. The possibility to analyze with conventional MRI the signal appearance of menisci repaired with bioabsorbable arrows was also studied. The postoperative use of MDCT was studied in surgically treated tibial plateau fractures: to establish the frequency and indications of MDCT and to assess the common findings and their clinical impact in a level-one trauma hospital.

This thesis focused on MDCT and MRI of knee injuries. Radiographs were analyzed when applicable, and compared to MDCT findings in Studies I and V. All images were evaluated with clinical workstations, and only the injured knees were studied. MDCT was considered the gold standard in Study I, and MRI the gold standard in Studies II, III, and IV. Arthroscopy was considered the standard of reference in Study III for some of the patients.

Study I showed that radiography in two views had a sensitivity of only 83%, and their negative predictive value was 49%. Radiographs underestimated tibial plateau articular depression. This study also showed that MDCT is useful in severe knee injuries in order to evaluate complex fracture morphology adequately. It can be concluded that radiography constitutes the basis for imaging acute knee injury, but MDCT can yield information beyond the capabilities of radiography. Especially in severely injured patients', sufficient radiographs

are often difficult to obtain, and in those patients, radiography is unreliable to rule out fractures.

Study II showed that MDCT can serve to evaluate cruciate ligaments as well. MDCT detected intact cruciate ligaments with good specificity, accuracy, and negative predictive value, but the assessment of torn ligaments was unreliable. Interobserver variation for the anterior cruciate ligament (ACL) was significant, but insignificant for the posterior cruciate ligament. Intraobserver variation was insignificant for both cruciate ligaments.

A total of 36% (14/39) patients with tibial plateau fracture had an unstable meniscal tear in MRI. No significant correlation appeared between degree of articular depression and site or morphologic features of the meniscal injury. Correspondingly, no statistically significant correlation was evident between normal menisci and degree of articular depression, nor was a significant correlation evident between differing fracture groups and meniscal findings. When a meniscal tear is properly detected preoperatively, treatment can be combined with primary fracture fixation, thus avoiding another operation. The number of meniscal contusions was high. Awareness of the imaging features of this meniscal abnormality can help radiologists increase specificity by avoiding false-positive findings in meniscal tears.

Postoperative menisci treated with bioabsorbable arrows showed no difference, among different signal intensities in MRI, among menisci between patients with operated or intact ACL. The highest incidence of menisci with an increased signal intensity extending to the meniscal surface was in patients whose surgery was within the previous 18 months. Those patients who had a normal-looking meniscus had a significantly longer time (mean 36 months) between operation and imaging than did patients with an increased signal intensity extending to the meniscal surface (mean 14 months). The results may indicate that a rather long time is necessary for menisci to heal completely after arrow repair. Whether the menisci with an increased signal intensity extending to the meniscal surface represent improper healing or re-tear, or whether this is just the earlier healing feature in the natural process remains unclear, and further prospective studies are needed to clarify this.

Postoperative MDCT was performed for 36 (9%) of 381 surgically treated knees with tibial plateau fracture. The main indications were assessment and follow-up of the joint articular surface, and evaluation of fracture healing. Orthopedic hardware caused no actual diagnostic

problems in MDCT. Postoperative MDCT yielded additional clinically important information for 29 (81%) patients, and 14 (39%) patients underwent reoperation. Postoperative use of MDCT in tibial plateau fractures was rather infrequent even in this large trauma center, but when performed, it revealed clinically significant information, thus benefitting patients in regard to treatment.

REVIEW OF THE LITERATURE

PERTINENT KNEE ANATOMY AND BIOMECHANICS

The knee is the largest joint in the body, with a complex anatomy [94, 114, 220]. It is a modified hinge joint composed of three bones: the femur, tibia, and patella [114], and has three articulations: one between the femur and patella, and two between the femoral condyles and tibial plateaus (Appendix, Fig. 1) [94, 171]. The knee bears the majority of human body weight [171]. In addition to flexion and extension, some axial rotation is possible in the flexed position [194, 273]. The supporting structures of the knee joint include the medial collateral ligament (MCL), the lateral collateral ligament (LCL), the anterior cruciate ligament (ACL), the posterior cruciate ligament (PCL), and the quadriceps femoris and patellar tendons (Appendix, Figs. 1–2) [94, 273]. The medial and lateral menisci are situated within the knee joint surface between the femoral condyles and the tibial plateau (Appendix, Fig. 2). These structures, together with the muscles and a wide and lax joint capsule, maintain and support knee stability [122, 273].

Bony structures

Femur

The femur is the strongest and longest bone in the human body [94]. The medial and lateral femoral condyles form the distal femur (Appendix, Fig. 2). The anterior groove between the condyles forms the articular surface for the patella, and the intercondylar notch separates the condyles inferiorly [94, 273]. The condyles are slightly flattened anteriorly and diverge distally and posteriorly. The lateral condyle is wider in front than at the back, while the medial is of more constant width [220, 273].

Tibia

The medial and lateral condyles form the proximal tibia. The articular surface of the condyles forms the medial and lateral tibial plateaus that articulate with the femoral condyles (Appendix, Fig. 2) [94, 273]. The tibia plateaus are angulated posteriorly 5–15 degrees from the horizontal plane [177]. The intercondylar eminence separates the plateaus [220].

Patella

The patella is the largest sesamoid bone in the human body, and it forms patellofemoral joint with the patellar groove of the femur (Appendix, Fig. 2) [33, 94]. It has medial and lateral articular surfaces (facets) (Appendix, Fig. 3) [33]. The medial surface can be subdivided into the medial facet and a much smaller “odd” facet which is located along the medial border of the patella. A small vertical bridge separates the odd facet from the medial facet [86]. The quadriceps tendon inserts on the superior margin of the patella, the vastus medialis muscle on its medial margin, and the vastus lateralis muscle on its lateral margin. The quadriceps tendon extends the anterior surface of the patella, joins the infrapatellar tendon, and inserts on the anterior tibial tuberosity (Appendix, Figs. 3–4) [33, 94]. The patella serves as a lever arm of the quadriceps in effecting knee extension or resisting knee flexion [126, 138].

Fibula

The head of the fibula is 1–1.5 cm distal to the lateral tibial plateau articular surface (Appendix, Fig. 2). The apex of the fibular head forms the styloid process. The posterolateral surface of the lateral tibial condyle and fibular head form the tibiofibular joint [94, 220].

Articular cartilage

Articular hyaline cartilage covers the distal end of the femur, the proximal part of the tibia, and the patella (Appendix, Figs. 1 and 5) [94]. It consists of 65–80% water by wet weight, 5% chondrocytes, 10–20% type II collagen, and 10–15% proteoglycans [207]. Cartilage has five zones, or layers: A superficial gliding zone (40 μm), a transitional zone (500 μm), a middle (radial) zone (1000 μm), a tidemark (5 μm), and a calcified zone (300 μm) [29]. The calcified zone, together with thin cortical bone, comprises the subchondral plate which attaches the cartilage to underlying bone. The thickness of hyaline cartilage in the femur and the tibia is 4–5 mm in the central portion, 1–2 mm in the periphery, and in the trochlear surface of the femur 2–3 mm [145]. The hyaline cartilage of the patella is the thickest in the human body, reaching a thickness of 5.4–6.4 mm in its central portion [86, 145].

Soft tissue structures

Joint capsule

The fibrous knee joint capsule is partly deficient structure, and tendinous expansions reinforce it. Various intra-articular structures, such as ligaments and fat pads, are situated between the capsule or tendinous expansions and the synovia [94, 216]. The joint capsule maintains and supports the stability of the knee [273].

Anteriorly, the capsule is absent above and over the surface of the patella, and the ligamentous sheath is composed of tendinous expansions from the rectus femoris, vastus medialis, and vastus lateralis muscles. These are attached to the superior margin of the patella and patellar ligament [94, 216]. Posteriorly, capsular fibers are proximally attached to femoral condyles and distally to tibial condyles and the intercondylar area. The oblique popliteal ligament derived from the semimembranosus tendon and the arcuate popliteal ligament emerging from the fibular head reinforces the posterior part of the capsule [94, 216]. Medially, capsular fibers are attached to the femoral and tibial condyles just beyond the articular margins. The capsule blends with the MCL which reinforces the capsule on the medial side [94, 216]. Laterally, capsular fibers are attached to the femoral and tibial condyles. The LCL, embedded in the tendon of the biceps femoris muscles, reinforces the capsule on the lateral side [94, 216].

The synovial membrane of the knee joint is the most extensive and complex in the human body. It has several parts: a central portion, a suprapatellar synovial pouch, posterior femoral recesses, and a subpopliteal recess. Numerous additional bursae are associated with the knee [94, 216]. The synovial membrane provides nourishment to surrounding structures.

Menisci

The medial and lateral menisci are C-shaped structures measuring approximately 35 mm in diameter, situated between the femoral condyles and tibial plateau (Appendix, Fig. 5) [173, 215]. Biochemically, the menisci is a fibrocartilaginous tissue that is composed of 72% water, 22% collagen type I, 0.8% glycosaminoglycans, and 0.12% DNA [115]. The outer one-third of the meniscus is vascularised (red zone), whereas the inner two-thirds is avascular (white zone) [11]. Each meniscus can be divided into an anterior horn, body, and posterior horn

[173]. The upper margin of the menisci is called the superior articular surface, and the lower margin the inferior articular surface. The transverse ligament joins the anterior horns in front [173, 215]. The menisci move as the femur and tibia move. The lateral meniscus is more mobile than the medial meniscus, and the anterior horns move more than the posterior horns [211, 218, 272]. Meniscus function includes shock absorption, joint lubrication and nutrition, proprioception related to nerve fibers in the anterior and posterior horns, load transmission, stress reduction, and joint stabilization [6, 54, 115]. The posterior horns transmit more of the load than do the anterior horns [215, 272]. The lateral and medial geniculate arteries provide the blood supply to the menisci [11, 54].

The anterior horn of the medial meniscus attaches to the anterior surface of the tibial plateau in front of the tibial insertion of the ACL. The posterior horn of the medial meniscus is attached to the posterior surface of the tibial plateau in front of the tibial insertion of the PCL. The periphery of the medial meniscus is continuously attached to the joint capsule. The medial meniscus firmly attaches to the femur and tibia through a thickening in the joint capsule known as the deep MCL [54, 215].

The anterior horn of the lateral meniscus attaches to the tibia, anterior to the intercondylar eminence and behind the tibial insertion of the ACL. The posterior horn of the lateral meniscus attaches to the tibia posterior to the intercondylar eminence. The lateral meniscus has a loose peripheral attachment to the joint capsule, but it has no attachment to the LCL [54, 215]. Anterior (Humphrey) or posterior (Wrisberg) menisiofemoral ligaments run from the posterior horn of the lateral meniscus to the lateral aspect of the medial femoral condyle [143]. These ligaments are part of the PCL and, together with the popliteus muscle, control the mobility of the posterior horn of the lateral meniscus [109].

Cruciate ligaments

The cruciate ligaments are intracapsular, extrasynovial structures located within the intercondylar notch of the femur (Appendix, Fig. 2) [10, 165, 273]. The ACL arises from a fossa on the anterior eminence of the tibia and inserts into a fossa on the medial surface of the lateral femoral condyle [10, 84, 92]. It is composed of multiple collagen fibers surrounded by connective tissue and covered by a synovial membrane [10, 84]. From a structural and functional view, the two major parts are the anteromedial (tight in flexion) and the

posterolateral (tight in extension) bands [31, 84, 88]. The average ACL length ranges between 3.7 cm and 4.1 cm, with an average width of 1.1 cm [92, 140]. The PCL arises from the posterior intercondylar eminence and inserts on the lateral surface of the medial femoral condyle [92, 259, 273]. The PCL is made up of collagen fibers surrounded by connective tissue and covered by a synovial fold [44]. The PCL consists of two major bands, the anterolateral (tight in flexion) and posteromedial (tight in extension) bands [1, 44, 165]. The PCL has an average length of 3.2–3.8 cm, and the average width of 1.3 cm [44, 92, 165, 278]. The ACL is the primary restraint to anterior displacement of the tibia, and a secondary restraint to tibial rotation, particularly internal rotation [31, 88, 269]. The PCL functions as the primary restraint to posterior displacement of the tibia, and as a secondary restraint to external rotation of the tibia [1, 44, 278]. Both cruciate ligaments also resist varus and valgus angulation.

Collateral ligaments

The MCL is comprised of superficial and deep components, extending from the medial femoral condyle to the tibia distal to the joint margin (Appendix, Fig. 2) [50, 268]. The average total length of the superficial component of the MCL is about 10–11 cm. The LCL arises on the lateral femoral condyle and inserts on the fibular head as a conjoined tendon together with the biceps femoris tendon (Appendix, Fig. 2) [208]; the LCL has no attachment to the tibia and is approximately 7 cm in length [220]. The MCL is a primary restraint to limit valgus angulation and rotatory stress at the knee [98, 122, 268]. The LCL is a primary restraint to limit varus angulation of the knee [98, 123, 208].

Muscles

The main muscles in the front of the knee are the quadriceps muscles, which include the vastus lateralis, vastus intermedius, vastus medialis, and rectus femoris muscles (Appendix, Figs. 3–4) [214]. The quadriceps muscles help to straighten and extend the leg [273].

The main muscles at the back of the knee are the hamstrings and the gastrocnemius muscles. The three hamstring muscles are the biceps femoris, semimembranosus, and semitendinosus muscles (Appendix, Figs. 1 and 4) [153]. The hamstring muscles flex the knee joint [273]. The gastrocnemius muscles function as knee flexors and also raise the heel [94, 158].

Arteries

The main arteries in the knee area are the popliteal and the anterior tibial artery. The popliteal artery is fixed at the borders of the popliteal fossa. This fixation allows only a little displacement, thus being predisposed to injuries. The anterior tibial artery originates from the popliteal artery distally in the popliteal fossa. It passes anteriorly through an opening above the proximal border of the interosseous membrane [94, 216, 220]. The vascular supply to the menisci is from the medial and lateral geniculate arteries (both the inferior and superior) [215].

Nerves

The sciatic nerve divides into the tibial and common peroneal nerves in the popliteal fossa. The tibial nerve is larger and runs distally through the middle of the popliteal fossa, with the posterior tibial artery deep in the gastrocnemius muscle. The common peroneal nerve passes along the biceps muscle at the lateral side of the popliteal fossa, and runs over the head and around the neck of the fibula [94, 216, 220].

Posterolateral corner

The posterolateral corner (PLC) of the knee has a complex anatomy including various muscles, tendons, and ligaments [63, 181, 234]. The popliteus muscle, biceps femoris muscle, and lateral gastrocnemius muscle serve as dynamic stabilizers [63, 274]. The LCL, fabellofibular ligament, arcuate ligament, popliteofibular ligament, and the posterolateral part of the knee capsule serve as static stabilizers [63, 274]. These structures play a major role in preventing translation and varus angulation, and preventing excessive external rotation of the knee [63, 245].

KNEE INJURY

A knee injury is usually the result of a traffic accident, a simple fall, or a twisting injury [96, 186, 220, 228]. These injuries are common events throughout life, are often seen in emergency rooms, and make knee radiography one of the most commonly performed radiological examinations [14, 72, 96, 233, 249]. Despite the fact that only 6%–12% of the cases include a fracture, over 90% of patients with acute knee injury undergo knee

radiography [14, 72, 131, 233]. Clinical decision rules have been undergoing study to help physicians be more selective in use of knee radiography [72, 248, 249]. According to referral guidelines for imaging by European Commission, knee radiography is not indicated if physical signs of injury are minimal. Radiography is, however, indicated when a patient's knee is unable to bear weight or shows pronounced bony tenderness, particularly at the patella and the head of the fibula after a fall or blunt trauma [70]. Overlooked knee fracture can lead to knee instability, restriction of motion, deformity of the knee, or persistent pain [131, 186, 276]. The benefits of well-directed radiology are to avoid diagnostic errors and reduce unnecessary radiography [72].

Tibial plateau fractures

Tibial plateau fractures comprise 1% of all lower extremity fractures affecting patients during the most productive years of their lives and can produce major disability [228, 239, 247, 253]. Although originally described as “fender” or “bumper” fractures produced by lateral force from an automobile against a pedestrian's knee [228], tibial plateau fractures usually result from indirect forces such as from a fall [186]. Of all tibial plateau fractures: 75–80% are isolated lateral, 10–15% are combined lateral and medial, and 5–10% are isolated medial fractures [186, 216]. Tibial plateau fractures often manifest with severe meniscal or ligamentous injuries in the knee [28, 40, 89, 142].

Femur, patella and fibula fractures

Fractures of the distal femur are quite rare, and account for 5% of all femoral fractures [216]. These fractures are usually due to a high energy trauma or falling from heights, and intra-articular involvement is common [252]. Patella fractures account for 1% of all skeletal injuries and are most commonly due to a direct anterior blow [33, 125, 237]. Patella fracture is usually transverse or slightly oblique, involving the midportion of the patella [33, 96, 237]. Bilateral patella fractures are rare [112], and isolated fibular head or neck fractures are also rare, with fractures of the fibular head usually combined with fractures of the lateral tibial plateau [108]. In cases of fractured fibula, the possibility of peroneal nerve injury always exists [108, 220].

Meniscal injury

The vast majority of meniscal lesions are considered traumatic, but other disorders also affect menisci, such as, metabolic, inflammatory, or degenerative processes [68, 82, 120]. A recent study showed that among middle-aged and elderly persons incidental meniscal findings are frequent and increase with aging in the general population [68].

Classification of meniscal tears. Studies have described several meniscal tear configurations, but no uniformly accepted classification system for meniscal tears exists [216]. A horizontal or cleavage tear is parallel to the tibial plateau and separates the meniscus into upper and lower parts. A longitudinal tear is vertical, occurring between the circumferential collagen fibers perpendicular to the tibial plateau. A radial tear is vertical, occurring perpendicular to the main axis of the meniscus. An oblique or parrot-beak tear is vertical and propagates obliquely to the main axis of the meniscus. A complex tear has two or more tear configurations. A bucket-handle tear is a special type of a longitudinal or oblique tear, in which the inner meniscal segment is flipped most commonly into the intercondylar space. A flap tear is a short segment horizontal tear with a fragment. A root tear occurs at the root of the meniscus in the tibial attachment [82, 132]. A transient injury to the menisci can lead to a meniscal contusion not representing a frank tear [42].

A recent functional MRI study showed that longitudinal, radial, and complex meniscal tears are usually unstable, whereas horizontal tears are stable [26]. Unstable tears have been associated with pain.

The medial meniscus is involved more frequently than the lateral meniscus [82]. A concomitant meniscal tear exists in 15–96% of knees with ACL injury [238, 242, 270].

Meniscocapsular separation represents a rare injury in which the meniscus is detached from its capsular attachment [223].

Ligament injuries

Ligament injuries are due to a variety of injury mechanisms, mostly traffic accidents and sports injuries [44, 229]. ACL, PCL, MCL, and LCL injuries occur in 10–12% of tibial plateau fractures [220], and of these ligaments, the MCL is the most frequently injured

ligament of the knee [151, 230]. ACL injuries are also frequent, as high as 40% of ligamentous injuries of the knee involve the ACL alone. PCL injuries account for 1–44% of all knee injuries [7, 229, 278]. An ACL avulsion fracture from the tibia or femur is rare [140]. Isolated ACL injuries can also occur [140]. A high incidence of meniscal injuries is associated with an isolated ACL tear [35, 128, 140]; a cruciate ligament tear usually involves collagenous fibers of the ligament, and less frequently an avulsion fracture at its insertion [97].

Posterolateral corner

Injury of the PLC of the knee is infrequent, and is often associated with injury to cruciate ligaments [45, 123]. Isolated PLC injury is uncommon: DeLee and colleagues reported that of 735 knees treated for ligament injury, 1.6% had an isolated PLC instability [55]. The PLC injury is usually caused by a direct blow to the anteromedial aspect of the proximal tibia, and less frequently by a noncontact external rotation hyperextension injury [15, 55]. PLC injury is mostly due to sports, a traffic accident, or a fall [55, 148]. Misdiagnosed or untreated PLC injury may lead to significant posttraumatic osteoarthritis or chronic instability, and it contributes markedly to ACL and PCL graft failure [45, 279].

IMAGING OF KNEE INJURY

Radiography

Radiography can be determined as projection imaging. It has developed continuously since Wilhem Conrad Röntgen discovered x-rays in 1895. An x-ray tube is used to generate x-rays which are absorbed in tissues. The tube is contained in an evacuated chamber, and an x-ray generator feeds energy to the x-ray tube in the form of rapidly moving electrons. These electrons are emitted by a cathode and accelerated toward an anode, which emits x-rays at a characteristic wavelength [57, 285].

Analog x-ray imaging. With direct analogue techniques, when the x-rays pass through the patient, the image is created directly on a radiographic film or a fluorescent screen [281]. Traditional direct fluoroscopy where the image is observed directly on the fluorescent screen by a radiologist is no longer used. Today, the fluoroscopy x-ray projection image is created on

the fluorescent screen but not observed directly on that screen. From the fluorescent screen the image is transmitted as an electric signal to a monitor where the final x-ray image is then observed by the radiologist [60, 281]. Tomography is a special technique that involves movement of the x-ray tube and film, providing sectional images. Only a thin plane through the patient is imaged sharply. Conventional tomography plays no role in musculoskeletal imaging at this moment [61, 281].

Digital x-ray imaging. Digital projection x-ray images can be produced in several ways. With computed radiography (CR) in place of a film, which is used in conventional radiography, a special imaging plate is used and scanned with a laser beam. The energy is released as light or luminescence. Photo-detectors record the emitted light, and the signal is further digitalized. The final x-ray image can be observed on a monitor or can be printed onto a film [59, 282].

With digital radiography (DR), special receptors in the detector are used, with no plates needed. DR images can be almost instantly displayed on a screen [59, 282].

CR and DR allow a wider dynamic range, optimization of image quality, and lower radiation dose than with conventional radiography [23]. Other advantages include no lost films, the ability of multiple clinicians' accessing images simultaneously, and easy comparison with previous studies [23].

Conventional radiography has a spatial resolution of 0.1 mm and digital radiography of 0.3 mm [286]. In radiography, a typical effective radiation dose is less than 0.01 mSv for a peripheral joint such as the knee [71].

Radiography in anterior-posterior (AP) and lateral views is the basis for primary evaluation of the knee injury [64]. Additional oblique views to eliminate superimposed structures have been supported by several authors [23, 47, 95]. With additional views for knee fracture, a sensitivity of 0.85 and specificity of 0.92 has been reported in radiography [95]. Radiography is sufficient to demonstrate most tibial plateau fractures. Non-displaced fractures, however, can be subtle and easily overlooked. Fractures in the posterior portion of the tibia are also challenging to detect in radiography. Due to 5–15 degrees of posterior sloping of the tibial plateau, radiography can be misleading in detecting the exact amount of articular surface

depression: Anterior articular surface depression can be underestimated, and posterior articular surface depression can be overestimated [177, 186, 220]. A recent study showed that tibial plateau fractures were among the most commonly overlooked fractures in the emergency room [243].

An axial (tangential, “sunrise”) view, originally described by Settegast in 1921 (unpublished) [27], is necessary when a patella fracture is suspected [96, 108, 183]. Bradley and colleagues [27] were the first to publish an axial view of the patella called the mountain view in the radiological literature. In that view the patient is supine with knees flexed 45 degrees. The mountain view was originally introduced into the orthopedic literature by Ian Macnab [161], and later modified by Merchant and colleagues [172]. Laurin and colleagues introduced a tangential X-ray view to diagnose a subluxation of the patella where the patient is supine with knees flexed 20–30 degrees [154, 155]. Daffner and colleagues [47] introduced a special trauma oblique view for the patella where the x-ray tube is angled 45 degrees, and two exposures are made perpendicular to each other. Moore and colleagues [177] introduced a 105-degree AP view (central x-ray tangential to the tibial plateau) for tibial plateau evaluation.

Splints, bandages, and casts should be removed before radiography to increase image resolution [186].

Digital tomosynthesis. Digital tomosynthesis is a technique that can produce section images with high spatial resolution in the plane of the image. A digital detector and x-ray system with a moving x-ray tube is required [65, 286]. Tomosynthesis allows an unlimited number of in-focus planes that can be retrospectively generated from a sequence of projection radiographs acquired during a single motion of the x-ray tube. Desired planes can be reconstructed from these projection radiographs. Radiation dose is lower than in computed tomography (CT). A tomosynthetic method for joint space evaluation has been developed, and application of tomosynthesis to the knee joint is of interest [65].

Computed tomography

Sir Godfrey Hounsfield invented CT in the early 1970s. In that method, images are constructed from several projections obtained while measuring the transmission of x-rays

through the patient. Thin slices are exposed to the x-rays without disturbing superimposition or blurring of structures [61, 282]. Contrast resolution is far superior to projection x-ray techniques, but CT has a lower spatial resolution of 0.4 mm [286]. Conventional axial CT generates tomographic images by sequential scanning. Spiral computed tomography was introduced in 1988 with continuous volume data acquisition [189, 226].

Multi-detector computed tomography (MDCT)

A multi-detector computed tomography (MDCT) scanner was introduced in 1998. It provided increased speed, decreased image noise, and better temporal, spatial, and contrast resolution than in conventional CT [23, 75, 226]. MDCT allows thin slices with near isotropic voxels in every plane, and these are suitable for two-dimensional (2D) reformats and three-dimensional (3D) renderings [64, 75]. With new software and workstations, fast image processing is possible even in the emergency-room setting [23, 64]. MDCT allows imaging through splints and casts without decrease in image quality, and positioning of the knee is not as crucial as for radiography [226]. MDCT can also reduce metal artefacts due to orthopedic hardware [77, 190]. The well-known disadvantage of MDCT is radiation. The average effective dose for a peripheral joint such as the knee is 1mSv [185], and can be considered as a low-dose examination [71]. With new-generation scanners, the radiation dose is further decreasing [111, 203].

For evaluating structures of the knee in acute knee injury, MDCT is mostly performed without contrast enhancement [227]. Some authors have demonstrated, however, that non-contrast CT can also detect soft tissue structures like meniscal or cruciate ligament lesions with high accuracy [195, 196, 217]. Recently Mui and colleagues [180], and Irie and colleagues [130] demonstrated the value of CT in the assessment of cruciate ligament tears.

Postoperative follow-up is normally performed by radiography [36], but MDCT use may increase. Orthopedic hardware impairs image quality and thus can cause diagnostic problems. In particular, the osteosynthesis plates can severely impair the visibility of the articular surface or obscure fracture lines in radiographs. Modern MDCT scanners can solve these problems, providing better image quality than by radiography [190, 261].

Flat-panel volume CT

A recent development in CT technology is flat-panel volume CT, in which, compared to conventional MDCT, detector rows have been replaced by an area detector [101]. It has 0.15-mm spatial resolution, which is better than previous MDCT technology, but its contrast resolution is slightly inferior to that of MDCT [101, 286]. Flat-panel volume CT allows coverage of a large volume per rotation, it has a field-of-view (FOV) about 18 cm along the z-axis, compared to a FOV of 2–4 cm in MDCT scanners (16- to 64-row scanners) [210, 286]. A recent study showed promising results in musculoskeletal imaging, with flat-panel volume CT providing good visualization of bony anatomy and pathology [210]. Flat-panel volume CT also showed vessels, nerves, and tendons in detail without contrast resolution being a limiting factor. Radiation dose is, however, slightly higher than in previous MDCT technology [101].

Dual-energy CT

Dual-energy or dual-source CT is equipped with two x-ray tubes and two corresponding detectors [81]. These tubes and detectors are mounted onto the rotating gantry with an angular offset of 90 degrees. One detector scans the entire FOV, while the other detector is restricted to a smaller FOV [254]. The acquisition of dual-energy CT data allows better tissue characterization [134]. The first studies show promising results, but further studies are needed to determine the true diagnostic value of dual-energy CT [254, 286]. Dual-energy CT has an in-plane spatial resolution of 0.5 mm, without additional patient radiation dose [81, 134].

CT arthrography

CT and MDCT arthrography with direct intra-articular injection of contrast agent has been used in evaluating internal derangement of the knee [30, 198, 262–264]. For ACL abnormality, sensitivities and specificities have been comparable to those in magnetic resonance imaging (MRI) [263]. CT arthrography is also useful when assessing postoperative menisci [75, 184]. Ionizing radiation is a slight disadvantage of MDCT, and arthrography with contrast medium injection into the joint is invasive with possible complications and increases cost [147, 262].

Magnetic resonance imaging (MRI)

MRI is based on the principles of nuclear magnetic resonance, where the absorption and emission of energy in the radio frequency range of the electromagnetic spectrum is evaluated [56, 284]. The magnetic resonance (MR) phenomenon was independently discovered by Felix Bloch and Edward Purcell in 1946 [56]. Raymond Damadian showed in 1971 that the nuclear magnetic relaxation of normal tissues and tumors differ [48]. Sir Peter Mansfield and Paul C. Lauterbur further developed MRI use for medical imaging in the 1970s [156, 166]. Biological tissues have different signal intensities in T1 (longitudinal relaxation) and T2 (transverse relaxation)-weighted images. T1-weighted images generally demonstrate anatomy with good tissue contrast, and T2-weighted images demonstrate water content in tissues [187]. Special fat suppression techniques are used to reduce the signal from fat, and this helps in evaluation of pathological water content processes [80].

Basic components of the MR unit are a strong magnet, a radio transmitter, and a radio frequency receiver coil. The MR scanner can produce sectional images with excellent soft tissue contrast in any plane, without ionizing radiation [56, 264, 284].

Enthusiasm for studying the potential of MRI in evaluation of the musculoskeletal system started in the early 1980s [201]. Kean and colleagues [139], and Reicher and colleagues [211, 213] showed the potential of MRI in imaging of the normal anatomy and pathology of the knee joint. Today, MRI is often the method of choice to evaluate soft tissue injuries in acute knee trauma, and has widely replaced diagnostic arthroscopy [108, 202, 244, 263]. MRI is a non-invasive examination that allows excellent soft tissue contrast without ionizing radiation [264]. It is widely used in meniscal and ligamentous injuries, and previous MRI studies have shown a sensitivity of 90–98%, a specificity of 90–100%, and an accuracy of 90–98% for ACL abnormality [78, 102, 108, 176, 244], and an almost 100% sensitivity, specificity, and accuracy for PCL abnormality [78, 99]. MRI has a sensitivity, specificity, and accuracy of over 90% for meniscal tears [19, 46, 82, 212, 231, 291]. MRI has also been successfully used for evaluation of tibial plateau fractures [17, 287]. MRI can detect occult fractures or microfractures of the trabeculae with resultant marrow edema and hemorrhage not evident in radiography or MDCT [199, 202, 289]. A direct blow to a bone may produce a marrow contusion or bone “bruise” [175, 199]. Bone bruising may also follow ligament, capsule, or

retinaculum injuries when two articulating bones impact against one another. MRI can also detect nondisplaced macroscopic fractures which can be occult in radiography [216].

Intravenous contrast agents play no role in acute trauma knees; these are useful in detecting infectious or neoplastic disorders [118, 216, 227].

The most commonly used magnetic field strength for evaluating the knee is 1.5 tesla (T) [162, 164, 216]. Low field-strength systems also exist, many of these designated to image only the extremities [216]. Recently, 3.0T scanners have been employed to better assess the knee and other joints [162, 216]. 3.0T scanners provide a better signal-to-noise ratio, improved resolution, and shorter examination time than is 1.5T or low-field scanners [162, 205]. With higher field-strength, however, magnetic susceptibility and chemical shift artifacts increase [164].

A normal meniscus shows a homogenous low signal intensity in all sequences [255]. A previous histological study introduced a grading system for meniscal signal intensities in MRI [251]. According to this system, a grade 1 signal represents one or more punctate signal intensities not contacting the articular surface of the meniscus, occurring in response to mechanical load and degeneration. Grade 1 signal intensity is not clinically significant. A grade 2 signal represents a linear intrameniscal signal intensity without extension to the articular surface of the meniscus. Patients with grade 2 signal menisci are usually asymptomatic, and this signal intensity distinctly correlates with areas of mucinous degeneration [250]. A grade 3 signal represents signal intensity extending to the articular surface of the meniscus, and tear or fibrocartilagenous separation appears in all these menisci [250]. A meniscus is considered torn when increased internal signal intensity is unequivocally contacting the articular surface of the meniscus in one or more images, or the meniscus has abnormal morphology [82, 225]. A meniscal contusion is defined as an area of increased signal intensity in a meniscus, being less discrete and less well defined than the signal intensity associated with a tear or degeneration [42].

Conventional spin-echo (SE) sequences have been traditional in assessing menisci [21, 146]. Fast spin echo (FSE) sequences have been applied to reduce imaging time, but short TE times may increase blurring [21, 146]. Controversy exists among authors between SE and FSE images. Some authors recommend only SE [21, 110, 224, 225], while others prefer FSE [38,

69, 146]. Conventional proton density (PD) SE imaging has a sensitivity of 88–90%, and specificity of 87–90% for meniscal tear [82, 110, 224]. PD FSE imaging has a sensitivity of 82–96%, and specificity of 84–94% for a meniscal tear [38, 69, 265].

Another controversy exists regarding use of fat saturation [110]. Schäfer and colleagues [231] concluded that a fat-suppressed PD FSE sequence is comparable to a non-fat-suppressed PD FSE sequence in detecting meniscal tears. Another study reported a sensitivity of 93% and specificity of 97% for a meniscal tear when using fat-suppressed PD SE sequence [21].

Gradient echo (GRE) and T1-weighted sequences have also been used in evaluation of menisci [82]. Although 3D GRE imaging has shown a sensitivity of 87–100% and specificity of 78–94% for meniscal tear [113, 209], GRE sequences are today used in imaging of cartilage rather than in imaging of the meniscus [110]. One reason for this is that GRE imaging produces a higher signal in the meniscus than does SE imaging, and also a more widespread signal increase in a degenerated meniscus, thus reducing specificity [100, 209]. T1-weighted SE sequences have shown a sensitivity of 77–80% and specificity of 72–98% for meniscal tear [116, 209].

Normal MRI criteria used for non-operated menisci cannot be directly applied to postoperative menisci. Postoperative menisci can show a signal similar to tear without re-tear, and this signal may be just part of the natural healing process [9, 49, 51, 76, 246]. Controversy exists among authors. White and colleagues [277] reported good results with conventional MRI, comparable to those with MR arthrography. Indirect MR arthrography using an intravenous contrast agent is less invasive than is direct MR arthrography, where intra-articular contrast agent is applied directly to the knee joint, and several authors have demonstrated results comparable to those in direct MR arthrography [18, 106, 280]. Some authors prefer MR arthrography when imaging the postoperative knee [163, 232].

MRI has proven useful in evaluation of PLC injuries. One study showed that several structures of the PLC can be reliably imaged [221]. These include the LCL, arcuate ligament complex, meniscal-coronary ligaments, biceps femoris tendon, iliotibial band, popliteal tendon, the lateral head of the gastrocnemius, and the lateral patellar retinaculum. In a study of surgically verified grade III PLC injuries, mean sensitivity, specificity, and accuracy values for the injured PLC were: the iliotibial band-deep layer (91.7%, 100%, and 95%), the short

head of the biceps femoris-direct arm (81.3%, 100%, and 85%), the short head of the biceps femoris-anterior arm (92.9%, 100%, and 95%), the midthird lateral capsular ligament-meniscotibial (93.8%, 100%, and 95%), the LCL (94.4%, 100%, and 95%), the popliteus origin on the femur (93.3%, 80%, and 90%), the popliteofibular ligament (68.8%, 66.7%, and 68%), and the fabellofibular ligament (85.7%, 85.7%, and 85.7%) [152].

In a prospective MRI study, the positive predictive value (PPV) for meniscocapsular separation was 9% medially and 13% laterally, and MRI signs correlated poorly with arthroscopic findings [223].

MRI has some well-known disadvantages such as for patients with pace-makers or claustrophobia; these cannot undergo MRI [79, 91, 256].

Magnetic resonance (MR) arthrography

Hajek and colleagues [103, 104] studied diagnostic capabilities and potential contrast agents in several joints including the knee. They concluded that MR arthrography with intra-articular contrast agents is superior to MRI without contrast agent. Today, in knee imaging, MR arthrography is recommended by many authors as the method of choice for evaluation of postoperative menisci [49, 163, 232]. The method is, however, invasive, with potential complications and inconvenience to patients. Drape and colleagues [67], studying intravenous injection of contrast agent in knee imaging, concluded that this less-invasive method produces a sufficient arthrographic effect also for evaluation of meniscal injuries.

Arthrography

Today, conventional arthrography (single or double contrast) plays no role in knee imaging and is mostly replaced by MDCT or MR arthrography [23, 96]. The conventional arthrography has earlier been used for evaluation of cruciate ligaments and menisci [197, 198].

Ultrasonography

Ultrasonography (US) is a relatively inexpensive and non-invasive imaging method [39]. It can provide functional information without radiation, and has wide availability. It is, however, extremely operator-dependent and thus has limited acceptance by referring physicians [23, 39]. US can serve in imaging of muscle injuries as well. Recent studies conclude that US can accurately detect lipohemarthrosis, which can be an indirect sign of the knee fracture, but no fracture line or extent or direction of the fracture line can be depicted [24, 266]. Several studies showed in the 1990s that US has a sensitivity and specificity of more than 80% for meniscal tears, but this method has not been in favor with radiologists [43]. ACL and PCL cannot be directly visualized by US, and indirect signs must be used. This particular US technique is demanding and is not widely extended to knee imaging [43].

TREATMENT OPTIONS

Femur

Distal femoral fractures are challenging fractures often complicated with other injuries around the knee [236, 241]. The fractures usually require surgical treatment [167, 192].

Tibial plateau

Treatment of tibial plateau fractures has been controversial [22, 34, 117]. Non-operative treatment has been preferred, but today surgery is well accepted as the first choice [36, 119]. Indications for surgery have varied from minimal displacement to 10 mm articular depression [36, 117]. Some authors have suggested that anatomical reduction does not necessarily improve patient outcome [5, 150, 168]. In recent studies, however, anatomic reduction without articular step-off has been the primary goal to achieve good results [34, 36, 37, 191]. Operative treatment with plates, screws, or external fixation has been used [34, 87], and conservative treatment has been acceptable for minimally displaced fractures [239].

Patella

For undisplaced patella fractures, conservative treatment may provide a successful outcome, but most patella fractures need operative treatment through open reduction and internal fixation [33, 288].

Menisci

Although the first meniscal repair was performed over 100 years ago by Thomas Annandale [8], meniscal repair has received widespread acceptance only in the last two decades [52, 137].

Thomas J. Fairbank discovered in 1948 that complete removal of the meniscus of the knee leads to progression of cartilage degeneration and bone remodeling [73]. This finding altered the treatment of this common injury, and today a torn meniscus is repaired rather than removed [53, 105, 188]. Hamberg and colleagues were the first to introduce a better clinical outcome for patients with partial meniscectomy and repair than for the patients whose menisci were removed [105].

Don King [141] showed in dogs that healing can occur in meniscal tears if a peripheral blood supply exists. Nowadays, tears within the vascular zone in which the peripheral circumferential fibers remain intact with only minimal damage to the meniscus body are considered suitable for repair. In addition, the tear should have be more than 8 mm in length, as shorter tears may heal spontaneously [52]. The most common repairable tear types are vertical-longitudinal, peripheral, or nearly peripheral tears [52, 54]. Other tear types are not usually reparable and may require partial meniscectomy [132]. Among the various open and arthroscopic techniques described, meniscal repair is usually performed arthroscopically unless associated lesions require open arthrotomy [275]. Arthroscopic techniques involve inside-out, outside-in, and all-inside methods [2, 16, 32]; the all-inside technique, an increasingly popular method, can reduce nerve, vascular and soft tissue complications [3, 4, 16, 25, 200]. It is simple and easy with reduced operation time compared to that for traditional meniscal sutures [2]. Several devices have been developed to repair menisci with the all-inside technique [20]. Although this technique shows encouraging results the many complications reported include subcutaneous migration of the fixation devices, chondral injuries, granuloma formation, and loss of fixation [2, 25, 93, 193, 200, 222, 235]. A recent

study concluded that bioabsorbable arrows alone are insufficient in the repair of very long and unstable meniscal tears [257].

The first clinical study on meniscal transplantation appeared in 1989 [174]. Meniscal allografts are considered as an alternative to total meniscectomy, but these are still in the investigational phase [218, 219].

Cruciate ligaments

Treatment of the torn ACL has evoked much controversy in orthopedic surgery and led to many opinions on when and how to do the reconstruction [83, 133, 269]. The ACL was earlier regarded as a structure which performs a relatively unimportant role in knee function [121]. Several studies have shown, however, that a torn ACL can lead to a poor clinical outcome with knee pain, recurrent episodes of giving way, damage to the menisci, and premature osteoarthritis [84, 170, 271]. Reconstruction of the ACL is therefore nowadays the treatment of choice for most patients.

ACL injuries used to be treated with primary repair of the ligament (suturing), primary repair with augmentation, or prosthetic replacement; today, ligament repair combined with autograft or allograft tissue is preferred [12, 13, 74, 85, 149, 240, 271]. In the recent orthopedic literature, arthroscopically assisted anatomic double-bundle ACL reconstruction has shown promising results, being better than single-bundle reconstruction, but controversy remains among orthopedic surgeons regarding these two procedures [107, 136, 144, 160, 290].

In the past, the PCL was considered of little importance to the knee's long-term function [259]. Recently, however, its functional and pathologic anatomy has been better understood, leading to increased demand for surgical treatment [124, 259, 278]. Conservative treatment is indicated for isolated grade I–II PCL tears; otherwise surgical treatment should be considered [66, 278].

For undisplaced cruciate ligament avulsion fractures, conservative treatment is recommended, but displaced fractures are treated surgically [66, 97].

Collateral ligaments

In the past, nearly all MCL injuries were treated surgically, but nowadays conservative treatment with bracing is suggested even for grade III injuries, and treatment decisions are made on the basis of concomitant injuries like ACL rupture [127, 129, 135]. Injuries of the lateral ligaments of the knee are rare, and are often associated with concomitant injuries [148]. Recent studies support the theory that serious lateral ligament injuries require surgical treatment [148, 182].

Posterolateral corner

Although debate has been frequent regarding treatment of PLC injuries in the orthopedic journals, clinical data regarding the outcome of surgical treatment are still limited [245]. Conservative treatment for grade I or II injuries of the PLC may have a good clinical outcome, but complete tears require surgical treatment [45, 148]. Although there exists no agreement as to the best treatment [245], surgical treatment in the acute setting has, however, been shown to improve clinical outcome compared to results from surgery for chronic injuries [45, 55]. Some authors favor reconstruction of the PLC structures in the acute setting while others favor direct primary repair within 3 weeks after the injury [279].

AIMS OF THE STUDY

- I To evaluate MDCT findings of acute knee injury and to compare diagnostic accuracy of radiography with that of MDCT.
- II To explore whether MDCT can accurately detect cruciate ligament pathology in acute knee injury.
- III To evaluate the prevalence, type, and location of meniscal injuries with MRI, and in particular, to assess the prevalence of unstable meniscal tears in acute knee trauma with tibial plateau fractures.
- IV To establish the MRI signal characteristics and morphology of menisci repaired with bioabsorbable arrows.
- V To explore the value of postoperative MDCT in follow-up of tibial plateau fractures, and in particular, to assess the frequency and indications of such examinations, the findings, and their clinical significance.

PATIENTS AND METHODS

All the studies (I–V) were performed at Töölö Trauma Center, Helsinki, Finland. It is by far the largest trauma center in Finland, and serves as the only level-one trauma center for almost 1.5 million people, with about 150 patients with severe multiple traumas each year. The Töölö Trauma Center is an integral part of Helsinki University Central Hospital. The main clinical departments are orthopedics and traumatology, neurosurgery, and plastic surgery. The hospital is equipped with two MDCTs, a 1.5 T MR scanner, DSA suite, DR and CR units, and US. The total number of radiological examinations performed in the year 2008 was 70,532. The hospital, which been completely filmless since November 1999, has 12 staff radiologists and up to 6 residents on rotation. The hospital has 24/7 radiology (and radiologist) services.

The images in the study (radiographs, MDCT and MRI scans) were evaluated with the clinical Impax DS3000 (Version 4.5) picture archiving and communication system (PACS) workstations (Agfa-Gevaert N.V., Mortsel, Belgium). Pediatric patients under the age 15 were excluded because they are generally taken to the Children's Hospital. The studies were approved by the hospital ethics committee.

Study I — Knee fractures in radiography and MDCT

Based on the hospital's PACS, all emergency-room requests for patients who underwent MDCT for knee trauma during a period of 61 months, from August 2000 to the end of August 2004 were retrieved. All patients with acute knee injury and a subsequent MDCT in the acute phase were included. Indications for the MDCT were assessing the exact morphologic feature of the fracture preoperatively or, when clinically indicated, ruling out a fracture not evident in radiography. A total of 409 patients (208 male, 201 female, age-range 15–90 years, mean 49) comprised the final study group.

Two radiologists retrospectively evaluated radiographs and MDCT scans, reaching a consensus. They evaluated images by fracture location (distal femur, proximal tibia, proximal fibula, or patella) and injury mechanism. The distal femoral fractures were classified as supracondylar, intercondylar, medial condyle, lateral condyle, or avulsion fractures. Fractures of the proximal tibia were divided into tibial plateau and avulsion fractures. The tibial plateau

was further divided into four regions: anteromedial (region 1), anterolateral (region 2), posterolateral (region 3), and posteromedial (region 4). The maximal articular surface depression of the tibial plateau was also measured. Findings in radiography (AP and lateral views) were compared with findings in MDCT. In some cases where patella fracture was suspected, an axial (“sunrise”, tangential) view was also evaluated. Patients were divided into two groups: Group A comprised patients with a fracture determined in radiography, and MDCT was performed to evaluate the exact fracture morphology. Group B comprised patients with clinical suspicion of fracture not evident in radiography, and MDCT was performed to rule out a fracture. MDCT was considered the gold standard.

The main injury mechanisms were traffic accident for 131 (32%) patients, simple fall for 131 (32%), sport injury for 50 (12%), fall from a height for 40 (10%), twisting injury of the knee for 32 (8%), and violence for 22 (5%).

Study II — Cruciate ligaments in MDCT

Based on the hospital’s PACS, all emergency-room requests for patients who underwent MDCT for knee trauma during a period of 65 months, from August 2000 to the end of December 2004 were retrieved. All patients with acute knee injury and a subsequent MDCT in the acute phase (within a week, mean within 24 hours) were included provided they underwent a subsequent MRI within 4 weeks (mean 6 days). Patient charts allowed verification of clinical history, and all patients who had previously undergone knee surgery were excluded. Indications for the MDCT were revealing the complex fracture anatomy preoperatively or ruling out a fracture not evident in radiography. Indication for the MRI was clinical suspicion of a meniscal tear or ligament injury. A total of 42 patients (22 male, 20 female, age range 17–65 years, mean 39) comprised the final study group.

MDCT images were independently evaluated by four radiologists (Readers A–D), who assessed ACL and PCL integrity as normal or torn. Cruciate ligaments were assessed as normal if each appeared as a continuous structure, and torn if appearing as a fragmented structure or lack of visualization at sites where cruciate ligaments were expected to be visible on continuous axial, sagittal or coronal images. The readers also assessed visualization of cruciate ligaments in all three slice-directions: excellent, intermediate, poor, or non-assessable visualization. The readers were blinded to the patients’ clinical history, radiography, MRI,

and to the initial interpretation of the MDCT. The readers were able to adjust the window and level settings. To avoid recall bias, all cases underwent review in random order twice with at least 4 weeks separating the readings.

Finally, two radiologists aware of the patients' clinical history retrospectively evaluated MRI images for cruciate ligaments integrity (normal or torn), reaching a consensus. Having arthroscopy unavailable in some cases, MRI was considered the gold standard.

Study III — Meniscal injury in MRI

Based on the hospital's PACS, emergency-room requests for 718 patients who underwent MDCT for knee injury during a period of 80 months, from January 2001 to August 2007 were retrieved. A total of 554 patients had a tibial plateau fracture detected in the acute phase (within a week, mean within 24 hours). Indications for the MDCT were clinical: to reveal the complex fracture anatomy preoperatively or to rule out a fracture. Of these 554 patients, 46 had a subsequent MRI within 3 weeks (mean 3 days). Indication for the MRI was clinical suspicion of a soft tissue injury. All patients with any sign of osteoarthritis (four patients), were excluded to reduce the number of patients with possible degenerative changes in the menisci. The patients' clinical history was verified from patient charts, and all with previous knee surgery (three patients) were excluded. A total of 39 patients (21 male, 18 female, age range 17–76 years, mean 37) comprised the final study group.

Two radiologists, aware of the preoperative clinical history, evaluated MDCT and MRI images, reaching a consensus. The radiologists were blinded to any surgery findings and to initial interpretations. Tibial plateau fractures were assessed as B or C (the type) and 1, 2, or 3 (the group) according to the Arbeitsgemeinschaft für Osteosynthesefragen-Orthopedic Trauma Association (AO/OTA) classification (Fig. 6), and the maximal articular surface depression was measured. ACL or PCL avulsion fractures (A1.3) from tibia insertions were noted if tibial plateau fracture also existed.

The anterior horn, body, and posterior horn were assessed separately as normal or torn for each meniscus in MRI. Tears were classified as follows: horizontal, vertical (subdivided into longitudinal and radial), flap, bucket-handle, or complex (two or more tear configurations).

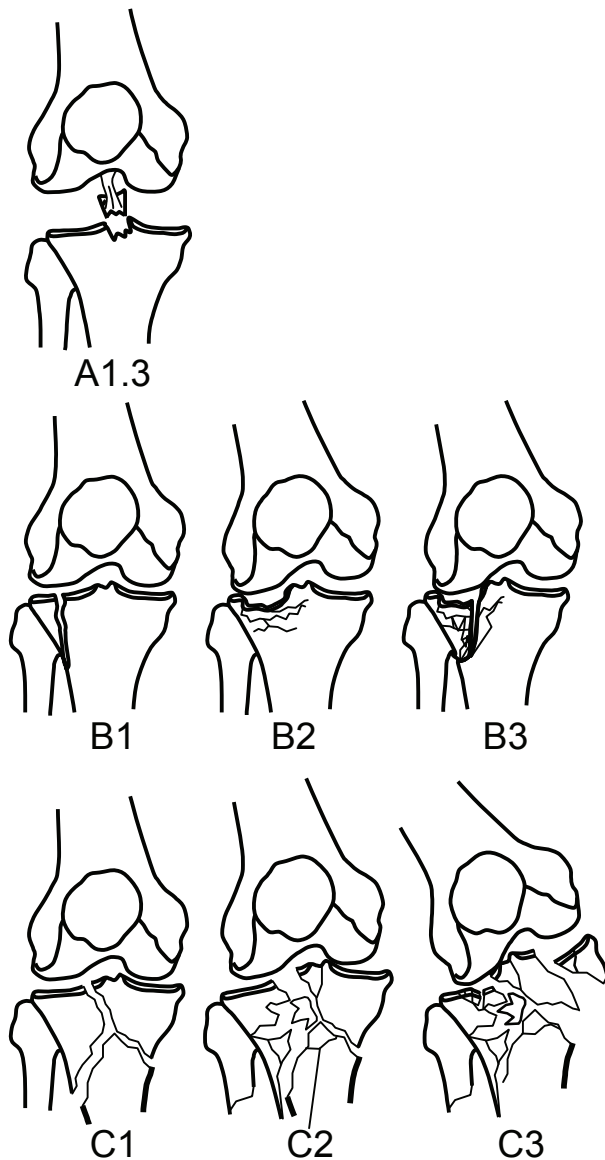


Figure 6: Arbeitsgemeinschaft für Osteosynthesefragen-Orthopedic Trauma Association (AO/OTA) classification of tibial plateau fractures. Reprinted with permission from the American Journal of Roentgenology from Antti O. Mustonen, Mika P. Koivikko, Jan Lindahl, Seppo K. Koskinen: MRI of acute meniscal injury associated with tibial plateau fractures: Prevalence, type, and location. *AJR Am J Roentgenol* 191:1002–1009, 2008.

Horizontal tears were considered stable, with longitudinal, radial, flap, or complex tears as unstable. The presence of any meniscal contusion, meniscocapsular separation, or root tear was also noted. A meniscal contusion was defined as an area of increased internal signal intensity in the meniscus which was less discrete and less well defined than in a case of intrasubstance degeneration or tear [42].

Knee arthroscopy was performed for clinical indications in the acute phase and regarded as the gold standard for 28 patients, with 8 of them having normal MRI. MRI was regarded the gold standard for 11 patients who had neither an abnormal meniscus on MRI nor clinical symptoms of meniscal tear, so that arthroscopy for them was deemed ethically unacceptable.

The injury mechanisms were traffic accident for 19 patients, simple fall for 9, sport injury for 6, and twisting injury for 5.

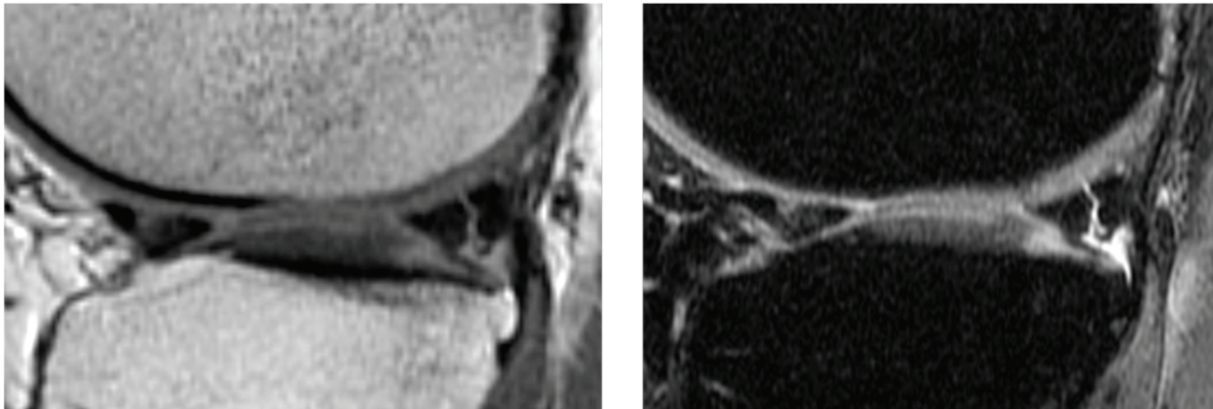
Study IV — Meniscal repair in MRI

A total of 80 patients with meniscal tears treated with bioabsorbable arrows (Bionx Medical Arrows, Bionx Implants Ltd., Tampere, Finland) were identified. Of these, 7 patients could not be traced and were excluded; 2 patients had previous knee surgery and were excluded; 27 patients had undergone a second operation for failed repair or re-tear due to a new injury and were also excluded. The remaining 44 patients (26 male, 18 female, age-range 20–77 years, mean 35) with 47 operated menisci comprised the final study group and were offered a follow-up clinical visit and MRI examination.

The patients each underwent surgery in the period January 1997 through March 2001 at the Department of Orthopaedics and Traumatology, Helsinki University Central Hospital, Helsinki, Finland. The surgery procedure had been introduced in 1993 by Albrecht-Olsen and colleagues [3]. The tears treated were vertical and longitudinal, situated either in or near the vascular zone. No second-look arthroscopy was performed.

Two radiologists evaluated the MRI images, reaching a consensus. Patient charts allowed verification of clinical history. The anterior horn, body, and posterior horn were assessed separately for each meniscus. Meniscal signal intensity was assessed according to four grades: Grade 0 (G0) menisci showed low signal intensity on all sequences with normal configuration and were considered normal or properly healed. Grade 1 (G1) menisci showed increased signal intensity without extending to the meniscal surface. Grade 2 (G2) menisci showed increased signal intensity linear in shape, which did or did not communicate with the capsular margin of the meniscus without extending to the meniscal surface. G1 and G2 signal intensities were considered to correspond to a scar in healed or healing menisci. Grade 3 (G3) menisci showed increased signal intensity extending to the meniscal surface, and were

considered to represent improper healing or a re-tear. G3 menisci were further divided into G3a and G3b groups: G3a menisci showed G3 signal intensity on PD images, but not on fluid-sensitive images, and were considered to represent a scar, not a re-tear. G3b menisci showed increased signal intensity on both PD and fluid-sensitive fat-saturated images, and were considered to represent a re-tear or no healing (Fig. 7).



*Figure 7: MRI appearance of Grade 3b lateral meniscus showing full-thickness increased signal intensity in the posterior horn both on proton density image (TR 1800, TE 20) (left) and T2-weighted fat-suppressed image (TR 2700, TE 37) (right). With kind permission from Springer Science + Business Media from Antti O. Mustonen, Laura Tielinen, Jan Lindahl, Eero Hirvensalo, Martti J. Kiuru, Seppo K. Koskinen: MRI of menisci repaired with bioabsorbable arrows. *Skeletal Radiol* 35:515–521, 2006.*

Study V — Postoperative tibial plateau fractures in MDCT

Based on the hospital's PACS, all emergency room MDCT requests regarding knee injury during a period of 86 months, from January 2001 to March 2008 were retrieved (782 patients). Indications for primary diagnostic MDCT were to reveal the complex fracture anatomy preoperatively or to rule out a fracture. Of the 782 patients, 592 had a tibial plateau fracture detected in the acute phase (within a week, mean within 24 hours), and 381 underwent surgery, of whom 36 (9%) also underwent a postoperative MDCT. Those 36 patients (24 male, 12 female, age-range 15–79 years, mean 47) comprised the final study group. Patient charts allowed verification of clinical history.

Aware of the clinical history, a radiologist and an orthopedic surgeon evaluated the MDCT images, reaching a consensus. They assessed tibial plateau fractures according to the AO/OTA (Fig. 6) and Schatzker (Fig. 8) classification. Reduction was retrospectively

considered good or suboptimal from the first postoperative radiographs by the orthopedic surgeon. Reduction was considered as good if it was anatomical or if only a minor (less than 3-mm) articular step-off was evident. Reduction was considered suboptimal if diastasis or an articular step-off of 3 mm or more was evident. For immediate reoperation, an articular step-off of more than 5 mm has served as a general guideline at Töölö Trauma Center.

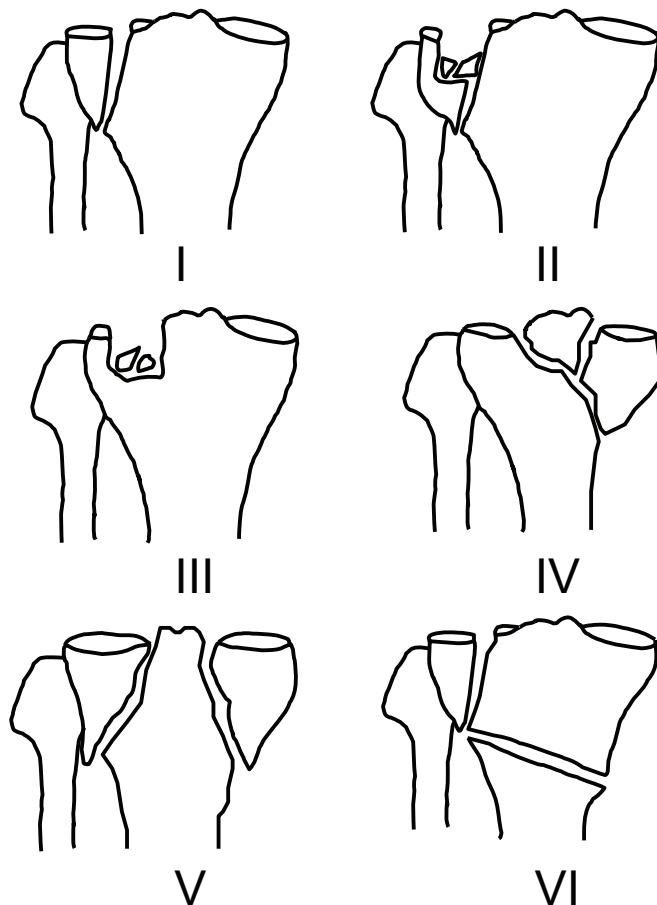


Figure 8. Schatzker classification of tibial plateau fractures.

Fracture healing was, from the MDCT, determined as completely ossified, partly ossified, or non-union in the later phase. A fracture was judged as completely ossified when an undisputable dense cortical bridging facing the cortical bones was detectable in continuous axial slices in both anterior and posterior cortexes or when dense continuous endosteal callus formation was evident. A fracture was judged as partly ossified when dense cortical bridging was evident in one cortex only, or clear endosteal callus formation was evident but was not visible in indisputable continuity. A fracture was judged as a non-union (pseudoarthrosis)

when no dense cortical bridging was evident, and a clear, lucent cleft between rounded bone edges was determined.

Image quality deterioration because of orthopedic hardware was also evaluated. Finally, the MDCT findings were compared with contemporaneous radiography to assess the usefulness and clinical impact of the MDCT.

The injury mechanisms were traffic accident for 16 patients, simple fall for 13, sports injury for 4, and fall from heights for 3.

STATISTICAL ANALYSIS

Study I — Knee fractures in radiography and MDCT

The appropriate procedures in the Arcus QuickStat Biomedical 1.1 (Addison Wesley Longman Limited, Cambridge, U.K.) software served for statistical computations. The difference between radiography and MDCT images in determining the maximal articular surface depression was analyzed by paired t-test with two-sided p -values. The statistical significance level was set at $p < 0.05$.

Study II — Cruciate ligaments in MDCT

The appropriate procedures in the SAS System 9.1.3 (SAS, Cary, N.C., USA) software served for statistical computations. Friedman's test served to compare the level of agreement with several measurements both between readers separately for each visit and between the visits for each reader separately. The proportion of agreement (POA) served to test agreement of measurements between and within the readers (inter- and intra-observer variation). The strength of the POA was determined as follows: $0.0 \leq \text{POA} \leq 0.2$, poor; $0.2 < \text{POA} \leq 0.4$, fair; $0.4 < \text{POA} \leq 0.6$, moderate; $0.6 < \text{POA} \leq 0.8$, good; $0.8 < \text{POA} \leq 1.0$, excellent. A generalized linear mixed model compared ratabilities between the different slice directions. Slice direction and visit were fixed factors; patient and reader were random factors. In this case, conclusions from the generalized linear mixed model were drawn with the concept of the odds ratio. The statistical significance level was set at $p < 0.05$.

Values determined were sensitivity, specificity, accuracy, PPV, and negative predictive value (NPV) of MDCT for abnormality of cruciate ligaments. Inter- and intra-observer differences were assessed with 95% confidence intervals, as well.

Study III — Meniscal injury in MRI

The appropriate procedures in the SPSS 15.0 (SPSS Inc., Chicago, IL, USA) software were used for statistical computations. Correlation of articular surface depression and menisci findings between different groups (normal menisci, menisci contusions, and torn menisci) was analyzed by one-way analysis of variance (ANOVA, Tukey's test). Correlation of articular depression and menisci findings between normal menisci and abnormal menisci (tear or contusion) was analyzed by the Mann-Whitney U-test (non-parametric data). The statistical significance level was set at $p < 0.05$.

In cases with arthroscopy verification, values determined were sensitivity, specificity, accuracy, PPV, and NPV of MRI for meniscal tear.

Study IV — Meniscal repair in MRI

The appropriate procedures in the SAS/STAT 8.02 (SAS, Cary, NC, USA) software were used for statistical computations. The time difference between operation and MRI was analyzed by one-way analysis of variance (ANOVA, Duncan's multiple range test). The differences between medial and lateral menisci and between patients with intact and operated ACL were analyzed by Mann-Whitney U-test (non-parametric data). The statistical significance level was set at $p < 0.05$.

IMAGING METHODS

Radiography protocol

Radiography was performed with a computed radiography unit (Agfa ADC compact 5145/100, Agfa-Gevaert N.V., Mortsel, Belgium), or a direct radiography unit (Philips Optimus 50, Philips Healthcare, Best, Netherlands). Radiography was done in the standard AP and lateral views. At Töölö Trauma Center, the lateral view is usually taken with a vertical beam, and with a horizontal beam only if the patient is unable to rotate the leg by 90

degrees. In those cases where fracture of the patella was suspected axial view of the patella was also obtained.

MDCT protocol

The MDCT images were obtained with a four-section multi-detector scanner (LightSpeed QX/i; GE Medical Systems, Milwaukee, WI, USA). The routine knee MDCT examination protocol was performed as follows: 4 x 1.25 mm collimation, interval 0.62 mm, gantry rotation time 1.0 s, pitch 3, table feed 3.75 mm, 120 kV, 150 mA, approximate total exposure time 10–15 s. Routine multi-planar reconstructions (MPR) were done in standard sagittal and coronal planes: slice thickness of 2.0 mm and reconstruction increment of 2.0 mm (Volume Share 2 – AW 4.4, GE Healthcare, Waukesha, WI, USA). MDCT scanning ranged from the upper pole of the patella to caudal to the fibular head. Multitrauma patients also underwent the trauma patient MDCT protocol (head, neck, and whole body MDCT) in the acute phase.

MRI protocol

The MR images were obtained with a 1.5T unit (Signa MRI Echospeed, GE Medical Systems, Milwaukee, WI, USA). Two different dedicated knee coils were used: a transmit-receive quadrature lower extremity coil, internal diameter 18 cm (Medical Advances Inc., Milwaukee, WI, USA), and an 8-channel HD knee array coil, internal diameter 19 cm (MRI Devices Corporation, Gainesville, FL, USA). The standard clinical sequences were coronal T2-weighted fast spin echo with fat saturation, sagittal proton density spin echo, sagittal proton density fast spin echo with fat saturation, sagittal T2-weighted fast spin echo, and axial proton density fast spin echo with fat saturation (Table 1).

	T2-Weighted FS Coronal FSE	Proton Density Sagittal SE	Proton Density FS Sagittal FSE	T2-Weighted Sagittal FSE	Proton Density FS Axial FSE
TR (ms)	4700	1800	2700	4000	3000
TE (ms)	40	20	37	88	26
Echo train length	8	NA	4	16	6
Matrix size	512 x 512	256 x 256	384 x 192	512 x 512	512 x 512
NEX	3	1	2	2	3
FOV	16	14	14	14	14
Thickness/space	4/1	3/1	3/1	3/1	3/1

Table 1: MRI Parameters. Note—FS = Fat-Suppressed, FSE = Fast Spin Echo, SE = Spin Echo, TR = Time of Repetition, TE = Time to Echo, NEX = Number of Excitations, FOV = Field of View, NA = not applicable

RESULTS

Study I — Knee fractures in radiography and MDCT

In 356 patients, MDCT detected 451 fractures in 362 knees (87%) (Table 2). Of those 53 patients without a fracture in MDCT, in 8 patients a fracture was suspected in radiography (false-positive), and in 45 patients, radiography was normal (true-negative), but clinical findings indicated MDCT. A total of 246 (69%) patients underwent surgery. Joint effusion was evident in 374 (90%) cases in MDCT.

Bone	No. of Fractures
Distal Femur	49
Supracondylar	7
Lateral Condyle	13
Medial Condyle	12
Intercondylar	7
MCL Insertion	8
LCL Insertion	2
Proximal Tibia	307
Tibial Plateau	259
Anterior Eminence	23
Posterior Eminence	16
Segond Fracture	9
Fibula	72
Patella	23
Total	451

Table 2: Anatomical distribution of knee fractures detected in 356 patients with MDCT

Radiographs were available for 316 (76%) cases, of which 225 (71%) had a subsequent MDCT to evaluate the complex fracture anatomy (Group A), and 91 (29%) had a subsequent MDCT after negative radiographs (Group B). For 49 (15%) cases, radiographs were deemed suboptimal due to positioning.

Sensitivity for radiography was 83%, including cases with the suboptimal positioning. In Group A, 217 of the 225 radiographs were true-positive and 8 false-positive, and PPV was

96%. In Group B, 45 of the 91 radiographs were true-negative and 46 false-negative, and NPV was 49%. Of those 46 false-negative cases, 9 (20%) patients had an operatively treated knee fracture (Fig. 9).



Fig. 9: 38-year-old man after a simple fall. AP (upper left) or lateral (upper right) radiograph demonstrates no fracture, but a fat-fluid level (arrows) indicating lipohemarthrosis is evident on lateral view obtained with a horizontal beam. On coronal MDCT scan (lower), a non-displaced fracture of the femoral medial condyle is clearly evident (arrows). Reprinted with permission from Taylor & Francis Ltd. from Antti O. Mustonen, Seppo K. Koskinen, Martti J. Kiuru: Acute knee trauma: Analysis of multidetector computed tomography findings and comparison to conventional radiography. Acta Radiol 46:866–874, 2005.

Articular surface depression of the tibial plateau was underestimated in radiography in one-region fractures. In fractures involving two regions, radiography underestimated articular

surface depression in regions 1+3, 1+4, 2+3, and 2+4, whereas in regions 1+2 and 3+4 it was overestimated.

A bony fragment was detected in 51 (12%) patients in MDCT, and in 43 (84%) cases, the site of origin was clearly evident. Radiographs were available in 43 cases: true-positive in 25 (58%), false-negative in 18 (42%).

Study II — Cruciate ligaments in MDCT

Mean values of MDCT for ACL abnormality observed were: sensitivity 58%, specificity 86%, accuracy 77%, PPV 67%, and NPV 83%. Mean values for PCL abnormality were: sensitivity 25%, specificity 96%, accuracy 88%, PPV 54%, and NPV 90%. For ACL and PCL, intra-observer variation was nonsignificant. For ACL, inter-observer variation was significant, but for PCL was nonsignificant. The axial direction was judged as the best for ACL evaluation, although statistically nonsignificant compared to the coronal direction. The sagittal direction was judged as the best for PCL evaluation.

Study III — Meniscal injury in MRI

A total of 33 (42%) abnormal menisci (17 medial and 16 lateral) were detected in 24 patients. A total of 16 (41%) patients each had a meniscal tear, with 14 of them having an unstable tear. Complex tears occurred in 9 (12%) menisci and bucket-handle tears in 2 (3%), but neither isolated flap tears nor meniscal root injuries. Anatomic distribution of tears and contusions is shown in Table 3. All types of tibia plateau fractures except C1 were evident in MDCT.

A knee arthroscopy was performed in 28 (72%) patients, and 56 menisci were assessed. Of those 28 patients, 20 had a tear detected in MRI, and 8 with normal MRI had clinical symptoms. A total of 4 false-positive and 2 false-negative assessments were based on arthroscopy, and for meniscal tear, the values in MRI were: sensitivity 88%, specificity 90%, accuracy 89%, PPV 78%, and NPV 95%.

No significant correlation emerged between meniscal injury site or morphology and degree of articular surface depression. Correspondingly, no significant correlation was apparent

between normal menisci and degree of articular surface depression, nor any significant association between various fracture groups and menisci findings.






											
	Contusion		Longitudinal tear		Radial tear		Flap tear		Horizontal tear		
Meniscal parts	Lat	Med	Lat	Med	Lat	Med	Lat	Med	Lat	Med	Total
Anterior horn	6	1	2	—	—	—	—	—	—	—	9
Body	2	3	3	1	—	2	—	—	—	3	14
Posterior horn	4	4	4	6	2	2	1	3	1	4	31
Total	12	8	9	7	2	4	1	3	1	7	

Table 3: Anatomical distribution of abnormal menisci findings in 78 menisci in MRI. Note—Lat = lateral, Med = medial. Dash (—) indicates no findings were evident. Some menisci had multiple tears and total number of tears (n=34) does not match the total number of menisci with tears (n=20). Reprinted with permission from the American Journal of Roentgenology from Antti O. Mustonen, Mika P. Koivikko, Jan Lindahl, Seppo K. Koskinen: MRI of acute meniscal injury associated with tibial plateau fractures: Prevalence, type, and location. AJR Am J Roentgenol 191:1002–1009, 2008.

Study IV — Meniscal repair in MRI

Distribution of meniscal findings is shown in Table 4. Of the 12 patients with menisci showing increased signal intensity extending to the meniscal surface (Grade 3), 9 were imaged less than 18 months from the surgery, with 6 of them having a concurrent ACL reconstruction. Neither meniscal cysts nor foreign body reactions were evident. All patients underwent clinical examinations, and 16 (35%) patients reported slight symptoms not interfering with daily life, with an equal distribution between the groups. The remaining 28 (65%) patients were clinically asymptomatic.

No significant correlation emerged between medial and lateral menisci for distribution of different grades, nor for the difference between patients with operated or intact ACL. The time difference from surgery to MRI was significant between those menisci showing low signal intensity on all sequences (Grade 0) and menisci showing increased signal intensity extending to the meniscal surface (Grade 3) ($p = 0.0221$).

Grades		Time from Surgery (Months)	
		Mean	Range
G0	13	36	15–67
G1	13	27	5–57
G2	9	26	12–67
G3	12	14	5–28
G3a	3		
G3b	9		
Total	47		

Table 4: Distribution of menisci findings in 47 patients. Note—G0 = menisci showed low signal intensity on all sequences with normal configuration. G1 = increased signal intensity without extending to the meniscal surface. G2 = increased signal intensity linear in shape, which may or may not communicate with the capsular margin of the meniscus without extending to the meniscal surface. G3 = increased signal intensity extending to meniscal surface. G3a = G3 signal intensity on proton density images, but not on fluid-sensitive images. G3b = increased signal intensity on both proton density and fluid-sensitive fat-saturated images.

Study V — Postoperative tibial plateau fractures in MDCT

All types of tibia plateau fractures were evident in MDCT. All patients underwent open surgery. Based on the immediate postoperative radiography, the orthopedic surgeon retrospectively judged the reduction as good for 25 and suboptimal for 11 patients. Of these 36 patients, a bone graft from the iliac crest was used in 25 and bone cement in 2. For fracture fixation, medial plates were used in 3, lateral in 13, and both medial and lateral in 3 patients. In 8 patients, contra- or ipsilateral screw fixation together with plates was used, and in 9 only screw fixation.

The postoperative MDCTs were performed from 2 to 396 (mean 131) days after surgery. In 11 (30%) cases, when reduction was judged as suboptimal after the first postoperative radiography, and MDCT was performed in the immediate postoperative period (within 14 days, mean 6); indication for the MDCT was evaluation of tibial articular surface congruency.

The MDCTs were performed during follow-up for the remaining 25 patients: For 18, the indication for the MDCT was assessment of fracture ossification that was uncertain from

radiography, and for 7, evaluation of suspected worsening of the articular depression in radiography. MDCT was performed to determine ossification (121–396 days after surgery) in 18 patients, of whom 4 had fracture union, 5 ongoing ossification, and 9 non-unions. The bone density had noticeably decreased in 14 patients between pre- and postoperative MDCT.

At the time of the postoperative MDCT, all knees contained orthopedic hardware, and metallic artifacts slightly impaired assessment of fracture gaps in two patients, and of the joint surface in one, but did not cause true diagnostic problems.

Postoperative MDCT provided additional clinically useful information and was judged as necessary in 29 cases when compared to radiography. In the other 7 cases, the MDCT revealed less additional radiological information than did radiography.

A total of 14 patients (39%) underwent reoperation after the postoperative MDCT. Of those, 2 underwent reoperation immediately after postoperative radiography and subsequent MDCT due to a suboptimal reduction, 4 patients due to articular surface depression during follow-up confirmed by MDCT, and 8 patients due to non-union detected with MDCT.

DISCUSSION

Knee injury is common and if not detected accurately, can have severe sequelae [131, 186, 276]. Radiography in AP and lateral views is the basis for primary evaluation of the knee injury. Conventional radiography is quick, widely available, and quite economical. The obtaining of additional views has been supported by several authors [23, 47, 95]. In severely injured patients, however, additional views are demanding or sometimes even impossible to obtain. Partly because of this difficulty, the next-step study in the evaluation of the knee trauma at many hospitals nowadays is MDCT.

MDCT scanners produce images of good quality almost in seconds and are therefore suitable for acute trauma cases. These scanners yield isotropic voxels enabling 2D reformats in any plane and also 3D reformats [75, 189]. Scanning through casts and splints is also possible without impairing image quality.

Diagnostic medical exposures are the major source of man-made radiation exposure of the population, and it is known that no radiation dose is entirely without risk [58, 71, 283]. In spite of the fact that the average effective dose for MDCT of the knee is 1mSv, and for radiography of the knee 0.01mSv, MDCT of the knee can, however, be considered a low-dose examination [71, 185], and with newer-generation scanners the dose is still decreasing [111]. Furthermore, adult knee is mainly composed of yellow bone marrow which is not as sensitive to radiation as is red bone marrow [58, 94, 283]. Thus, it can be concluded that although at population level, specific attention should be paid to radiation dose, in case of any single patient with suspected knee fracture, radiography or subsequent MDCT or both are certainly justified in these potentially severe injuries.

MRI has been the method of choice when evaluating internal knee derangement. It has excellent sensitivity, specificity, and accuracy in detecting meniscal and ligament injuries [46, 108, 244]. MRI has shown potential for imaging of tibial plateau fractures, as well [28, 287].

Both traumatic and degenerative meniscal tears exist, and it is possible that degenerative changes precede meniscal tears [216]. Because meniscal injury, meniscectomy, and even partial resection are known to associate strongly with cartilage loss and premature arthrosis,

the meniscus should be preserved whenever possible [4]. Even for an experienced orthopedic surgeon in acute knee trauma, clinical assessment of meniscal tear and especially recognition of any potentially repairable torn meniscus remains challenging [142, 239]. Many authors, therefore, prefer MRI preoperatively, but other opinions also exist [132, 169]. For many orthopedic surgeons, pain is an important criterion in planning treatment. Degenerative tears are usually asymptomatic and incidental findings [216]. A recent functional MRI study showed that horizontal tears are stable, and longitudinal, radial, flap, or complex tears are unstable [26]. Preoperative MRI can thus help to determine whether a tear is stable or not and thus guide the surgeon in decision-making.

Conventional MRI has been less accurate in detecting re-tear or repair in the operated meniscus [49, 62, 76, 159]. The MRI finding of a healed meniscal tear may simulate tear or re-tear for over 10 years after the operation [178]. Fluid-sensitive sequences may be helpful, and MR arthrography has also been recommended [159, 232, 258].

The role of arthroscopy as the gold standard deserves some comment. Arthroscopy is historically well accepted as the gold standard in the radiologic and orthopedic literature, and many CT and MRI accuracy values are based on a subsequent arthroscopy [176, 179]. Thus the lack of arthroscopy has been considered an unavoidable limitation in some otherwise well-conducted studies. Arthroscopy has, however, some known limitations in evaluation of meniscal tears. It is operator-dependent, direct visualization is limited, and findings are partially based on probing the meniscus rather than on direct visualization of a tear; false-negative findings therefore occur. False-negative findings at arthroscopy occur mostly in the posterior horn of the medial meniscus [204]. These tears are often small or stable or both, requiring no surgery, so the true risk of overlooking clinically significant meniscal tears with MRI is rather low [49, 176]. Moreover, if only patients with arthroscopy verification are included in a study, bias may result against more complicated cases, which have a clinical indication for arthroscopy. Although arthroscopy has these limitations, it is nevertheless the gold standard in evaluating meniscal tears at the moment. Patients without arthroscopy should be more often included in studies, as well, however. As also shown in Study III, MRI has excellent sensitivity, specificity, and accuracy in detecting meniscal tears.

All patients in this thesis were treated in a level-one trauma center caring for the most complicated cases. This may be a potential limitation, but to date MDCT and MRI scanners

are available in many hospitals, making the results useful in all hospitals receiving severely injured patients.

Study I — Knee fractures in radiography and MDCT

Due to difficulties in appropriate positioning of severely injured patients, a great number (15%) of radiographs were suboptimal. MDCT is therefore nowadays more often used as the next-step study at Töölö Trauma Center, with additional views in radiography thus deemed unnecessary. Tibial plateau articular depression, important in surgical decision-making, may be overlooked in radiography [177, 186, 220], although radiography in AP and lateral views can demonstrate the majority of knee fractures. The fact that the tibial plateau slopes down posteriorly approximately 10 degrees causes a distortion in radiography; anterior surface depression can be underestimated and posterior surface depression overestimated [177, 186, 220]. This was also evident in this study where radiography underestimated tibial articular depression in all regions except the 1+2 and 3+4 regions, where articular depression was overestimated. One-region fractures were the ones most often overlooked. Superimposed structures may obscure these fractures if only two-view evaluation is done. In detecting loose fragments and the site of origin, MDCT was superior to radiography. Joint effusion may indicate an intra-articular fracture [96, 220], as was also seen in this study, in which 90% of the patients had a knee effusion. Lee and colleagues [157], however, concluded that only 65% of intra-articular knee fractures show hemarthrosis; thus, the absence of hemarthrosis is insufficient to exclude a fracture.

In conclusion, radiography is the basis for evaluation of acute knee trauma patients. Radiographs of good quality are mostly sufficient for excluding a fracture for patients with mild symptoms, and when there is no discrepancy with the clinical examination. In patients with clinical suspicion of fracture despite normal radiography, MDCT is recommended as a complementary examination (Fig. 10). MDCT is also useful in preoperative planning of complex fractures. In this study, with severely injured patients, MDCT provided significantly more information than did radiography.

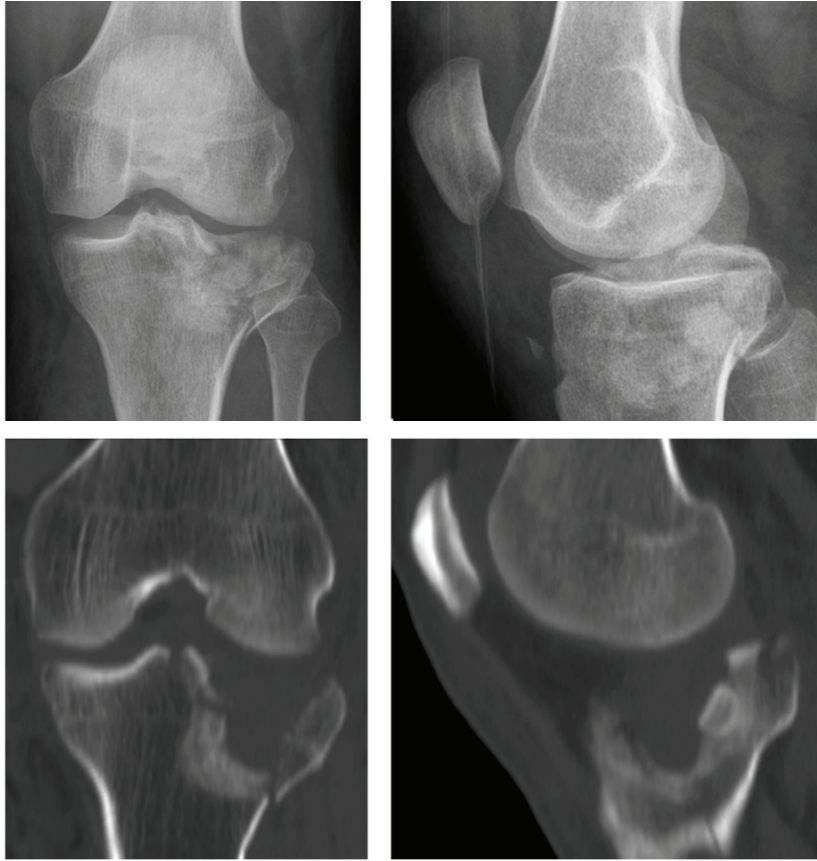


Fig. 10: 40-year-old man after a simple fall. Radiograph demonstrates a severe comminution of the lateral tibial condyle on AP (upper left) and lateral (upper right) views, but the true magnitude of depression of the tibial plateau remains unclear. Coronal (lower left) and sagittal (lower right) MDCT scans clearly demonstrate 26 mm articular depression. Reprinted with permission from Taylor & Francis Ltd. from Antti O. Mustonen, Seppo K. Koskinen, Martti J. Kiuru: Acute knee trauma: Analysis of multidetector computed tomography findings and comparison to conventional radiography. Acta Radiol 46:866–874, 2005.

Study II — Cruciate ligaments in MDCT

MRI studies have shown a sensitivity, specificity, and accuracy for ACL abnormality of over 90%, and for PCL abnormality of almost 100% [78, 99, 102]. The results showed that MDCT can detect intact cruciate ligaments with good specificity, accuracy, and NPV (Fig. 11), but not torn ligaments. Most patients showed knee joint effusion because imaging was done in the acute phase, which reduced the contrast difference between the ligaments and knee joint. This may in part explain the low sensitivity.

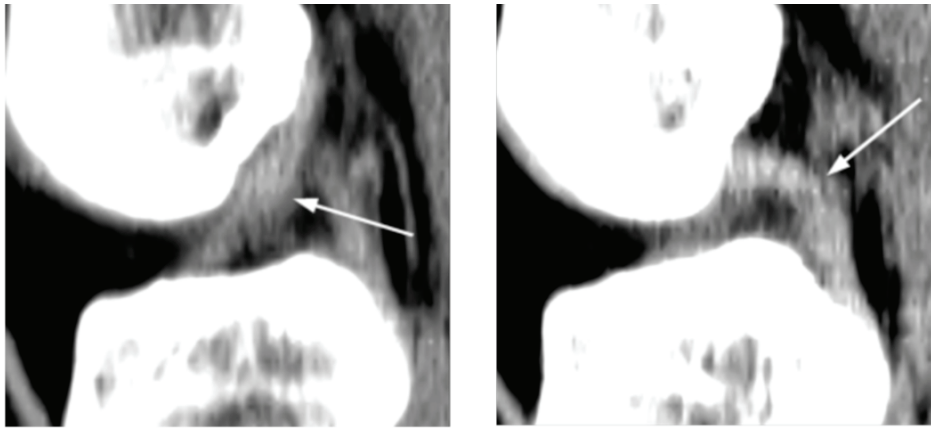


Fig. 11: Normal cruciate ligaments on sagittal multiplanar reconstructions from axial MDCT images. Left: ACL (arrow). Right: PCL (arrow). Reprinted with permission from Taylor & Francis Ltd. from Antti O. Mustonen, Mika P. Koivikko, Ville V. Haapamäki, Martti J. Kiuru, Antti E. Lamminen, Seppo K. Koskinen. MDCT in acute knee injuries – assessment of cruciate ligaments with MRI correlation. Acta Radiol 48:104–11, 2007.

When Mui and colleagues [180] retrospectively studied cruciate ligaments with tibial plateau fractures by CT and MDCT without contrast agent, they concluded that CT yields a high NPV for excluding ligament injury. They regarded MRI as the gold standard, without surgical or arthroscopic confirmation.

Lack of arthroscopy confirmation may be a limitation of this study, but MRI is known to determine ACL and PCL injuries with high accuracy, sensitivity, and specificity.

The aim is not to replace MRI by MDCT, but because the number of MDCT examinations is further increasing, it is therefore important to fully utilize all possible information from MDCT examinations and thus perhaps avoid a subsequent MRI examination. This could possibly accelerate treatment decisions.

It can be concluded that when ACL or PCL is detected as a continuous band-like structure in MDCT, these structures are doubtless intact, and no subsequent MRI is needed, otherwise MDCT results are indifferent, and MRI is needed as the complementary examination in evaluation of cruciate ligaments.

The clinical application was straightforward and helped to optimize both time-usage and cost-efficiency: In MDCT scans for knee trauma, the reliable detection of intact cruciate ligaments rendered further MRI unnecessary. In the future, 64- or more slice scanners, or new CT

technology will provide an interesting study tool, perhaps for other soft tissue evaluation such as of the MCL or LCL, as well.

Study III — Meniscal injury in MRI

Tibial plateau fractures are often associated with meniscal injuries [17, 28, 40, 89, 142, 239, 267, 287]. To the author's knowledge, however, no MRI studies with a more detailed analysis of meniscal injury (such as prevalence of unstable meniscal tears and exact location of a tear) are available in settings of acute knee trauma with tibial plateau fractures. One study showed that unstable meniscal tears are more commonly associated with pain than are stable tears [26]. At arthroscopy a meniscus can be determined as stable or unstable by probing it with direct visualization. In clinical practice, pain is an important criterion for orthopedic surgeons considering meniscal treatment.

In this study a high number of unstable tears were evident. No meniscal root tears were evident in MRI or arthroscopy despite the high-energy fractures. When originally designing the study, root injuries were assumed to exist in this study group. More meniscal contusions were found than described by Cothran and colleagues [42]. However, the present study differs significantly from Cothran's: The patient population exhibited tibial plateau fractures with a notable average articular depression of over 3 mm. These can be considered high-energy fractures, whereas Cothran studied knees with bone contusion only and no tibial plateau fractures. The present study found no correlation between fracture pattern and meniscal injury, and similarly, no correlation between articular surface depression and meniscal findings. Although the limited number of patients may influence this finding, it can be hypothesized that even non-displaced tibial plateau fractures can be associated with severe meniscal injuries, and on the other hand, clearly displaced tibial plateau fractures can demonstrate normal menisci. A high number of ligamentous injuries, most of which needed surgery, were evident, as has been noted by other authors [28, 40, 89].

The lack of arthroscopic or surgical verification in 11 patients with normal MRI findings in their menisci may be a potential limitation of this study, but MRI is known to detect meniscal tears with excellent sensitivity, specificity, and accuracy [46, 82, 212, 231, 291], which was also seen in this study. It is known that joint effusion does not interfere with accurate MRI detection of meniscal lesions [212], and the high NPV in this study strongly suggests that

those 11 patients had true-negative findings; therefore, they were included. Clinical tests revealed no signs of meniscal tears, and arthroscopy after normal MRI without clinical symptoms would have been ethically unacceptable.

Contusion was an isolated finding in nine menisci, and at arthroscopy the menisci were intact. It can be thus hypothesized that if contusion is an isolated finding, it should be managed conservatively. A lack of follow-up MRI, however, represents a limitation of this hypothesis; the natural behavior of this increased contusion signal in the menisci over a long period remains unknown, and further studies with follow-up MRI are thus necessary.

When a meniscal tear is detected preoperatively, meniscal repair (arthroscopic or open surgery) can be combined with fracture fixation, so that another operation is unnecessary. It is therefore suggested that a knee MRI should be considered as a complementary study after MDCT in patients suffering high-energy tibial plateau fractures.

Study IV — Meniscal repair in MRI

In all MRI sequences a normal meniscus has low signal intensity [82, 255]. Two accepted diagnostic criteria for a meniscal tear in a knee without prior meniscal surgery are abnormal internal signal unequivocally extending to the meniscal articular surface, and abnormal morphology of the meniscus [82]. These criteria have, however, only limited diagnostic usefulness in evaluating postoperative menisci, and assessment cannot be based solely on signal intensity [49, 51, 232]. A fluid extending into the tear on T2-weighted images may be helpful to distinguish between re-tear and natural healing [159, 258]. Thus, MR arthrography has been used, but it is invasive, with possible complications. Because no grading system exists for menisci repaired with bioabsorbable arrows, a widely used grading system was applied in this study [251].

Cooper and colleagues [41] demonstrated increased healing rates in menisci with repair combined with ACL surgery. In the present study, no difference appeared between different grades among patients with intact or operated ACL. Based on the findings of this study, increased signal intensity extending to the meniscal surface (Grade 3 signal) is a common finding in postoperative menisci. Whether this finding represents re-tear or improper healing, or whether it is only one part of the natural healing process, remains unclear. A limitation

preventing further analysis of this finding is that neither arthroscopy nor MR arthrography could be performed in those clinically asymptomatic patients, making further prospective studies desirable. An invasive examination such as MR arthrography or, especially, arthroscopy was deemed ethically unacceptable for asymptomatic patients. The number of Grade 3 menisci was highest in menisci imaged less than 18 months after surgery. Thus, MR arthrography is recommended for that patient group.

Study V — Postoperative tibial plateau fractures in MDCT

In operatively treated tibial plateau fractures, follow-up imaging is usually done by radiography [261]. MDCT has become increasingly important in the primary diagnosis of acute knee trauma. This, together with the increasing number of MDCT scanners, can lead to increased MDCT use for postoperative imaging, as well. As this study was conducted in a level-one trauma center, it may be biased towards more complicated fractures, making the results, in theory, perhaps inapplicable to all surgically treated tibial plateau fractures. A perfect cross-section of the population is elusive. Acute orthopedic surgery is, to date, mostly concentrated at Töölö Trauma Center in a metropolitan area, making the patient population representative of a level-one trauma center dealing with orthopedic trauma. The assessment of relevance and reduction retrospectively, although done in consensus with the orthopedic surgeon, is subjective, and is also another limitation of the study. A prospective approach would probably be more precise. Such a study, however, limiting a subgroup of patients to radiography only or blinding clinical decisions from MDCT, would certainly be unethical.

In only three cases, did the orthopedic hardware slightly impair image quality, but this caused no diagnostic problems. MDCT was the most useful in the immediate postoperative period, when appropriate radiographs, in particular, are difficult or even impossible to obtain due to orthoses and to pain. In seven cases, MDCT, in retrospect, provided no additional radiological information compared to that from radiography. Based on the chart view, some of those MDCTs might have been avoidable with better knowledge of radiology or of fracture patterns. The assessment of postoperative radiography of the knee with tibial plateau fracture is, however, a task challenging even to an experienced radiologist or orthopedic surgeon, and diagnostic errors or misinterpretations in daily clinical practice will occur. On the one hand, for symptomatic patients, MDCT can be also used to evaluate possible additional findings that might explain the symptoms even if no suspected complications are evident in radiography.

On the other hand, MDCT is sometimes needed to confirm findings also evident in radiography.

At the moment, new guidelines for postoperative use of MDCT in tibial plateau fractures are in the process of establishment at Töölö Trauma Center. Factors under consideration are 1) In the immediate postoperative phase, no MDCT is needed if the first postoperative radiographs show good reduction, and if orthopedic hardware does not obscure the articular surface. 2) Marked malreduction in radiographs indicates MDCT to reveal the exact morphology, hardware position, and position of bony fragments in comparison to orthopedic hardware. In such cases, MDCT findings can aid the orthopedic surgeon in decision-making regarding any reoperation or especially in a decision not to reoperate although radiographs show suboptimal reduction. 3) In the later postoperative phase, no MDCT is needed if follow-up radiographs show no worsening in reduction or no increasing articular step-off. 4) For symptomatic patients, however, MDCT should be considered to exclude additional findings – beyond the capabilities of radiography – that explain the symptoms. 5) MDCT is recommended as a complementary examination if, in follow-up radiography, there is suspicion of increasing articular surface depression, hardware failure, or non-union.

The main indications for postoperative MDCT were the assessment and follow-up of the joint articular surface, and evaluation of fracture healing. After postoperative MDCT, 39% of the patients underwent reoperation – further justifying MDCT use. Here, it has been shown that currently a small number of patients (9%) with tibial plateau fracture undergo postoperative imaging with MDCT. Targeted MDCT, however, provides relevant and detailed information and reveals clinical problems beyond the capabilities of radiography.

Future aspect of the knee trauma imaging

A clinical study with arthroscopic verification showed that physical examination in patients with internal derangement of the knee has a clinical accuracy of only 75% [206], thus justifying appropriate imaging in evaluating patients with knee injuries.

Because use of MDCT in acute knee trauma is increasing, demand will certainly arise for soft tissue evaluation, as well. With modern MDCT scanners, soft tissues like cruciate ligaments can be visualized with good accuracy. The quick transformation of CT to MDCT has once

again shown that a modern technique can produce useful new applications. Recently, the term “MRIzation of the CT” has been introduced, emphasizing the versatility of current CT technology in choosing among different imaging parameters. With a new application of dual-energy CT the soft tissues can be better displaced than by the previous CT technology [254]. This may improve assessment of soft tissue structures of the knee, as well.

Treatment of tibial plateau injury is technically demanding [260]. Achievement of anatomical restoration of the knee joint requires preoperative evaluation with MDCT or MRI or both (Fig. 27). In tibial plateau fractures, surgical treatment is often needed. Postoperative follow-up imaging is usually performed by radiography, but in the next few years MDCT use in postoperative imaging may increase, especially now when new techniques such as flat-panel volume CT and dual-energy CT have been introduced for clinical application. With these new scanners, improved resolution can help in follow-up imaging of these challenging injuries.

Today, treatment options for more patient groups are available, resulting in the need for high-quality postoperative imaging. In many cases, however, MRI will not be the method of choice because of artifacts from implant materials. Use of MDCT can avoid this problem, and determination of healing or complications is possible even when metal plates are involved. GE Healthcare has just announced the world’s first high-definition low-dose CT scanner with new spectral technology [90]. This scanner is based on a garnet gemstone detector, allowing increased spatial resolution without increasing the radiation dose. Improved tissue characterization separates materials such as calcium, iodine, and water. It also reduces beam-hardening artefacts normally attributed to bone and metal. This may also help in imaging of patients with orthopedic hardware.

Radiologists and orthopedic surgeons should be familiar with various imaging modalities and possible treatment options. This all requires a continuous education (life-long learning) and well-organized trauma units to assure patients the best clinical outcome. Radiologists should work together with orthopedic surgeons to stay in touch with demand for interpretations and to design adequate examinations to reveal all possible findings from an injured knee. Imaging and interpretation should be arranged rapidly, and in severely injured patients almost online. In level-one trauma centers, 24/7 services can generally respond to this demand. Trauma radiology of good quality needs evidence-based studies.

CONCLUSIONS

Study I — Knee fractures in radiography and MDCT

Negative radiography is inadequate to rule out a knee fracture, and MDCT is recommended as a complementary examination in severely injured patients. MDCT reveals complex fracture anatomy, benefiting preoperative planning and patient care.

Study II — Cruciate ligaments in MDCT

MDCT detects intact cruciate ligaments with good accuracy, specificity, and NPV. The evaluation of torn cruciate ligaments is, however, unreliable.

Study III — Meniscal injury in MRI

In patients with tibial plateau fractures, an unstable meniscal tear is a common finding, and a subsequent MRI should be considered for those patients. A high number of meniscal contusions also occur, and knowledge of this abnormality helps radiologists to avoid false-positive meniscal tears.

Study IV — Meniscal repair in MRI

Whether the increased signal intensity contacting the articular surface of the meniscus represents a re-tear or improper healing, or if it is just a part of the normal healing process remains unclear and calls for further prospective studies. MR arthrography is recommended for exact assessment of menisci repaired with bioabsorbable arrows for patients who undergo knee MRI less than 18 months after the surgery.

Study V — Postoperative tibial plateau fractures in MDCT

Postoperative use of MDCT in tibial plateau fractures was rather infrequent even in this large trauma center, but when performed postoperatively for suspicion of increasing articular step-off or fracture non-union, it revealed clinically significant information in the majority of cases.

ACKNOWLEDGEMENTS

This study was carried out at Töölö Hospital, Helsinki Medical Imaging Center, Helsinki Central University Hospital, Helsinki, Finland, during the years 2004–2009.

I am the most grateful to my supervisors Docents Seppo Koskinen and Martti Kiuru, for their inspiring guidance, remarkable patience, and constant support during these years.

I would like to express my gratitude to Professor Leena Kivisaari, Head of the Department of Diagnostic Radiology, who first guided me when planning the overall research subject and introduced me to Seppo and Martti. I also express my gratitude to Docent Juhani Ahovuo, former CEO of Helsinki Medical Imaging Center, Docent Pekka Tervahartiala, Medical Director of Helsinki Medical Imaging Center, and Jyrki Putkonen, CEO of Helsinki Medical Imaging Center, for providing me first-class working facilities.

I wish to thank all my expert co-authors. Docents Eero Hirvensalo, Antti Lamminen, and Jari Salo, and Drs. Ville Haapamäki, Mika Koivikko, Jan Lindahl, and Laura Tielinen.

I especially wish to thank the official reviewers, Professor Osmo Tervonen, and Docent Arsi Harilainen for their inspiring attitude towards the revision of the manuscript. You gave me many valuable comments which markedly improved the final version of the manuscript.

I have had the honor to work with the very best radiologists in the field, and my colleagues from Töölö Hospital are acknowledged for their encouraging support: Docent Marko Kangasniemi, Drs. Nina Dalin-Hirvonen, Liisa Kerttula, Jussi Numminen, Johanna Pekkola, Kristiina Poussa, and Margit Vikki.

I wish to thank Dr. Carol Norris, for the excellent language revision of this thesis and her friendship when guiding me in the difficult world of English.

I am very grateful to my brother Ville, my mother Sirkka, and my late mother-in-law Sisko Nurmikumpu, for their measureless help during this long work. My special thanks go my father Olavi; I am sure you would have been proud of me.

Finally, I express my greatest gratitude to my beloved family: Piia, Ida-Maria, and Sara. Without your continuous patient support and understanding this work would have never finished.

This study was supported by the Pehr Oscar Klingendahl Foundation, the Emil Aaltonen Foundation, and the Radiological Society of Finland.

REFERENCES

1. Ahmad CS, Cohen ZA, Levine WN, Gardner TR, Ateshian GA, Mow VC. Codominance of the individual posterior cruciate ligament bundles. An analysis of bundle lengths and orientation. *Am J Sports Med* 31:221–225, 2003.
2. Al-Othman AA. Biodegradable arrows for arthroscopic repair of meniscal tears. *Int Orthop* 26:247–249, 2002.
3. Albrecht-Olsen P, Kristensen G, Törmälä P. Meniscus bucket-handle fixation with an absorbable Biofix tack: development of a new technique. *Knee Surg Sports Traumatol Arthrosc* 1:104–106, 1993.
4. Albrecht-Olsen P, Lind T, Kristensen G, Falkenberg B. Failure strength of a new meniscus arrow repair technique: biomechanical comparison with horizontal suture. *Arthroscopy* 13:183–187, 1997.
5. Ali AM, El-Shafie M, Willett KM. Failure of fixation of tibial plateau fractures. *J Orthop Trauma* 16:323–329, 2002.
6. Anderson MW. MR imaging of the meniscus. *Radiol Clin North Am* 40:1081–1094, 2002.
7. Andrews JR, Edwards JC, Satterwhite YE. Isolated posterior cruciate ligament injuries. History, mechanism of injury, physical findings, and ancillary tests. *Clin Sports Med* 13:519–530, 1994.
8. Annandale T. An operation for displaced semilunar cartilage. *Br Med J* 1:779, 1885.
9. Applegate GR, Flannigan BD, Tolin BS, Fox JM, Del Pizzo W. MR diagnosis of recurrent tears in the knee: value of intraarticular contrast material. *AJR Am J Roentgenol* 161:821–825, 1993.
10. Arnoczky SP. Anatomy of the anterior cruciate ligament. *Clin Orthop Relat Res* 172:19–25, 1983.
11. Arnoczky SP, Warren RF. Microvasculature of the human meniscus. *Am J Sports Med* 10:90–95, 1982.
12. Arnoczky SP, Warren RF, Ashlock MA. Replacement of the anterior cruciate ligament using a patellar tendon allograft. An experimental study. *J Bone Joint Surg Am* 68:376–385, 1986.
13. Arnoczky SP, Warren RF, Minei JP. Replacement of the anterior cruciate ligament using a synthetic prosthesis. An evaluation of graft biology in the dog. *Am J Sports Med* 14:1–6, 1986.
14. Bachmann LM, Haberzeth S, Steurer J, ter Riet G. The accuracy of the Ottawa knee rule to rule out knee fractures: a systematic review. *Ann Intern Med* 140:121–124, 2004.

15. Baker CL, Jr., Norwood LA, Hughston JC. Acute posterolateral rotatory instability of the knee. *J Bone Joint Surg Am* 65:614–618, 1983.
16. Barber FA, Herbert MA. Meniscal repair devices. *Arthroscopy* 16:613–618, 2000.
17. Barrow BA, Fajman WA, Parker LM, Albert MJ, Drvaric DM, Hudson TM. Tibial plateau fractures: evaluation with MR imaging. *Radiographics* 14:553–559, 1994.
18. Bergin D, Schweitzer ME. Indirect magnetic resonance arthrography. *Skeletal Radiol* 32:551–558, 2003.
19. Bikkina RS, Tujo CA, Schraner AB, Major NM. The "floating" meniscus: MRI in knee trauma and implications for surgery. *AJR Am J Roentgenol* 184:200–204, 2005.
20. Billante MJ, Diduch DR, Lunardini DJ, Treme GP, Miller MD, Hart JM. Meniscal repair using an all-inside, rapidly absorbing, tensionable device. *Arthroscopy* 24:779–785, 2008.
21. Blackmon GB, Major NM, Helms CA. Comparison of fast spin-echo versus conventional spin-echo MRI for evaluating meniscal tears. *AJR Am J Roentgenol* 184:1740–1743, 2005.
22. Blokker CP, Rorabeck CH, Bourne RB. Tibial plateau fractures. An analysis of the results of treatment in 60 patients. *Clin Orthop Relat Res* 182:193–199, 1984.
23. Bohndorf K, Kilcoyne RF. Traumatic injuries: imaging of peripheral musculoskeletal injuries. *Eur Radiol* 12:1605–1616, 2002.
24. Bonnefoy O, Diris B, Moinard M, Aunoble S, Diard F, Hauger O. Acute knee trauma: role of ultrasound. *Eur Radiol* 16:2542–2548, 2006.
25. Bonshahi AY, Hopgood P, Shepard GJ. Migration of a broken meniscal arrow: a case report and review of the literature. *Knee Surg Sports Traumatol Arthrosc* 12:50–51, 2004.
26. Boxheimer L, Lutz AM, Zanetti M, Treiber K, Labler L, Marincek B, Weishaupt D. Characteristics of displaceable and nondisplaceable meniscal tears at kinematic MR imaging of the knee. *Radiology* 238:221–231, 2006.
27. Bradley WG, Ominsky SH. Mountain view of the patella. *AJR Am J Roentgenol* 136:53–58, 1981.
28. Brophy DP, O'Malley M, Lui D, Denison B, Eustace S. MR imaging of tibial plateau fractures. *Clin Radiol* 51:873–878, 1996.
29. Buckwalter JA, Mankin HJ. Articular cartilage: Part I: Tissue design and chondrocyte-matrix interactions. *J Bone Joint Surg Am* 79:600–611, 1997.
30. Buttner-Janzen K, Schellnack K, Rieder T. Noninvasive diagnosis of cruciate ligament damage with particular reference to computed tomography with arthrography. *Am J Sports Med* 17:501–504, 1989.

31. Cabaud HE. Biomechanics of the anterior cruciate ligament. *Clin Orthop Relat Res* 172:26–31, 1983.
32. Cannon WD, Morgan CD. Meniscal repair: arthroscopic repair techniques. *J Bone Joint Surg Am* 76:294–311, 1994.
33. Carpenter JE, Kasman R, Matthews LS. Fractures of the patella. *J Bone Joint Surg Am* 75:1550–1561, 1993.
34. Catagni MA, Ottaviani G, Maggioni M. Treatment strategies for complex fractures of the tibial plateau with external circular fixation and limited internal fixation. *J Trauma* 63:1043–1053, 2007.
35. Cerabona F, Sherman MF, Bonamo JR, Sklar J. Patterns of meniscal injury with acute anterior cruciate ligament tears. *Am J Sports Med* 16:603–609, 1988.
36. Cetik O, Cift H, Asik M. Second-look arthroscopy after arthroscopy-assisted treatment of tibial plateau fractures. *Knee Surg Sports Traumatol Arthrosc* 15:747–752, 2007.
37. Chan PS, Klimkiewicz JJ, Luchetti WT, Esterhai JL, Kneeland JB, Dalinka MK, Heppenstall RB. Impact of CT scan on treatment plan and fracture classification of tibial plateau fractures. *J Orthop Trauma* 11:484–489, 1997.
38. Cheung LP, Li KC, Hollett MD, Bergman AG, Herfkens RJ. Meniscal tears of the knee: accuracy of detection with fast spin-echo MR imaging and arthroscopic correlation in 293 patients. *Radiology* 203:508–512, 1997.
39. Chhem RK, Kaplan PA, Dussault RG. Ultrasonography of the musculoskeletal system. *Radiol Clin North Am* 32:275–289, 1994.
40. Colletti P, Greenberg H, Terk MR. MR findings in patients with acute tibial plateau fractures. *Comput Med Imaging Graph* 20:389–394, 1996.
41. Cooper DE, Arnoczky SP, Warren RF. Arthroscopic meniscal repair. *Clin Sports Med* 9:589–607, 1990.
42. Cothran RL, Jr., Major NM, Helms CA, Higgins LD. MR imaging of meniscal contusion in the knee. *AJR Am J Roentgenol* 177:1189–1192, 2001.
43. Court-Payen M. Sonography of the knee: intra-articular pathology. *J Clin Ultrasound* 32:481–490, 2004.
44. Covey CD, Sapega AA. Injuries of the posterior cruciate ligament. *J Bone Joint Surg Am* 75:1376–1386, 1993.
45. Covey DC. Injuries of the posterolateral corner of the knee. *J Bone Joint Surg Am* 83:106–118, 2001.
46. Crues JV, 3rd, Mink J, Levy TL, Lotysch M, Stoller DW. Meniscal tears of the knee: accuracy of MR imaging. *Radiology* 164:445–448, 1987.

47. Daffner RH, Tabas JH. Trauma oblique radiographs of the knee. *J Bone Joint Surg Am* 69:568–572, 1987.
48. Damadian R. Tumor detection by nuclear magnetic resonance. *Science* 171:1151–1153, 1971.
49. Davis KW, Tuite MJ. MR imaging of the postoperative meniscus of the knee. *Semin Musculoskelet Radiol* 6:35–45, 2002.
50. De Maeseneer M, Van Roy F, Lenchik L, Barbaix E, De Ridder F, Osteaux M. Three layers of the medial capsular and supporting structures of the knee: MR imaging-anatomic correlation. *Radiographics* 20:S83–S89, 2000.
51. De Smet AA. MR imaging and MR arthrography for diagnosis of recurrent tears in the postoperative meniscus. *Semin Musculoskelet Radiol* 9:116–124, 2005.
52. DeHaven KE. Meniscus repair. *Am J Sports Med* 27:242–250, 1999.
53. DeHaven KE. Meniscus repair in the athlete. *Clin Orthop Relat Res* 198:31–35, 1985.
54. DeHaven KE, Arnoczky SP. Meniscal repair. *J Bone Joint Surg Am* 76:140–152, 1994.
55. DeLee JC, Riley MB, Rockwood CA, Jr. Acute posterolateral rotatory instability of the knee. *Am J Sports Med* 11:199–207, 1983.
56. Dendy PP, Heaton B. Magnetic resonance imaging. In: *Physics for diagnostic radiology*, 2nd ed. Institute of Physics Pub., Philadelphia, 378–407, 1999.
57. Dendy PP, Heaton B. Production of x-rays. In: *Physics for diagnostic radiology*, 2nd ed. Institute of Physics Pub., Philadelphia, 20–58, 1999.
58. Dendy PP, Heaton B. Radiobiology and radiation risks. In: *Physics for diagnostic radiology*, 2nd ed. Institute of Physics Pub., Philadelphia, 279–305, 1999.
59. Dendy PP, Heaton B. Special radiographic techniques. In: *Physics for diagnostic radiology*, 2nd ed. Institute of Physics Pub., Philadelphia, 219–248, 1999.
60. Dendy PP, Heaton B. The image receptor. In: *Physics for diagnostic radiology*, 2nd ed. Institute of Physics Pub., Philadelphia, 83–113, 1999.
61. Dendy PP, Heaton B. Tomographic imaging. In: *Physics for diagnostic radiology*, 2nd ed. Institute of Physics Pub., Philadelphia, 249–278, 1999.
62. Deutsch AL, Mink JH, Fox JM, Arnoczky SP, Rothman BJ, Stoller DW, Cannon WD, Jr. Peripheral meniscal tears: MR findings after conservative treatment or arthroscopic repair. *Radiology* 176:485–488, 1990.
63. Diamantopoulos A, Tokis A, Tzurbakis M, Patsopoulos I, Georgoulis A. The posterolateral corner of the knee: evaluation under microsurgical dissection. *Arthroscopy* 21:826–833, 2005.

64. Dirschl DR, Dawson PA. Injury severity assessment in tibial plateau fractures. *Clin Orthop Relat Res* 423:85–92, 2004.
65. Dobbins JT, 3rd, Godfrey DJ. Digital x-ray tomosynthesis: current state of the art and clinical potential. *Phys Med Biol* 48:R65–R106, 2003.
66. Dowd GS. Reconstruction of the posterior cruciate ligament. Indications and results. *J Bone Joint Surg Br* 86:480–491, 2004.
67. Drape JL, Thelen P, Gay-Depassier P, Silbermann O, Benacerraf R. Intraarticular diffusion of Gd-DOTA after intravenous injection in the knee: MR imaging evaluation. *Radiology* 188:227–234, 1993.
68. Englund M, Guermazi A, Gale D, Hunter DJ, Aliabadi P, Clancy M, Felson DT. Incidental meniscal findings on knee MRI in middle-aged and elderly persons. *N Engl J Med* 359:1108–1115, 2008.
69. 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 Am J Roentgenol* 167:1223–1227, 1996.
70. European Commission. Clinical problems, investigations, recommendations and comments: K. Trauma. In: Dixon A (ed.) Radiation protection 118 referral guidelines for imaging, 1st ed. Office for Official Publications of the European Communities, Luxembourg, 93, 2001.
71. European Commission. Optimizing radiation dose. In: Dixon A (ed.) Radiation protection 118 referral guidelines for imaging, 1st ed. Office for Official Publications of the European Communities, Luxembourg, 18–21, 2001.
72. Fagan DJ, Davies S. The clinical indications for plain radiography in acute knee trauma. *Injury* 31:723–727, 2000.
73. Fairbank TJ. Knee joint changes after meniscectomy. *J Bone Joint Surg Br* 30:664–670, 1948.
74. Fanelli GC, Orcutt DR, Edson CJ. The multiple-ligament injured knee: evaluation, treatment, and results. *Arthroscopy* 21:471–486, 2005.
75. Farber JM. CT arthrography and postoperative musculoskeletal imaging with multichannel computed tomography. *Semin Musculoskelet Radiol* 8:157–166, 2004.
76. Farley TE, Howell SM, Love KF, Wolfe RD, Neumann CH. Meniscal tears: MR and arthrographic findings after arthroscopic repair. *Radiology* 180:517–522, 1991.
77. Fayad LM, Bluemke DA, Fishman EK. Musculoskeletal imaging with computed tomography and magnetic resonance imaging: when is computed tomography the study of choice? *Curr Probl Diagn Radiol* 34:220–237, 2005.

78. Fischer SP, Fox JM, Del Pizzo W, Friedman MJ, Snyder SJ, Ferkel RD. Accuracy of diagnoses from magnetic resonance imaging of the knee. A multi-center analysis of one thousand and fourteen patients. *J Bone Joint Surg Am* 73:2–10, 1991.
79. Fisher JD. MRI: safety in patients with pacemakers or defibrillators: is it prime time yet? *Pacing Clin Electrophysiol* 28:263, 2005.
80. Fleckenstein JL, Archer BT, Barker BA, Vaughan JT, Parkey RW, Peshock RM. Fast short-tau inversion-recovery MR imaging. *Radiology* 179:499–504, 1991.
81. Flohr TG, McCollough CH, Bruder H, Petersilka M, Gruber K, Suss C, Grasruck M, Stierstorfer K, Krauss B, Raupach R, Primak AN, Kuttner A, Achenbach S, Becker C, Kopp A, Ohnesorge BM. First performance evaluation of a dual-source CT (DSCT) system. *Eur Radiol* 16:256–268, 2006.
82. Fox MG. MR imaging of the meniscus: review, current trends, and clinical implications. *Magn Reson Imaging Clin N Am* 15:103–123, 2007.
83. Frank CB, Jackson DW. The science of reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Am* 79:1556–1576, 1997.
84. Fu FH, Bennett CH, Lattermann C, Ma CB. Current trends in anterior cruciate ligament reconstruction. Part 1: Biology and biomechanics of reconstruction. *Am J Sports Med* 27:821–830, 1999.
85. Fu FH, Bennett CH, Ma CB, Menetrey J, Lattermann C. Current trends in anterior cruciate ligament reconstruction. Part II. Operative procedures and clinical correlations. *Am J Sports Med* 28:124–130, 2000.
86. Fulkerson JP, Hungerford DS. Disorders of the patellofemoral joint, 2nd ed. Williams & Wilkins, Baltimore, 1990.
87. Furey A, Floyd CP, O'Toole RV. Treatment of tibial plateau fractures. *Curr Opin Orthop* 18:49–53, 2007.
88. Furman W, Marshall JL, Girgis FG. The anterior cruciate ligament. A functional analysis based on postmortem studies. *J Bone Joint Surg Am* 58:179–175, 1976.
89. Gardner MJ, Yacoubian S, Geller D, Suk M, Mintz D, Potter H, Helfet DL, Lorch DG. The incidence of soft tissue injury in operative tibial plateau fractures: a magnetic resonance imaging analysis of 103 patients. *J Orthop Trauma* 19:79–84, 2005.
90. GE Healthcare. GE's high-definition CT promises new era in image quality and dose reduction. <http://medicalphysicsweb.org/cws/article/newfeed/38171>
91. Gimbel JR, Kanal E, Schwartz KM, Wilkoff BL. Outcome of magnetic resonance imaging (MRI) in selected patients with implantable cardioverter defibrillators (ICDs). *Pacing Clin Electrophysiol* 28:270-273, 2005.
92. Girgis FG, Marshall JL, Monajem A. The cruciate ligaments of the knee joint. Anatomical, functional and experimental analysis. *Clin Orthop Relat Res* 106:216–231, 1975.

93. Gliatis J, Kouzelis A, Panagopoulos A, Lambiris E. Chondral injury due to migration of a Mitek RapidLoc meniscal repair implant after successful meniscal repair: a case report. *Knee Surg Sports Traumatol Arthrosc* 13:280–282, 2005.
94. Gray H, Williams PL, Bannister LH. Gray's anatomy : the anatomical basis of medicine and surgery, 38th ed. Churchill Livingstone, New York, 678–712, 1995.
95. Gray SD, Kaplan PA, Dussault RG, Omary RA, Campbell SE, Chrisman HB, Futterer SF, McGraw JK, Keats TE, Hillman BJ. Acute knee trauma: how many plain film views are necessary for the initial examination? *Skeletal Radiol* 26:298–302, 1997.
96. Greenspan A. Knee. In: Greenspan A (ed.) Orthopedic imaging : a practical approach, 4th ed. Lippincott Williams & Wilkins, Philadelphia, 243–291, 2004.
97. Griffith JF, Antonio GE, Tong CW, Ming CK. Cruciate ligament avulsion fractures. *Arthroscopy* 20:803–812, 2004.
98. Grood ES, Noyes FR, Butler DL, Suntay WJ. Ligamentous and capsular restraints preventing straight medial and lateral laxity in intact human cadaver knees. *J Bone Joint Surg Am* 63:1257–1269, 1981.
99. Gross ML, Grover JS, Bassett LW, Seeger LL, Finerman GA. Magnetic resonance imaging of the posterior cruciate ligament. Clinical use to improve diagnostic accuracy. *Am J Sports Med* 20:732–737, 1992.
100. Guckel C, Jundt G, Schnabel K, Gachter A. Spin-echo and 3D gradient-echo imaging of the knee joint: a clinical and histopathological comparison. *Eur J Radiol* 21:25–33, 1995.
101. Gupta R, Cheung AC, Bartling SH, Lisauskas J, Grasruck M, Leidecker C, Schmidt B, Flohr T, Brady TJ. Flat-panel volume CT: fundamental principles, technology, and applications. *Radiographics* 28:2009–2022, 2008.
102. Ha TP, Li KC, Beaulieu CF, Bergman G, Ch'en IY, Eller DJ, Cheung LP, Herfkens RJ. Anterior cruciate ligament injury: fast spin-echo MR imaging with arthroscopic correlation in 217 examinations. *AJR Am J Roentgenol* 170:1215–1219, 1998.
103. Hajek PC, Baker LL, Sartoris DJ, Neumann CH, Resnick D. MR arthrography: anatomic-pathologic investigation. *Radiology* 163:141–147, 1987.
104. Hajek PC, Sartoris DJ, Neumann CH, Resnick D. Potential contrast agents for MR arthrography: in vitro evaluation and practical observations. *AJR Am J Roentgenol* 149:97–104, 1987.
105. Hamberg P, Gillquist J, Lysholm J. Suture of new and old peripheral meniscus tears. *J Bone Joint Surg Am* 65:193–197, 1983.
106. Hantes ME, Zachos VC, Zibis AH, Papanagiotou P, Karachalios T, Malizos KN, Karantanas AH. Evaluation of meniscal repair with serial magnetic resonance imaging: a comparative study between conventional MRI and indirect MR arthrography. *Eur J Radiol* 50:231–237, 2004.

107. Harner CD, Poehling GG. Double bundle or double trouble? *Arthroscopy* 20:1013–1014, 2004.
108. Harris JH. Knee. In: Harris JH, Harris WH (eds.) *The radiology of emergency medicine*, 4th ed. Lippincott Williams & Wilkins, Philadelphia, 815–837, 2000.
109. Heller L, Langman J. The Menisco-Femoral Ligaments of the Human Knee. *J Bone Joint Surg Br* 46:307–313, 1964.
110. Helms CA. The meniscus: recent advances in MR imaging of the knee. *AJR Am J Roentgenol* 179:1115–1122, 2002.
111. Henckel J, Richards R, Lozhkin K, Harris S, Baena FM, Barrett AR, Cobb JP. Very low-dose computed tomography for planning and outcome measurement in knee replacement. The imperial knee protocol. *J Bone Joint Surg Br* 88:1513–1518, 2006.
112. Hensal F, Nelson T, Pavlov H, Torg JS. Bilateral patellar fractures from indirect trauma. A case report. *Clin Orthop Relat Res* 178:207–209, 1983.
113. Heron CW, Calvert PT. Three-dimensional gradient-echo MR imaging of the knee: comparison with arthroscopy in 100 patients. *Radiology* 183:839–844, 1992.
114. Hertzmark MH. The evolution of the knee joint. *J Bone Joint Surg Am* 20:77–84, 1938.
115. Herwig J, Egner E, Buddecke E. Chemical changes of human knee joint menisci in various stages of degeneration. *Ann Rheum Dis* 43:635–640, 1984.
116. Hodler J, Haghghi P, Pathria MN, Trudell D, Resnick D. Meniscal changes in the elderly: correlation of MR imaging and histologic findings. *Radiology* 184:221–225, 1992.
117. Honkonen SE. Indications for surgical treatment of tibial condyle fractures. *Clin Orthop Relat Res* 302:199–205, 1994.
118. Hopkins KL, Li KC, Bergman G. Gadolinium-DTPA-enhanced magnetic resonance imaging of musculoskeletal infectious processes. *Skeletal Radiol* 24:325–330, 1995.
119. Houben PF, van der Linden ES, van den Wildenberg FA, Stapert JW. Functional and radiological outcome after intra-articular tibial plateau fractures. *Injury* 28:459–462, 1997.
120. Hough AJ, Jr., Webber RJ. Pathology of the meniscus. *Clin Orthop Relat Res* 252:32–40, 1990.
121. Hughston JC. Anterior cruciate deficient knee. *Am J Sports Med* 11:1–2, 1983.
122. Hughston JC, Andrews JR, Cross MJ, Moschi A. Classification of knee ligament instabilities. Part I. The medial compartment and cruciate ligaments. *J Bone Joint Surg Am* 58:159–172, 1976.

123. Hughston JC, Andrews JR, Cross MJ, Moschi A. Classification of knee ligament instabilities. Part II. The lateral compartment. *J Bone Joint Surg Am* 58:173–179, 1976.
124. Hughston JC, Bowden JA, Andrews JR, Norwood LA. Acute tears of the posterior cruciate ligament. Results of operative treatment. *J Bone Joint Surg Am* 62:438–450, 1980.
125. Huie G. Diagnosing a patellar fracture. *JAAPA* 16:51–52, 2003.
126. Hungerford DS, Barry M. Biomechanics of the patellofemoral joint. *Clin Orthop Relat Res* 144:9–15, 1979.
127. Indelicato PA. Non-operative treatment of complete tears of the medial collateral ligament of the knee. *J Bone Joint Surg Am* 65:323–329, 1983.
128. Indelicato PA, Bittar ES. A perspective of lesions associated with ACL insufficiency of the knee. A review of 100 cases. *Clin Orthop Relat Res* 198:77–80, 1985.
129. Indelicato PA, Hermansdorfer J, Huegel M. Nonoperative management of complete tears of the medial collateral ligament of the knee in intercollegiate football players. *Clin Orthop Relat Res* 256:174–177, 1990.
130. Irie K, Yamada T. Three-dimensional virtual computed tomography imaging for injured anterior cruciate ligament. *Arch Orthop Trauma Surg* 122:93–95, 2002.
131. Jackson JL, O'Malley PG, Kroenke K. Evaluation of acute knee pain in primary care. *Ann Intern Med* 139:575–588, 2003.
132. Jee WH, McCauley TR, Kim JM, Jun DJ, Lee YJ, Choi BG, Choi KH. Meniscal tear configurations: categorization with MR imaging. *AJR Am J Roentgenol* 180:93–97, 2003.
133. Johnson RJ. The anterior cruciate: a dilemma in sports medicine. *Int J Sports Med* 3:71–79, 1982.
134. Johnson TR, Krauss B, Sedlmair M, Grasmuck M, Bruder H, Morhard D, Fink C, Weckbach S, Lenhard M, Schmidt B, Flohr T, Reiser MF, Becker CR. Material differentiation by dual energy CT: initial experience. *Eur Radiol* 17:1510–1517, 2007.
135. Jones RE, Henley MB, Francis P. Nonoperative management of isolated grade III collateral ligament injury in high school football players. *Clin Orthop Relat Res* 213:137–140, 1986.
136. Järvelä T, Moisala AS, Sihvonen R, Järvelä S, Kannus P, Järvinen M. Double-bundle anterior cruciate ligament reconstruction using hamstring autografts and bioabsorbable interference screw fixation: prospective, randomized, clinical study with 2-year results. *Am J Sports Med* 36:290–297, 2008.
137. Kalliakmanis A, Zourntos S, Bousgas D, Nikolaou P. Comparison of arthroscopic meniscal repair results using 3 different meniscal repair devices in anterior cruciate ligament reconstruction patients. *Arthroscopy* 24:810–816, 2008.

138. Kaufer H. Mechanical function of the patella. *J Bone Joint Surg Am* 53:1551–1560, 1971.
139. Kean DM, Worthington BS, Preston BJ, Roebuck EJ, McKim-Thomas H, Hawkes RC, Holland GN, Moore WS. Nuclear magnetic resonance imaging of the knee: examples of normal anatomy and pathology. *Br J Radiol* 56:355–364, 1983.
140. Kennedy JC, Weinberg HW, Wilson AS. The anatomy and function of the anterior cruciate ligament. As determined by clinical and morphological studies. *J Bone Joint Surg Am* 56:223–235, 1974.
141. King D. The healing of semilunar cartilages. *J Bone Joint Surg Am* 18:333–342, 1936.
142. Kode L, Lieberman JM, Motta AO, Wilber JH, Vasen A, Yagan R. Evaluation of tibial plateau fractures: efficacy of MR imaging compared with CT. *AJR Am J Roentgenol* 163:141–147, 1994.
143. Kohn D, Moreno B. Meniscus insertion anatomy as a basis for meniscus replacement: a morphological cadaveric study. *Arthroscopy* 11:96–103, 1995.
144. Kondo E, Yasuda K, Azuma H, Tanabe Y, Yagi T. Prospective clinical comparisons of anatomic double-bundle versus single-bundle anterior cruciate ligament reconstruction procedures in 328 consecutive patients. *Am J Sports Med* 36:1675–1687, 2008.
145. Kopsch F. Rauber-Kopsch Lehrbuch und atlas der anatomie des menschen, 12th ed. G. Thieme, Leipzig, 305–318, 1922.
146. Kowalchuk RM, Kneeland JB, Dalinka MK, Siegelman ES, Dockery WD. MRI of the knee: value of short echo time fast spin-echo using high performance gradients versus conventional spin-echo imaging for the detection of meniscal tears. *Skeletal Radiol* 29:520–524, 2000.
147. Kramer J, Recht MP. MR arthrography of the lower extremity. *Radiol Clin North Am* 40:1121–1132, 2002.
148. Krukhaug Y, Molster A, Rodt A, Strand T. Lateral ligament injuries of the knee. *Knee Surg Sports Traumatol Arthrosc* 6:21–25, 1998.
149. Lambert KL. Vascularized patellar tendon graft with rigid internal fixation for anterior cruciate ligament insufficiency. *Clin Orthop Relat Res* 172:85–89, 1983.
150. Lansinger O, Bergman B, Korner L, Andersson GB. Tibial condylar fractures. A twenty-year follow-up. *J Bone Joint Surg Am* 68:13–19, 1986.
151. LaPrade RF, Engebretsen AH, Ly TV, Johansen S, Wentorf FA, Engebretsen L. The anatomy of the medial part of the knee. *J Bone Joint Surg Am* 89:2000–2010, 2007.
152. LaPrade RF, Gilbert TJ, Bollom TS, Wentorf F, Chaljub G. The magnetic resonance imaging appearance of individual structures of the posterolateral knee. A prospective study of normal knees and knees with surgically verified grade III injuries. *Am J Sports Med* 28:191–199, 2000.

153. LaPrade RF, Morgan PM, Wentorf FA, Johansen S, Engebretsen L. The anatomy of the posterior aspect of the knee. An anatomic study. *J Bone Joint Surg Am* 89:758–764, 2007.
154. Laurin CA, Dussault R, Levesque HP. The tangential x-ray investigation of the patellofemoral joint: x-ray technique, diagnostic criteria and their interpretation. *Clin Orthop Relat Res* 144:16–26, 1979.
155. Laurin CA, Levesque HP, Dussault R, Labelle H, Peides JP. The abnormal lateral patellofemoral angle: a diagnostic roentgenographic sign of recurrent patellar subluxation. *J Bone Joint Surg Am* 60:55–60, 1978.
156. Lauterbur PC. Progress in n.m.r. zeugmatography imaging. *Philos Trans R Soc Lond B Biol Sci* 289:483–487, 1980.
157. Lee JH, Weissman BN, Nikpoor N, Aliabadi P, Sosman JL. Lipohearthrosis of the knee: a review of recent experiences. *Radiology* 173:189–191, 1989.
158. Li L, Landin D, Grodesky J, Myers J. The function of gastrocnemius as a knee flexor at selected knee and ankle angles. *J Electromyogr Kinesiol* 12:385–390, 2002.
159. Lim PS, Schweitzer ME, Bhatia M, Giuliano V, Kaneriya PP, Senyk RM, Oliveri M, Johnson W, Amster B, Parker L. Repeat tear of postoperative meniscus: potential MR imaging signs. *Radiology* 210:183–188, 1999.
160. Lubowitz JH, Poehling GG. Techniques in double-bundle anterior cruciate ligament reconstruction: as simple as ABC, or putting the cart before the horse? *Arthroscopy* 24:1089–1091, 2008.
161. Macnab I. Recurrent dislocation of the patella. *J Bone Joint Surg Am* 34:957–967, 1952.
162. Magee T. Three-tesla MR imaging of the knee. *Magn Reson Imaging Clin N Am* 15:125–132, 2007.
163. Magee T, Shapiro M, Rodriguez J, Williams D. MR arthrography of postoperative knee: for which patients is it useful? *Radiology* 229:159–163, 2003.
164. Magee T, Williams D. 3.0-T MRI of meniscal tears. *AJR Am J Roentgenol* 187:371–375, 2006.
165. Makris CA, Georgoulis AD, Papageorgiou CD, Moebius UG, Soucacos PN. Posterior cruciate ligament architecture: evaluation under microsurgical dissection. *Arthroscopy* 16:627–632, 2000.
166. Mansfield P, Maudsley AA. Medical imaging by NMR. *Br J Radiol* 50:188–194, 1977.
167. Markmiller M, Konrad G, Sudkamp N. Femur-LISS and distal femoral nail for fixation of distal femoral fractures: are there differences in outcome and complications? *Clin Orthop Relat Res* 426:252–257, 2004.

168. Marsh JL, Buckwalter J, Gelberman R, Dirschl D, Olson S, Brown T, Llinias A. Articular fractures: does an anatomic reduction really change the result? *J Bone Joint Surg Am* 84:1259–1271, 2002.
169. Matava MJ, Eck K, Totty W, Wright RW, Shively RA. Magnetic resonance imaging as a tool to predict meniscal reparability. *Am J Sports Med* 27:436–443, 1999.
170. McDaniel WJ, Jr., Dameron TB, Jr. The untreated anterior cruciate ligament rupture. *Clin Orthop Relat Res* 172:158–163, 1983.
171. McGinty G, Irrgang JJ, Pezzullo D. Biomechanical considerations for rehabilitation of the knee. *Clin Biomech (Bristol, Avon)* 15:160–166, 2000.
172. Merchant AC, Mercer RL, Jacobsen RH, Cool CR. Roentgenographic analysis of patellofemoral congruence. *J Bone Joint Surg Am* 56:1391–1396, 1974.
173. Messner K, Gao J. The menisci of the knee joint. Anatomical and functional characteristics, and a rationale for clinical treatment. *J Anat* 193 (Pt 2):161–178, 1998.
174. Milachowski KA, Weismeier K, Wirth CJ. Homologous meniscus transplantation. Experimental and clinical results. *Int Orthop* 13:1–11, 1989.
175. Mink JH, Deutsch AL. Occult cartilage and bone injuries of the knee: detection, classification, and assessment with MR imaging. *Radiology* 170:823–829, 1989.
176. Mink JH, Levy T, Crues JV, 3rd. Tears of the anterior cruciate ligament and menisci of the knee: MR imaging evaluation. *Radiology* 167:769–774, 1988.
177. Moore TM, Harvey JP, Jr. Roentgenographic measurement of tibial-plateau depression due to fracture. *J Bone Joint Surg Am* 56:155–160, 1974.
178. Muellner T, Egkher A, Nikolic A, Funovics M, Metz V. Open meniscal repair: clinical and magnetic resonance imaging findings after twelve years. *Am J Sports Med* 27:16–20, 1999.
179. Muellner T, Weinstabl R, Schabus R, Vecsei V, Kainberger F. The diagnosis of meniscal tears in athletes. A comparison of clinical and magnetic resonance imaging investigations. *Am J Sports Med* 25:7–12, 1997.
180. Mui LW, Engelsohn E, Umans H. Comparison of CT and MRI in patients with tibial plateau fracture: can CT findings predict ligament tear or meniscal injury? *Skeletal Radiol* 36:145–151, 2007.
181. Munshi M, Pretterklieber ML, Kwak S, Antonio GE, Trudell DJ, Resnick D. MR imaging, MR arthrography, and specimen correlation of the posterolateral corner of the knee: an anatomic study. *AJR Am J Roentgenol* 180:1095–1101, 2003.
182. Murphy KP, Helgeson MD, Lehman RA, Jr. Surgical treatment of acute lateral collateral ligament and posterolateral corner injuries. *Sports Med Arthrosc* 14:23–27, 2006.

183. Murray TF, Dupont JY, Fulkerson JP. Axial and lateral radiographs in evaluating patellofemoral malalignment. *Am J Sports Med* 27:580–584, 1999.
184. Mutschler C, Vande Berg BC, Lecouvet FE, Poilvache P, Dubuc JE, Maldague B, Malghem J. Postoperative meniscus: assessment at dual-detector row spiral CT arthrography of the knee. *Radiology* 228:635–641, 2003.
185. Nagel HD. Dose values from CT examinations. In: Nagel HD (ed.) Radiation exposure in computed tomography, 1st ed. CTB Publications, Hamburg, 15–24, 2002.
186. Newberg AH, Greenstein R. Radiographic evaluation of tibial plateau fractures. *Radiology* 126:319–323, 1978.
187. Nitz W. Principles of magnetic resonance imaging and magnetic resonance angiography. In: Reimer P, Parizel PM, Stichnoth F-A (eds.) Clinical MR imaging: a practical approach, 2nd ed. Springer-Verlag, Heidelberg, 1–52, 2003.
188. Northmore-Ball MD, Dandy DJ, Jackson RW. Arthroscopic, open partial, and total meniscectomy. A comparative study. *J Bone Joint Surg Br* 65:400–404, 1983.
189. Novelline RA, Rhea JT, Rao PM, Stuk JL. Helical CT in emergency radiology. *Radiology* 213:321–339, 1999.
190. Ohashi K, El-Khoury GY, Bennett DL, Restrepo JM, Berbaum KS. Orthopedic hardware complications diagnosed with multi-detector row CT. *Radiology* 237:570–577, 2005.
191. Ohdera T, Tokunaga M, Hiroshima S, Yoshimoto E, Tokunaga J, Kobayashi A. Arthroscopic management of tibial plateau fractures--comparison with open reduction method. *Arch Orthop Trauma Surg* 123:489–493, 2003.
192. Okcu G, Aktuglu K. Antegrade nailing of femoral shaft fractures combined with neck or distal femur fractures. A retrospective review of 25 cases, with a follow-up of 36-150 months. *Arch Orthop Trauma Surg* 123:544–550, 2003.
193. Otte S, Klinger HM, Beyer J, Baums MH. Complications after meniscal repair with bioabsorbable arrows: two cases and analysis of literature. *Knee Surg Sports Traumatol Arthrosc* 10:250–253, 2002.
194. Palmer WE. Magnetic resonance imaging of knee trauma: biomechanical approach. *Top Magn Reson Imaging* 14:161–178, 2003.
195. Passariello R, Trecco F, De Paulis F, De Amicis R, Bonanni G, Masciocchi C. Computed tomography of the knee joint: clinical results. *J Comput Assist Tomogr* 7:1043–1049, 1983.
196. Passariello R, Trecco F, De Paulis F, Masciocchi C, Bonanni G, Beomonte Zobel B. CT demonstration of capsuloligamentous lesions of the knee joint. *J Comput Assist Tomogr* 10:450–456, 1986.
197. Pavlov H. The radiographic diagnosis of the anterior cruciate ligament deficient knee. *Clin Orthop Relat Res* 172:57–64, 1983.

198. Pavlov H, Hirschy JC, Torg JS. Computed tomography of the cruciate ligaments. *Radiology* 132:389–393, 1979.
199. Pennes DR, Louis DS, Fechner K. Bone marrow imaging. *Radiology* 170:894–895, 1989.
200. Petsche TS, Selesnick H, Rochman A. Arthroscopic meniscus repair with bioabsorbable arrows. *Arthroscopy* 18:246–253, 2002.
201. Pettersson H, Hamlin DJ, Mancuso A, Scott KN. Magnetic resonance imaging of the musculoskeletal system. *Acta Radiol Diagn (Stockh)* 26:225–234, 1985.
202. Prickett WD, Ward SI, Matava MJ. Magnetic resonance imaging of the knee. *Sports Med* 31:997–1019, 2001.
203. Prokop M. General principles of MDCT. *Eur J Radiol* 45 Suppl 1:S4–S10, 2003.
204. Quinn SF, Brown TF. Meniscal tears diagnosed with MR imaging versus arthroscopy: how reliable a standard is arthroscopy? *Radiology* 181:843–847, 1991.
205. Ramnath RR, Magee T, Wasudev N, Murrah R. Accuracy of 3-T MRI using fast spin-echo technique to detect meniscal tears of the knee. *AJR Am J Roentgenol* 187:221–225, 2006.
206. Raunest J, Oberle K, Loehnert J, Hoetzing H. The clinical value of magnetic resonance imaging in the evaluation of meniscal disorders. *J Bone Joint Surg Am* 73:11–16, 1991.
207. Recht MP, Resnick D. MR imaging of articular cartilage: current status and future directions. *AJR Am J Roentgenol* 163:283–290, 1994.
208. Recondo JA, Salvador E, Villanua JA, Barrera MC, Gervas C, Alustiza JM. Lateral stabilizing structures of the knee: functional anatomy and injuries assessed with MR imaging. *Radiographics* 20:S91–S102, 2000.
209. Reeder JD, Matz SO, Becker L, Andelman SM. MR imaging of the knee in the sagittal projection: comparison of three-dimensional gradient-echo and spin-echo sequences. *AJR Am J Roentgenol* 153:537–540, 1989.
210. Reichardt B, Sarwar A, Bartling SH, Cheung A, Grasruck M, Leidecker C, Bredella MA, Brady TJ, Gupta R. Musculoskeletal applications of flat-panel volume CT. *Skeletal Radiol* 37:1069–1076, 2008.
211. Reicher MA, Bassett LW, Gold RH. High-resolution magnetic resonance imaging of the knee joint: pathologic correlations. *AJR Am J Roentgenol* 145:903–909, 1985.
212. Reicher MA, Hartzman S, Duckwiler GR, Bassett LW, Anderson LJ, Gold RH. Meniscal injuries: detection using MR imaging. *Radiology* 159:753–757, 1986.
213. Reicher MA, Rauschnig W, Gold RH, Bassett LW, Lufkin RB, Glen W, Jr. High-resolution magnetic resonance imaging of the knee joint: normal anatomy. *AJR Am J Roentgenol* 145:895–902, 1985.

214. Reider B, Marshall JL, Koslin B, Ring B, Girgis FG. The anterior aspect of the knee joint. *J Bone Joint Surg Am* 63:351–356, 1981.
215. Renström P, Johnson RJ. Anatomy and biomechanics of the menisci. *Clin Sports Med* 9:523–538, 1990.
216. Resnick D, Kang HS, Pretterklieber ML. Knee. In: Resnick D, Kang HS, Pretterklieber ML (eds.) *Internal derangements of joints*, 2nd ed. Saunders/Elsevier, Philadelphia, 1561–2011, 2007.
217. Rickards D, Chapman JA. Computed tomography of the anterior cruciate ligament. *Clin Radiol* 35:327–329, 1984.
218. Rijk PC. Meniscal allograft transplantation--part I: background, results, graft selection and preservation, and surgical considerations. *Arthroscopy* 20:728–743, 2004.
219. Rijk PC. Meniscal allograft transplantation--part II: alternative treatments, effects on articular cartilage, and future directions. *Arthroscopy* 20:851–859, 2004.
220. Rogers LF. The knee and shafts of the tibia and fibula. In: Rogers LF (ed.) *Radiology of skeletal trauma*, 2nd ed. Churchill Livingstone, New York, 1199–1317, 1992.
221. Ross G, Chapman AW, Newberg AR, Scheller AD, Jr. Magnetic resonance imaging for the evaluation of acute posterolateral complex injuries of the knee. *Am J Sports Med* 25:444–448, 1997.
222. Ross G, Grabill J, McDevitt E. Chondral injury after meniscal repair with bioabsorbable arrows. *Arthroscopy* 16:754–756, 2000.
223. Rubin DA, Britton CA, Towers JD, Harner CD. Are MR imaging signs of meniscocapsular separation valid? *Radiology* 201:829–836, 1996.
224. 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 pulse sequences. *AJR Am J Roentgenol* 162:1131–1135, 1994.
225. Rubin DA, Paletta GA, Jr. Current concepts and controversies in meniscal imaging. *Magn Reson Imaging Clin N Am* 8:243–270, 2000.
226. Rydberg J, Buckwalter KA, Caldemeyer KS, Phillips MD, Conces DJ, Jr., Aisen AM, Persohn SA, Kopecky KK. Multisection CT: scanning techniques and clinical applications. *Radiographics* 20:1787–1806, 2000.
227. Schoenberg NY, Beltran J. Contrast enhancement in musculoskeletal imaging. Current status. *Radiol Clin North Am* 32:337–352, 1994.
228. Schulak DJ, Gunn DR. Fractures of tibial plateaus. A review of the literature. *Clin Orthop Relat Res* 109:166–177, 1975.
229. Schulz MS, Russe K, Weiler A, Eichhorn HJ, Strobel MJ. Epidemiology of posterior cruciate ligament injuries. *Arch Orthop Trauma Surg* 123:186–191, 2003.

230. Schweitzer ME, Tran D, Deely DM, Hume EL. Medial collateral ligament injuries: evaluation of multiple signs, prevalence and location of associated bone bruises, and assessment with MR imaging. *Radiology* 194:825–829, 1995.
231. Schäfer FK, Schäfer PJ, Brossmann J, Frahm C, Hilgert RE, Heller M, Jahnke T. Value of fat-suppressed proton-density-weighted turbo spin-echo sequences in detecting meniscal lesions: comparison with arthroscopy. *Acta Radiol* 47:385–390, 2006.
232. Sciulli RL, Boutin RD, Brown RR, Nguyen KD, Muhle C, Lektrakul N, Pathria MN, Pedowitz R, Resnick D. Evaluation of the postoperative meniscus of the knee: a study comparing conventional arthrography, conventional MR imaging, MR arthrography with iodinated contrast material, and MR arthrography with gadolinium-based contrast material. *Skeletal Radiol* 28:508–514, 1999.
233. Seaberg DC, Yealy DM, Lukens T, Auble T, Mathias S. Multicenter comparison of two clinical decision rules for the use of radiography in acute, high-risk knee injuries. *Ann Emerg Med* 32:8–13, 1998.
234. Seebacher JR, Inglis AE, Marshall JL, Warren RF. The structure of the posterolateral aspect of the knee. *J Bone Joint Surg Am* 64:536–541, 1982.
235. Seil R, Rupp S, Dienst M, Mueller B, Bonkhoff H, Kohn DM. Chondral lesions after arthroscopic meniscus repair using meniscus arrows. *Arthroscopy* 16:E17, 2000.
236. Seinsheimer F, 3rd. Fractures of the distal femur. *Clin Orthop Relat Res* 153:169–179, 1980.
237. Shabat S, Mann G, Kish B, Stern A, Sagiv P, Nyska M. Functional results after patellar fractures in elderly patients. *Arch Gerontol Geriatr* 37:93–98, 2003.
238. Shelbourne KD, Heinrich J. The long-term evaluation of lateral meniscus tears left in situ at the time of anterior cruciate ligament reconstruction. *Arthroscopy* 20:346–351, 2004.
239. Shepherd L, Abdollahi K, Lee J, Vangsness CT, Jr. The prevalence of soft tissue injuries in nonoperative tibial plateau fractures as determined by magnetic resonance imaging. *J Orthop Trauma* 16:628–631, 2002.
240. Sherman OH, Banffy MB. Anterior cruciate ligament reconstruction: which graft is best? *Arthroscopy* 20:974–980, 2004.
241. Siliski JM, Mahrng M, Hofer HP. Supracondylar-intercondylar fractures of the femur. Treatment by internal fixation. *J Bone Joint Surg Am* 71:95–104, 1989.
242. Smith JP, 3rd, Barrett GR. Medial and lateral meniscal tear patterns in anterior cruciate ligament-deficient knees. A prospective analysis of 575 tears. *Am J Sports Med* 29:415–419, 2001.
243. Sprivulis P, Frazer A, Waring A. Same-day X-ray reporting is not needed in well-supervised emergency departments. *Emerg Med (Fremantle)* 13:194–197, 2001.

244. Stabler A, Glaser C, Reiser M. Musculoskeletal MR: knee. *Eur Radiol* 10:230–241, 2000.
245. Stannard JP, Brown SL, Robinson JT, McGwin G, Jr., Volgas DA. Reconstruction of the posterolateral corner of the knee. *Arthroscopy* 21:1051–1059, 2005.
246. Steinbach LS, Palmer WE, Schweitzer ME. Special focus session. MR arthrography. *Radiographics* 22:1223–1246, 2002.
247. Stevens DG, Beharry R, McKee MD, Waddell JP, Schemitsch EH. The long-term functional outcome of operatively treated tibial plateau fractures. *J Orthop Trauma* 15:312–320, 2001.
248. Stiell IG, Greenberg GH, Wells GA, McDowell I, Cwinn AA, Smith NA, Cacciotti TF, Sivilotti ML. Prospective validation of a decision rule for the use of radiography in acute knee injuries. *JAMA* 275:611–615, 1996.
249. Stiell IG, Wells GA, Hoag RH, Sivilotti ML, Cacciotti TF, Verbeek PR, Greenway KT, McDowell I, Cwinn AA, Greenberg GH, Nichol G, Michael JA. Implementation of the Ottawa knee rule for the use of radiography in acute knee injuries. *JAMA* 278:2075–2079, 1997.
250. Stoller DW, Li AE, Anderson LJ, Cannon DW. The knee. In: Stoller DW (ed.) *Magnetic resonance imaging in orthopaedics and sport medicine*, 3rd ed. Lippincott Williams & Wilkins, Baltimore, 305–731, 2007.
251. Stoller DW, Martin C, Crues JV, 3rd, Kaplan L, Mink JH. Meniscal tears: pathologic correlation with MR imaging. *Radiology* 163:731–735, 1987.
252. Stover M. Distal femoral fractures: current treatment, results and problems. *Injury* 32:S3–S13, 2001.
253. Su EP, Westrich GH, Rana AJ, Kapoor K, Helfet DL. Operative treatment of tibial plateau fractures in patients older than 55 years. *Clin Orthop Relat Res* 421:240–248, 2004.
254. Sun C, Miao F, Wang XM, Wang T, Ma R, Wang DP, Liu C. An initial qualitative study of dual-energy CT in the knee ligaments. *Surg Radiol Anat* 30:443–447, 2008.
255. Thornton DD, Rubin DA. Magnetic resonance imaging of the knee menisci. *Semin Roentgenol* 35:217–230, 2000.
256. Thorpe S, Salkovskis PM, Dittner A. Claustrophobia in MRI: the role of cognitions. *Magn Reson Imaging* 26:1081–1088, 2008.
257. Tielinen L, Lindahl J, Koskinen S, Hirvensalo E. Clinical and MRI evaluation of meniscal tears repaired with bioabsorbable arrows. *Scand J Surg* 96:252–255, 2007.
258. Totty WG, Matava MJ. Imaging the postoperative meniscus. *Magn Reson Imaging Clin N Am* 8:271–283, 2000.

259. Trickey EL. Injuries to the posterior cruciate ligament: diagnosis and treatment of early injuries and reconstruction of late instability. *Clin Orthop Relat Res* 147:76–81, 1980.
260. Walton NP, Harish S, Roberts C, Blundell C. AO or Schatzker? How reliable is classification of tibial plateau fractures? *Arch Orthop Trauma Surg* 123:396–398, 2003.
261. Vande Berg B, Malghem J, Maldague B, Lecouvet F. Multi-detector CT imaging in the postoperative orthopedic patient with metal hardware. *Eur J Radiol* 60:470–479, 2006.
262. Vande Berg BC, Lecouvet FE, Poilvache P, Dubuc JE, Bedat B, Maldague B, Rombouts JJ, Malghem J. Dual-detector spiral CT arthrography of the knee: accuracy for detection of meniscal abnormalities and unstable meniscal tears. *Radiology* 216:851–857, 2000.
263. Vande Berg BC, Lecouvet FE, Poilvache P, Dubuc JE, Maldague B, Malghem J. Anterior cruciate ligament tears and associated meniscal lesions: assessment at dual-detector spiral CT arthrography. *Radiology* 223:403–409, 2002.
264. Vande Berg BC, Lecouvet FE, Poilvache P, Maldague B, Malghem J. Spiral CT arthrography of the knee: technique and value in the assessment of internal derangement of the knee. *Eur Radiol* 12:1800–1810, 2002.
265. Vande Berg BC, Malghem J, Poilvache P, Maldague B, Lecouvet FE. Meniscal tears with fragments displaced in notch and recesses of knee: MR imaging with arthroscopic comparison. *Radiology* 234:842–850, 2005.
266. Wang CY, Wang HK, Hsu CY, Shieh JY, Wang TG, Jiang CC. Role of sonographic examination in traumatic knee internal derangement. *Arch Phys Med Rehabil* 88:984–987, 2007.
267. Vangsness CT, Jr., Ghaderi B, Hohl M, Moore TM. Arthroscopy of meniscal injuries with tibial plateau fractures. *J Bone Joint Surg Br* 76:488–490, 1994.
268. Warren LA, Marshall JL, Girgis F. The prime static stabilizer of the medial side of the knee. *J Bone Joint Surg Am* 56:665–674, 1974.
269. Warren RF. Primary repair of the anterior cruciate ligament. *Clin Orthop Relat Res* 172:65–70, 1983.
270. Warren RF, Levy IM. Meniscal lesions associated with anterior cruciate ligament injury. *Clin Orthop Relat Res* 172:32–37, 1983.
271. Webb JM, Corry IS, Clingeffer AJ, Pinczewski LA. Endoscopic reconstruction for isolated anterior cruciate ligament rupture. *J Bone Joint Surg Br* 80:288–294, 1998.
272. Vedi V, Williams A, Tennant SJ, Spouse E, Hunt DM, Gedroyc WM. Meniscal movement. An in-vivo study using dynamic MRI. *J Bone Joint Surg Br* 81:37–41, 1999.

273. Welsh RP. Knee joint structure and function. *Clin Orthop Relat Res* 147:7–14, 1980.
274. Veltri DM, Warren RF. Posterolateral instability of the knee. *J Bone Joint Surg Am* 76:460–472, 1995.
275. Verdonk R. Alternative treatments for meniscal injuries. *J Bone Joint Surg Br* 79:866–873, 1997.
276. Verma A, Su A, Golin AM, O'Marrah B, Amorosa JK. A screening method for knee trauma. *Acad Radiol* 8:392–397, 2001.
277. White LM, Schweitzer ME, Weishaupt D, Kramer J, Davis A, Marks PH. Diagnosis of recurrent meniscal tears: prospective evaluation of conventional MR imaging, indirect MR arthrography, and direct MR arthrography. *Radiology* 222:421–429, 2002.
278. Wind WM, Jr., Bergfeld JA, Parker RD. Evaluation and treatment of posterior cruciate ligament injuries: revisited. *Am J Sports Med* 32:1765–1775, 2004.
279. Vinson EN, Major NM, Helms CA. The posterolateral corner of the knee. *AJR Am J Roentgenol* 190:449–458, 2008.
280. Vives MJ, Homesley D, Ciccotti MG, Schweitzer ME. Evaluation of recurring meniscal tears with gadolinium-enhanced magnetic resonance imaging: a randomized, prospective study. *Am J Sports Med* 31:868–873, 2003.
281. Wolbarst AB. Analog x-ray imaging. In: *Physics of radiology*, 1st ed. Appleton & Lange, Norwalk, 145–262, 1993.
282. Wolbarst AB. Digital imaging. In: *Physics of radiology*, 1st ed. Appleton & Lange, Norwalk, 297–334, 1993.
283. Wolbarst AB. Dose, biologic effects, and radiation protection. In: *Physics of radiology*, 1st ed. Appleton & Lange, Norwalk, 263–296, 1993.
284. Wolbarst AB. Magnetic resonance imaging. In: *Physics of radiology*, 1st ed. Appleton & Lange, Norwalk, 361–406, 1993.
285. Wolbarst AB. Production of x-rays. In: *Physics of radiology*, 1st ed. Appleton & Lange, Norwalk, 67–102, 1993.
286. Wolbarst AB, Hendee WR. Evolving and experimental technologies in medical imaging. *Radiology* 238:16–39, 2006.
287. Yacoubian SV, Nevins RT, Sallis JG, Potter HG, Lorich DG. Impact of MRI on treatment plan and fracture classification of tibial plateau fractures. *J Orthop Trauma* 16:632–637, 2002.
288. Yang KH, Byun YS. Separate vertical wiring for the fixation of comminuted fractures of the inferior pole of the patella. *J Bone Joint Surg Br* 85:1155–1160, 2003.

289. Yao L, Lee JK. Occult intraosseous fracture: detection with MR imaging. *Radiology* 167:749–751, 1988.
290. Yasuda K, Kondo E, Ichiyama H, Kitamura N, Tanabe Y, Tohyama H, Minami A. Anatomic reconstruction of the anteromedial and posterolateral bundles of the anterior cruciate ligament using hamstring tendon grafts. *Arthroscopy* 20:1015–1025, 2004.
291. Zanetti M, Pfirrmann CW, Schmid MR, Romero J, Seifert B, Hodler J. Patients with suspected meniscal tears: prevalence of abnormalities seen on MRI of 100 symptomatic and 100 contralateral asymptomatic knees. *AJR Am J Roentgenol* 181:635–641, 2003.