CONTROVERSIES IN THE TREATMENT OF TIBIAL PLATEAU FRACTURES

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To Jenny and Mikael
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This thesis is based on the following original publications:


These publications are referred to in the text by their Roman numerals. The articles have been reprinted with the permission of their copyright holders.
Tibia plateau fractures are relatively uncommon, but they are among the most challenging intra-articular fractures to treat. These fractures can lead to early posttraumatic osteoarthritis (OA) and cause disability and constant pain. Currently, the most common treatment is open reduction and stable internal fixation (ORIF), allowing early mobilization of the knee. Tibial plateau fractures can be associated with several concomitant soft tissue injuries of the knee. Historically, the operative treatment with internal fixation has also been related to an increased risk for serious wound complications.

The purpose of this study was to investigate the current management and outcome of proximal tibia fractures. The study population consisted of various groups of patients with proximal tibia fractures treated between 2002 and 2013 at our level I trauma center. The study aimed to determine factors predicting the development of posttraumatic OA following tibial lateral or medial plateau fractures. Another focus was on the incidence of concomitant injuries after the most common lateral plateau fracture type and the need for MRI as a diagnostic tool when treating these fractures. Finally, the predictors for deep surgical site infection after plate fixation of proximal tibia fracture were examined.

The results showed that relatively good functional outcome can be predicted after internal fixation of lateral and medial tibial plateau fractures. However, patients with lateral plateau fractures with residual depression of the articular surface >2 mm or valgus deformity >5° had significantly more severe (Kellgren-Lawrence grade 3–4) posttraumatic OA. The most significant predictor of posttraumatic OA after medial plateau fracture was the amount of initial depression of the articular surface measured from the preoperative computer tomography, while the quality of reduction was not found to predict OA.

MRI had low sensitivity and specificity in the diagnosis of concomitant injuries in the lateral tibial plateau fracture setting. Also nearly all of the clinically relevant concomitant injuries could be treated through the same lateral arthrotomy at the time of ORIF without the need for additional arthroscopy.

There is high morbidity associated with deep SSI in plated proximal tibial fractures. Patient’s age ≥50 years, obesity, history of alcohol abuse, and AO type C fracture are independent risk factors for infection. Performing a fasciotomy also increases the risk of deep infection and should be done with meticulous technique only when deemed necessary.

**Keywords:** proximal tibia fracture, lateral plateau, medial plateau, surgical site infection, posttraumatic arthritis, concomitant injury
TIIVISTELMÄ

Sääriluun yläosan kondyylimurtumat ovat suhteellisen harvinaisia vammoja, mutta toisaalta yleensä varsin vaativia ja haasteellisia hoitaa. Koska murtumiin liittyy polven kantavan nivelpinnan rikkoutuminen, ne voivat helposti johtaa ennenaikaisen nivelrikon kehittymiseen ja pysyvään toiminnan alenemiseen ja kipuun. Operatiivisen hoidon tarkoituksena on palauttaa nivelpinnan kongruenssi ja saavuttaa stabilin fiksaatio, joka sallii polven varhaisen mobilisaation. Lisen murtuman lisäksi kondyylimurtumiin liittyy riski pehmytkudoksien kohdistuvista liitännäisvammoista, kuten nivelkierukkavaurioista ja nivelsidevammoista. Avoimeen reduktioon ja sisäiseen fiksaatioon on perinteisesti liitnyt myös suurentunut vakavien haavakomplikaatioiden riski.


Tutkimus osoitti että nykyisellä levytyshoidolla on saavutettavissa keskimäärin verrattain hyvä funktionaalinen lopputulos. Ulomman nivelnastan murtumien hoidossa nivelpinnalle jäänyt >2 mm painuma tai >5° valgiteetti johtivat tilastollisesti todennäköisemmin hankalan (Kellgren-Lawrence 3–4 asteen) nivelrikon kehittymiseen. Sisemmän nivelnastan murtumien hoidossa murtuman primaridislokaation määrällä näytti olevan selvästi merkitystä posttraumaattisen nivelrikon kehittymiselle, kun taas saavutetun reduktion laadulla ei ollut selvää merkittävyyttä.

Tutkimuksessa kävi ilmi että magneettikuvauksen herkkyyys ja tarkkuus on verrattain alhainen liitännäisvammojen diagnoistikassa kun kyseessä on ulomman nivelnastan murtuman käsittävä polvi. Lähes kaikki kliinisesti merkittävät liitännäisvammat voitiin hoitaa saman artrotomian kautta, jota käytettiin murtuman reduktion ja näin ollen polvinivelen tähtykisen merkityksen jää vähäiseksi.

Osoitimme että sääriluun yläosan levyyksen jälkeiseen haavainfektioon liittyy merkittävä morbiditeetti. Erityisesti yli 50-vuotiaat, ylipainoiset ja alkoholin suurkuluttajat ovat riskissä saada syvä haavainfektiö levytyshoidon jälkeen. Myös hankalampi, molemmat kondyylit käsittävät murtuma altistaa infektiolle.
Aitiopainesyndrooman vuoksi tehdyt faskiotomiat lisäävät selvästi infektioriskiä ja ne tulisi suorittaa huolellista kirurgista tekniikka noudattaen silloin kun ne on arvioitu tarpeellisiksi.

**Avainsanat:** sääriluun yläosan murtuma, ulompi nivelnasta, sisempi nivelnasta, infektio, posttraumaattinen nivelrikko, liitännäisvamma
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACL</td>
<td>anterior cruciate ligament</td>
</tr>
<tr>
<td>AKSS</td>
<td>American Knee Society Score</td>
</tr>
<tr>
<td>AO</td>
<td>Arbeitsgemeinschaft für Osteosynthesefragen</td>
</tr>
<tr>
<td>AP</td>
<td>anteroposterior</td>
</tr>
<tr>
<td>ARIF</td>
<td>arthroscopic reduction and internal fixation</td>
</tr>
<tr>
<td>ASA</td>
<td>American Society of Anesthesiologists</td>
</tr>
<tr>
<td>BMI</td>
<td>body mass index</td>
</tr>
<tr>
<td>CI</td>
<td>confidence interval</td>
</tr>
<tr>
<td>CT</td>
<td>computer tomography</td>
</tr>
<tr>
<td>HSS</td>
<td>Hospital for Special Surgery</td>
</tr>
<tr>
<td>ICD</td>
<td>International Classification of Diseases</td>
</tr>
<tr>
<td>KL</td>
<td>Kellgren-Lawrence</td>
</tr>
<tr>
<td>KOOS</td>
<td>Knee injury and Osteoarthritis Outcome Score</td>
</tr>
<tr>
<td>LCL</td>
<td>lateral collateral ligament</td>
</tr>
<tr>
<td>m.</td>
<td>muscle (Latin musculus)</td>
</tr>
<tr>
<td>MCL</td>
<td>medial collateral ligament</td>
</tr>
<tr>
<td>MRI</td>
<td>magnetic resonance imaging</td>
</tr>
<tr>
<td>OA</td>
<td>osteoarthritis</td>
</tr>
<tr>
<td>OR</td>
<td>odds ratio</td>
</tr>
<tr>
<td>ORIF</td>
<td>open reduction and internal fixation</td>
</tr>
<tr>
<td>OTA</td>
<td>Orthopaedic Trauma Association</td>
</tr>
<tr>
<td>PCL</td>
<td>posterior cruciate ligament</td>
</tr>
<tr>
<td>ROM</td>
<td>range of motion</td>
</tr>
<tr>
<td>SSI</td>
<td>surgical site infection</td>
</tr>
<tr>
<td>TKA</td>
<td>total knee arthroplasty</td>
</tr>
<tr>
<td>WOMAC</td>
<td>Western Ontario and McMaster Universities Osteoarthritis Index</td>
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</table>
1. INTRODUCTION

Tibia plateau fractures are relatively uncommon, accounting for approximately 1% of all fractures. They are among the most challenging intra-articular fractures to treat. Tibia plateau fractures vary in severity from usually low-energy lateral plateau fractures to comminuted, high-energy bicondylar fractures. These injuries may result in premature osteoarthritis (OA) and constant pain and disability. The aim of operative treatment is anatomic reduction of the joint surface, restoration of the anatomical axis, and stable fixation, allowing early mobilization of the knee and preserving the functional range of motion. In the 1970s, treatment of proximal tibia fractures was mainly conservative, which led to poor radiological results. In the 1980s, rigid plate fixation from one extensive approach gained popularity, but was often accompanied by serious complications. In the early 1990s, infection rates as high as 80% were reported after operative treatment of tibial plateau fractures (Mallik et al. 1992, Young and Barrack 1994). This led to the development of minimally invasive reduction techniques such as isolated lateral plating with medial external fixation and hybrid external fixation. Unfortunately, satisfactory reduction of comminuted articular surfaces with indirect techniques is difficult, if not impossible. Over the last decade, a change in clinical practice focusing on preservation of the soft tissue envelope, including delayed definitive surgery and careful soft tissue handling, has resulted in a decrease in wound complications after plate fixation (Barei et al. 2004, Egol et al. 2005). Still, deep infection rates of up to 24% have been reported, especially in comminuted fractures (Manidakis et al. 2010, Morris et al. 2013, Ruffolo et al. 2015).

According to previous studies, the incidence of posttraumatic OA after tibial plateau fracture has varied from 20% to 44% (Rasmussen 1972, Volpin 1990, Honkonen 1995, Rademakers et al. 2007). However, only 7% of patients were found to develop posttraumatic OA needing arthroplasty in a 10-year follow-up (Wasserstein et al. 2014).

Concomitant injuries related to tibial plateau fractures are also common. The use of magnetic resonance imaging (MRI) is nowadays more common due to easier accessibility. MRI studies of tibial plateau fractures have shown that concomitant injuries, such as meniscal tears and cartilage lesions, occur with an incidence as high as 50–99%. Arthroscopic reduction and internal fixation (ARIF) of tibial condyle fracture has gained popularity during the last two decades. One potential advantage of ARIF is that these associated injuries can be addressed during fracture fixation. The role of MRI and arthroscopy in tibial plateau fractures is debatable, as no studies have compared MRI findings with arthroscopic ones.
INTRODUCTION

The optimal treatment of tibial unicondylar fractures remains controversial. Most authors have advocated operative fixation if an articular surface depression of >2–3 mm or a valgus deformity of >5° is identified in the lateral plateau (Ali et al. 2002, Giannoudis et al. 2010, Singleton et al. 2017) and if any dislocation is found in the medial plateau (Honkonen 1994). Nevertheless, little data exist on the medium and long-term outcomes following operative treatment of these fractures using such criteria. Some studies have questioned the effect of articular reduction on the end result (Marsh et al. 2002, Giannoudis et al. 2010). Evidence suggests that long-term outcome depends less on the fracture reduction per se and more on the achieved stability of the knee (Rasmussen 1973, Moore 1981, Lansinger et al. 1986). However, previous studies have often included heterogeneous fracture types, combinations of operative and nonoperative treatments, and both rigid and non-rigid fixations with varying periods of immobilization. Moreover, most of these studies have lacked validated outcome measurement tools.

This doctoral thesis was initiated to investigate the current management and outcome of proximal tibia fractures. The first two studies focus on factors predicting the development of posttraumatic OA following tibial lateral and medial plateau fractures. The third study examines the incidence of concomitant injuries after the most common tibial lateral plateau fracture type and the need for MRI as a diagnostic tool when treating these fractures. The fourth study investigates the predictors for deep surgical site infection after plate fixation of proximal tibia fracture.
2. REVIEW OF THE LITERATURE

2.1 EPIDEMIOLOGY

Proximal tibia fractures represent approximately 1% of all fractures (Moore et al. 1987). Plateau fractures occur due to a combination of axial loading and valgus/varus forces. In men, these fractures usually occur at a younger age and often result from high-energy trauma such as motor vehicle accidents. In women, the fractures more often occur later in life as a result of lower-energy trauma, often reflecting underlying osteoporosis (Schatzker et al. 1979). In a population of 753 patients with tibial plateau fractures, the average patient age was 44 years and 62% of patients were male (Moore et al. 1987). There was a sharp rise in the incidence (per 100 000 persons) of low-trauma knee fractures, including distal femur and proximal tibia fractures, in elderly (>60 years) Finnish women at the end of the last century; in 1970, the incidence was 55 and in 1997 remarkably higher, 124. This has been followed by a declining fracture rate for unknown reasons, with the incidence being 94 in 2006 (Kannus et al. 2009). In elderly (>60 years) men, the knee fracture incidence has not shown consistent trend changes over time; the incidence was 30 (per 100 000 persons) in 1970 and 36 in 2006. According to the Finnish National Hospital Discharge Register, the average incidence of proximal tibia fracture was 27 per 100 000 patients in 2016 (Figures 1 and 2). Patients treated only at the outpatient clinic of healthcare centers are not included in the register.

![Figure 1](image.png)

**Figure 1.** Incidence (per 100 000) of patients with proximal tibia fractures (ICD S82.1) in Finland in 2016.
2.2 ANATOMY

The proximal tibia is composed of medial and lateral weight-bearing articular surfaces, together known as the tibial plateau (Figure 3). The weight-bearing surfaces are asymmetrical in size and concavity; the medial plateau is larger, denser, and concave, whereas the lateral plateau is smaller and convex (Purnell et al. 2007). The medial plateau carries about 60% of the bodyweight and consequently has, relative to the lateral plateau, a denser subchondral bone (Berkson and Virkus 2006). The lateral plateau is also higher than the medial plateau, accounting for a few degrees of varus of the tibial plateau in relation to the tibia shaft (Hashemi et al. 2008). These structural differences, combined with the anatomical valgus axis of the knee and the natural tendency of external impact laterally, make the lateral side more prone to fractures. Medial plateau fractures are thought to usually result from a high-energy trauma, unlike the more common lateral plateau fractures. Tibia slopes anterior to posterior average 5 degrees; there is significant variation between individuals, with the sagittal slope ranging from 0 to 14 degrees on the lateral side and from -3 to +10 degrees on the medial side (Hashemi et al. 2008).

Figure 2. Incidence (per 100,000) of patients with operatively treated proximal tibia fracture in Finland in 2016.
There are two additional dense bony prominences serving as attachment sites for tendinous structures, and these are located in close proximity to the tibial plateau: the tibial tubercle located anteriorly and serving as the attachment of the patella tendon and Gerdy’s tubercle located anterolaterally and serving as the attachment of the iliotibial band. In most of the tibial plateau fractures, these structures remain intact. The proximal fibula articulates with a facet of the lateral cortex of the tibia and is not part of the knee articulation (McCarty and McAllister 2009).

On the medial side, the m. semimembranosus attaches to a ridge at the posteromedial corner of the medial plateau just below the joint line. Below this is pes anserinus (tendons of m. gracilis and m. semitendinosus), which attaches more anteriorly and distally, closer to the level of the tibial tubercle. These tendons should be identified and protected when approaching the tibial plateau from the medial side (Warren and Marshall 1979). The posterolateral corner consists of superficial and deep layers; the superficial layer comprises the biceps femoris tendon and the iliotibial band and the deep layer comprises the lateral collateral ligament (LCL), popliteus tendon, arcuate ligament, and popliteofibular ligament. There are no ligamentous attachments to the lateral tibial plateau, whereas the medial plateau
has a broad area of insertion for both the deep and superficial medial collateral ligament (MCL). On the lateral side, horizontal arthrotomy under the meniscus can be performed easily, allowing good visibility to the lateral articular surface, whereas on medial side this is limited due to MCL. Between the condyles, the intercondylar eminence serves as the site of attachment for the fibrocartilaginous menisci and the anterior and posterior cruciate ligaments (ACL and PCL).

The common peroneal nerve runs proximally under the cover of the biceps femoris muscle on the lateral side. More distally, it runs around the proximal head of the fibula laterally to the anterior side, where it divides into the deep and superficial parts inside the peroneus muscle. It is prone to distension, especially in varus injuries. Posterior to the knee is the popliteal fossa, which contains the popliteal neurovascular structures. The popliteal artery, which is at risk in knee dislocations, is rarely injured with tibia fractures.

2.3 INITIAL ASSESSMENT

An initial trauma survey is performed at the time of a patient’s admission to hospital, followed by radiographic and clinical evaluations. If a patient presents with clinical signs of acute compartment syndrome, an urgent four-compartment fasciotomy using two incisions should be performed with spanning external fixation (Mubarak and Owen 1977). For those who show no signs of acute compartment syndrome, immediate splinting or external fixation can be used depending on the soft tissue condition. External fixation should be used when there is substantial shortening or subluxation of the tibia caused by comminution or instability of the fracture. Presence of vascular injury, blistering, severe abrasions, and polytrauma are also considered indications for temporary external fixation (Barei et al. 2004, Egol et al. 2005, Parekh et al. 2008).

2.4 RADIOLOGICAL ASSESSMENT

Radiography

Initial diagnosis of tibial plateau fracture is usually based on plain radiographs. Anteroposterior (AP) and lateral views are the standard examinations. An AP view in the plane of the tibial plateau (10–15 degree caudal view) is also recommended, as it provides a better view of the articular surface and permits more accurate assessment of the initial depression (Moore and Harvey 1974).
**Computed tomography**

Due its good availability, computed tomography (CT) is currently a routine examination when there is suspicion of a fracture in plain radiographs. Axial, sagittal, and coronal views are obtained. They provide excellent detail of the fracture’s pathoanatomy. If the fracture causes substantial shortening or subluxation of the leg, it is useful to perform a CT scan after realigning the fracture with a spanning fixator. CT scans have been shown to help surgical planning and to change the treatment plan compared with use of only plain radiographs (Dias et al. 1987, Chan et al. 1997, Wicky et al. 2000). Three-dimensional reconstructions have been increasingly used and may be helpful in preoperative planning, although one study showed that it did not change the preoperative plan of a surgeon compared with use of only conventional CT scans (Dodd et al. 2015).

**Magnetic resonance imaging**

Magnetic resonance imaging (MRI) provides additional information about injuries to the soft tissue structures of the knee, such as meniscal and ligamentous lesions, that is not obtained by other imaging modalities. The information obtained from the MRI is important if the surgeon incorporates the management of these soft tissue injuries into the treatment strategy, but whether this improves patient outcome is controversial. MRI changed the treatment plan of a surgeon in one study in 23% of cases (Yacoubian et al. 2002). In another study comparing CT and MRI in patients with tibial plateau fractures, the sensitivity of CT scan to detect torn cruciate ligaments was found to be 80% and specificity 98% relative to MRI (Mui et al. 2007). The authors concluded that while CT is able to find cruciate ligament injuries with high sensitivity and specificity MRI remains necessary for the preoperative detection of meniscal injuries.
2.5 CLASSIFICATION OF PROXIMAL TIBIA FRACTURES

Many attempts have been made to classify tibial plateau fractures (Palmer 1951, Hohl and Luck 1956, Hohl 1967). Schatzker et al. (1979) published their classification system in 1979, deriving it from anteroposterior radiographs of a series of 94 patients, and it has become one of the most used classification systems. In the Schatzker classification system, tibia plateau fractures are divided into six types (Figure 4): split fracture of lateral tibial plateau (type I), split and depression of lateral tibial plateau (type II), central depression of lateral tibial plateau (type III), medial tibial plateau fracture (type IV), bicondylar tibial plateau fracture (type V), and dissociation between the metaphysis and diaphysis (type VI). Type IV medial plateau fractures encompass two subtypes: the medial plateau is either (A) split or (B) depressed and comminuted. Either (A) or (B) may be combined with fractures of the tibial spines.

Another commonly used classification system for these fractures is the AO/OTA system (Figure 5). This classification initially combined the Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification of fractures of long bones (Müller et al. 1990) and the Orthopaedic Trauma Association’s (OTA) classification system in 1996 (OTA 1996). A revised version of the AO/OTA system was published in 2007 (Marsh et al. 2007). The AO/OTA system categorizes fractures of the proximal tibia into three main types (A, B, C). These, in turn, are divided into three groups, each with three subgroups. This classification is more detailed and with many subgroups is also more complex to use. Neither the Schatzker system nor the OA/OTA system has been proven superior to the other. One study found the AO classification system to be more reliable among observers than the Schatzker system (Walton et al. 2003), while another study concluded that the Schatzker system had higher interobserver reliability than other classification systems, including the AO/OTA system (Maripuri et al. 2008).

Figure 5. AO/OTA classification system. Adapted with permission from Berkson et al. High-energy tibial plateau fractures. J Am Acad Orthop Surg 2006;14:20–31.
Because these classifications were based mainly on AP radiographs, they do not include injury patterns with major fracture lines in the coronal plane such as posteromedial fragments. Yet, this information is important when planning surgical approaches and patient positioning. In one recent study, posteromedial fragments were seen in 59% of bicondylar fractures, and on average they accounted for 25% of the total tibial plateau joint surface (Higgins et al. 2009). The posteromedial fragment was first addressed by Moore (1981) in his classification of “fracture-dislocation of the knee”. Luo et al. (2010) developed a “three-column” model based on axial (CT) imaging to classify tibial plateau fractures. In this model, tibial plateau is divided into three areas, which are defined as the lateral column, the medial column, and the posterior column (Figure 6). The benefit of this system is that it identifies posterior fractures needing a posterior approach and fixation.

Figure 6. Three-column classification. Adapted with permission from Luo et al. Three-column fixation for complex tibial plateau fractures. J Orthop Trauma;24:683–692.
Recently, a more specific “ten-segment classification” was introduced, which analyzed the fracture incidence of each specific plateau segment (Figure 7) (Krause et al. 2016). The authors noted that posterior segments were most frequently affected segments in AO/OTA type B and C fractures.

Figure 7. Ten-segment classification. Adapted with permission from Krause et al. Intra-articular tibial plateau fracture characteristics according to “ten-segment classification”. Injury;47:2551–2557.
2.6 OPERATIVE TREATMENT OF TIBIAL PLATEAU FRACTURES

2.6.1 INDICATIONS FOR NONOPERATIVE TREATMENT
Nonoperative treatment is indicated for stable tibial fractures that will heal without significant deformity or for patients with medical problems where operative intervention would cause a high risk. The type of fracture is critically important when choosing nonoperative treatment. The fracture should be stable enough to allow early movement of the knee with a hinged brace.

2.6.2 INDICATIONS FOR OPERATIVE TREATMENT
In the 1970s, most condyle fractures were treated nonoperatively, but some guidelines for operative treatment were developed. Rasmussen et al. (1973) suggested, based on his series of 204 tibia condylar fractures, that patients without clinical impairment of lateral or medial stability of the extended knee joint should be treated nonoperatively, irrespective of roentgenographic appearance of the knee, and those with an unstable knee should be treated operatively. Schatzker et al. (1979) arrived at the same conclusion in their study of 94 condyle fractures, as did Moore (1981) in his study on fracture dislocations of the knee. Also Lansinger et al. (1986) found in their long-term study of 102 tibial plateau fractures that some degree of joint depression can be tolerated, but joint deformity or lack of congruity that leads to instability produces suboptimal results.

Controversy continues on the subject of maximal acceptable step-off on the tibial plateau fracture (Table 1). One study with 131 operatively or nonoperatively treated tibial plateau fractures showed that patients with a more than 3 mm step-off at the articular surface had inferior outcomes to patients with smooth articular surface (Honkonen 1994). Additionally, even slight 1–5° varus malalignment was associated with inferior functional and subjective results compared with a normal axis, whereas valgus deformity up to 5° was rather well tolerated. Another recent study reported results of 41 patients with either operatively or nonoperatively treated AO/OTA B/C type plateau fracture (Singleton et al. 2017). Patients with >2.5 mm residual depression of joint surface at coronal plane tomogram had significantly lower functional results in Oxford Knee Score, Iowa Knee Score, and KOOS symptom and pain scores; no difference was found in other KOOS subgroups or WOMAC scores (Singleton et al. 2017). In this study, mechanical axis had no correlation with functional results.

A biomechanical study showed that increased articular step-off heights in lateral plateau progressively increase valgus angulation and average contact pressures; at a 6 mm step-off with straight leg, the valgus increased on average 7.6° and average contact pressure increased by 208% (Bai et al. 2001).
Table 1. Effect of articular step-off or depression on functional results after tibia plateau fracture.

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>No. of fractures</th>
<th>Fracture type</th>
<th>Intervention</th>
<th>Functional assessment</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wadell et al. (1981)</td>
<td>95</td>
<td>Lateral 75 Medial 8</td>
<td>ORIF 72%, CONS 28%</td>
<td>Satisfactory result = ROM &gt;90° flexion, &lt;5° malalignment, no OA, and absence of limp</td>
<td>Inferior outcome &gt;10 mm depression on lateral side. All medial fractures should be operated</td>
</tr>
<tr>
<td>Lansinger et al. (1986)*</td>
<td>102</td>
<td>Lateral 70 Medial 14</td>
<td>Operative 56% (ORIF or percutaneous cerclage), CONS 44%</td>
<td>Rasmussen score</td>
<td>Inferior outcome &gt;10 mm depression</td>
</tr>
<tr>
<td>Honkonen (1994)*</td>
<td>131</td>
<td>Lateral 68 Medial 12</td>
<td>ORIF 58%, CONS 42%</td>
<td>Honkonen score</td>
<td>Inferior outcome &gt;3 mm depression</td>
</tr>
<tr>
<td>Weigel et al. (2002)*</td>
<td>18</td>
<td>Schatzker Type II=1</td>
<td>Limited internal fixation and monolateral external fixator</td>
<td>Iowa knee score, SF-36</td>
<td>No correlation between articular surface reduction and knee score</td>
</tr>
<tr>
<td>Singleton et al. (2017)</td>
<td>41</td>
<td>Schatzker Type II=19</td>
<td>ORIF 85%, CONS 15%</td>
<td>Iowa knee score, Oxford knee score, KOOS, WOMAC</td>
<td>Inferior outcome &gt;2.5 mm depression in Iowa and Oxford scores, and in KOOS symptom and pain subscores</td>
</tr>
</tbody>
</table>

*Retrospective study
CONS=conservative

Currently, most authors advocate operative fixation for lateral tibial plateau fracture upon identifying articular surface depression of more than 2–3 mm, condylar widening of more than 5 mm, or valgus deformity of more than 5 degrees (Holzach et al. 1994, Honkonen 1994, Ali et al. 2002, Singleton et al. 2017).

Schatzker et al. (1979) treated seven medial plateau fractures, all (except one with no initial dislocation) with unacceptable results; one was operatively treated without proper reduction and the rest were conservatively treated. Also Wadell et al. concluded that all medial plateau fractures should be operatively reduced meticulously to their anatomic position (Wadell et al. 1981). Another study found that conservative treatment of medial plateau fractures with cast brace often results in loss of position (Delamarter and Hohl 1989). Furthermore, it has been shown that varus malalignment is more poorly tolerated than valgus malalignment (Honkonen 1994). Therefore, operative treatment should always be considered when managing dislocated medial plateau fractures. It should also be noted that isolated medial plateau fracture can actually represent a fracture dislocation of the knee.
Schatzker et al. (1979) found that, in the treatment of type VI fractures, 75% of nonoperatively treated patients had unacceptable results, whereas 80% of operatively treated patients had acceptable results. Bicondylar fractures are unstable and prone to dislocate in conservative treatment, and thus, should be treated operatively (Honkonen 1994). Only fissures of the condyles can be considered treated with a dynamic brace.

2.6.3 SURGICAL APPROACHES

The most commonly used approach is the anterolateral approach (Pape and Rommens 2007). It can be used for reduction and fixation of the anterolateral part of the tibial plateau. The patient is usually placed in supine position. The approach starts about 5 cm proximal to the joint line, continuing over Gerdy’s tubercle and descending distally, staying lateral to the anterior border of tibia. An arthrotomy can be done under the meniscus and the approach gives good visibility to most of the lateral plateau surface, excluding the most posterior part. To increase visibility to the posterior part of the lateral plateau, a femoral epicondylar osteotomy can be performed (Bowers and Huffman 2008, Yoon et al. 2015). Also the use of arthroscopy with or without fluid will help visualization of the posterior part.

The posteromedial approach is another commonly used approach when there is a medial plateau or bicondylar fracture (Pape and Rommens 2007). The patient is placed in supine position and the leg is abducted, externally rotated, and put in a “figure of four” position. The incision runs from the medial epicondyle towards the posteromedial edge of the tibia and extended distally as needed. As the MCL covers a broad area of the joint line medially, only a limited visibility can be achieved through the arthrotomy to the plateau surface. Arthroscopy can enhance the visibility of the joint surface. With this approach, plate fixation can be done with either a medially or posteromedially situated plate.

The posterior approach is becoming more commonly used, especially when a posteromedial shearing fracture is involved. This approach was first described 20 years ago (Lobenhoffer et al. 1997). Different modifications have since been presented (Fakler et al. 2007, Galla et al. 2009). One way to perform the approach is with the patient in prone position with an inverted L-shaped incision; beginning from the center of the popliteus fossa, running first medially and at the medial corner of the popliteus fossa turning to run in the distal direction (He et al. 2013). The medial head of the gastrocnemius muscle is then retracted in a lateral direction, protecting the neurovascular bundle. The dissection from medial to lateral direction is done at the surface of the bone, also elevating the popliteus and origin of soleus muscle from the bone. PCL avulsion can be fixed using the same approach. This approach also allows limited access to the posterolateral part of the plateau for reduction of fracture and placement of an oblique fashion buttress plate (Luo et al. 2010).
The most posterolateral part of the tibial plateau remains difficult to access through normal approaches. The **posterolateral approach** has been introduced to address this problem. The initial approaches included osteotomy of the fibula, which endangered the common peroneal nerve running on the surface of the fibula (Lobenhoffer et al. 1997). Subsequent methods have not required fibula osteotomy (Frosch et al. 2010). Malreduction of the posterior part of lateral plateau fractures is common. In one recent study, malreduction rates of up to 77% were demonstrated in postoperative CT scans at the posterior part of the lateral plateau (Meulenkamp et al. 2017). The posterolateral approach alone gives visibility only to the most posterior part of the lateral plateau, but it allows the possibility to use a buttress plate for fixation. Yet, most of the lateral plateau surface remains unvisualized through this approach. In one study, anatomical reconstruction was achieved only using a combination of anterolateral and posterolateral approaches (Salomon et al. 2013). However, in one study the posterolateral central region was successfully reduced from a single anterolateral approach in all cases with the help of arthroscopy (Krause et al. 2016). Especially for dislocated medial plateau fractures with severe impaction of the posterior and central parts of the lateral tibial articular surface but an intact lateral cortex, a lateral plateau osteotomy technique has also been introduced to help reduction (Sciadini and Sims 2013).

**2.6.4 FIXATION METHODS AND BONE VOID FILLERS**

The goal of open reduction and internal fixation is to have anatomical reduction of the fracture, provide stable fixation, and allow early mobilization of the knee. Definitive open reduction and plate fixation is performed according to AO principles when the swelling has decreased and the wrinkle test is positive (Pape and Rommens 2007). Currently, no consensus exists on either the best method of fixation or the optimal bone void filler (McNamara et al. 2015).

The use of minimally invasive osteosynthesis and an Ilizarov-type ring fixator has been advocated as a way to minimize ORIF complications, especially in complex C-type fractures. Even though minimal invasive reduction is usually related to worse articular reduction, good functional results have been achieved with this treatment pattern.

One trial compared the use of a circular fixator combined with insertion of percutaneous screws (hybrid fixation) versus standard open reduction and internal fixation (ORIF) in patients with open or closed Schatzker V–VI type tibial plateau fractures (Pirani et al. 2006). Results of the two groups (66 patients) were comparable for the WOMAC, HSS, and SF-36 at two years from the operation. Seven (18%) of the 40 patients in the ORIF group had a deep infection and patients in the hybrid fixation group had a lower risk for an unplanned reoperation.
Another trial compared the use of a minimally invasive lateral plate (LISS system) and conventional double plating (ORIF) in 84 patients who had open or closed bicondylar tibial plateau fracture (Jiang et al. 2008). In the ORIF group, a bone graft was used nearly twice as often (22 vs. 12 patients). There was significantly more malalignment in the LISS group than in the double plating group (14.6% vs. 2.3%), most frequently in the sagittal plane. The HSS scores were similar between the groups at 2 years from the operation.

Often after reduction of the plateau fracture, there is a void at the metaphyseal area of the tibia. The perfect void filler should have high osteoinductivity, osteogenecity, and osteoconductivity. The golden standard has been filling this void, if needed, with autograft bone from the iliac crest to get subarticular support. One prospective study with 109 Schatzker I–IV fractures, operated with conventional plates and/or screws, compared calcium phosphate cement (alpha-BSM) and autogenous iliac bone graft as a metaphyseal void filler (Russell and Leighton 2008). There were no infections found on the iliac crest harvest site, but naturally patients suffered initial pain caused by the harvest. At the final anteroposterior radiographs, there was significantly higher articular subsidence (≥2 mm) in the autogenous bone-graft group than in the alpha-BSM group (30% vs. 9%). Subsidence occurred between 3 and 6 months after surgery. At one year, calcium phosphate cement was still visible in the x-rays. No clinical outcomes were reported. In a systematic review evaluating outcomes after the use of calcium phosphate cement, hydroxyapatite granules, calcium sulphate, bioactive glass, tricalcium phosphate, demineralized bone matrix, and allografts, the use of calcium phosphate cement was found to result in at least secondary collapse of the knee joint surface (Goff et al. 2013).

In another study, the metaphyseal void was filled with either cancellous autograft or interporous hydroxyapatite, and no differences were found in roentgenographic and clinical results at the 12-month follow-up (Bucholz et al. 1989).

One prospective study compared the use of bioactive glass granules and autogenous bone as a bone substitute in the treatment of 25 unilateral (AO B2 and B3) tibial plateau fractures with conventional plate. No differences were found in radiological or functional results between the groups at the one-year follow-up (Heikkinä et al. 2011).

There is a cadaveric biomechanical study showing that plate-screw fixation is superior to screw fixation alone in a medial plateau split-fracture model (Huang et al. 2015). Biomechanical studies have also revealed that use of a raft of four cortical 3.5 mm subchondral screws compared with two cancellous 6.5 mm screws is biomechanically stronger, resisting axial compression in depressed plateau fractures (Karunakar et al. 2002, Patil et al. 2006).
2.6.5 LOCKING PLATE SYSTEMS

Anatomically pre-contoured plates with angle-stable fixation are common nowadays in the treatment of tibial plateau fractures. Locking plate systems are thought to be beneficial especially when treating elderly patients with osteoporotic bone. A locking plate can be placed distally with a minimally invasive technique functioning as an “internal-external fixator” where screws do not rely on plate-to-bone compression to resist patient load (Stannard et al. 2008). The advantages of locking plate include preservation of blood supply and better resistance to bending and torsional forces relative to conventional plates (Wagner 2003). Pre-contouring also saves time from bending the plate during the operation. No clinical studies have compared the results of conventional plating and locked plating in the treatment of unicompartmental plateau fractures (McNamara et al. 2015).

2.6.6 ARTHROSCOPIC REDUCTION AND INTERNAL FIXATION (ARIF)

Arthroscopically assisted reduction has been used for the treatment of less complex fractures for the last three decades (Caspari et al. 1985, Jennings 1985). Different kinds of mini-invasive reduction techniques have been developed with percutaneous screw fixation (Rossi et al. 2008). Potential advantages of the ARIF technique are that possible meniscal and cartilage lesions can be treated in the same procedure and the achieved reduction can be visualized with arthroscopy. ARIF may also accelerate rehabilitation and decrease postoperative morbidity compared with ORIF. Possible drawbacks include increased risk of compartment syndrome (Belanger and Fadale 1997), prolonged operative time, and additional costs. This technique is especially suitable for Schatzker type I pure split fractures and Schatzker type II fractures when there is only minimal dislocation. Satisfactory functional results, comparable with those of the ORIF technique, have been achieved using ARIF (Chen et al. 2015, Wang et al. 2017). Attempts have been made to show that the ARIF technique can yield better radiological results than the traditional ORIF technique (Fowble et al. 1993, Ohdera et al. 2003, Wang et al. 2017), but these claims have not been verified in a good-quality study.

2.7 ASSOCIATED INJURIES

As MRI has gained popularity in the diagnostics of proximal tibial fractures, many studies have reported the incidence of concomitant injuries related to these fractures.
2.7.1 MENISCAL INJURIES

Gardner et al. (2005) reported in their MRI study, with 103 Schatzker I–VI fractures, that the overall incidence of medial meniscus tear was 44%, lateral tear 74%, and lateral meniscus capsular separation 83%. Most of the fractures in the study were Schatzker II type fractures (62 of 103), and in this subgroup medial meniscus tear was found in 37%, lateral tear in 81%, and lateral meniscus capsular separation in 82%. Another MRI study, including 39 patients, found that 36% of the patients who had MRI done prior to operation of AO/OTA B- and C-type fracture had unstable meniscal tear (Mustonen et al. 2008).

In studies where diagnosis of meniscal tear has been based on arthroscopic examination, the incidence has usually been noticeably lower.

Table 2 shows the incidence of meniscal tears found in arthroscopy studies.

Table 2. Incidence of meniscal injuries in arthroscopy studies.

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Fracture type</th>
<th>n</th>
<th>Medial meniscus tear</th>
<th>Lateral meniscus tear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gill et al. (2001)</td>
<td>Schatzker I–IV</td>
<td>29</td>
<td>1 (3%)</td>
<td>8 (28%)</td>
</tr>
<tr>
<td>Hung et al. (2003)</td>
<td>Schatzker I–VI</td>
<td>31</td>
<td>2 (6%)</td>
<td>5 (16%)</td>
</tr>
<tr>
<td>Kayali et al. (2008)</td>
<td>Schatzker I–III</td>
<td>21</td>
<td>3 (14%)</td>
<td>7 (33%)</td>
</tr>
<tr>
<td>Rossi et al. (2008)</td>
<td>Schatzker II–III</td>
<td>46</td>
<td>0</td>
<td>13 (28%)</td>
</tr>
</tbody>
</table>

2.7.2 LIGAMENTOUS INJURIES

Dislocated cruciate ligament avulsion injuries have been typically treated in the acute stage with fixation (Berkson and Virkus 2006). In one MRI study, total (avulsion or complete tear) ACL rupture occurred in 57%, complete PCL injury in 28%, complete LCL tear in 29%, and MCL tear in 32% of patients with Schatzker I–VI fractures (Gardner et al. 2005). The incidence of destabilizing ACL injury concomitant with usually low-energy Schatzker II fracture was 53%. However, the incidence of ACL rupture in arthroscopy studies has been noticeably lower, ranging from 0 to 27% (Gill et al. 2001, Hung et al. 2003, Kayali et al. 2008, Rossi et al. 2008).

Collateral ligament injuries can occur with tibial plateau fractures. MCL ruptures are usually treated conservatively unless there is a distal rupture of the ligament, in which case re-fixation is indicated. Complete LCL ruptures are recommended to be treated operatively (Kannus 1989). Primary repair is indicated for acute bony avulsions; however, midsubstance tears should be treated with reconstruction. (Geeslin and LaPrade 2011). Gardner et al. (2005) showed in their MRI study a high incidence of complete LCL ruptures ranging from 18% to 57% and complete MCL ruptures ranging from 0 to 36% depending on fracture type. Another MRI
study showed the incidence of LCL ruptures to be 34% and MCL ruptures 55% (Coletti et al. 1996). There are no studies showing the incidence of collateral ligament injuries needing a repair at the time of fracture fixation.

2.7.3 NEUROLOGIC INJURIES

Little data exist on the incidence of neurological injuries after proximal tibia fractures. Manidakis et al. (2010) reported a single temporary peroneal palsy in a series of 125 proximal tibia fractures. Stevens et al. (2001) found that 4 (7%) of 54 patients had peroneal palsy and all of these patients had more severe Schatzker IV–VI type fractures; only two of them had satisfactory clinical recovery.

2.7.4 VASCULAR INJURIES

Particularly high-energy medial plateau fractures have been speculated to elevate the risk for vascular injuries (Moore 1981). However, there is not much evidence in the literature to support this. In one study, a routine arteriography was performed on all medial plateau fractures, but no vascular injuries were found (Bennet and Browner 1994). Also in more recent long-term follow-up studies with large cohorts of patients with Schatzker I–VI proximal tibia fractures, no vascular injuries have been described (Rademakers et al. 2007, Manidakis et al. 2010, Urruela et al. 2013).

2.8 COMPLICATIONS

2.8.1 WOUND COMPLICATIONS AND INFECTIONS

When open reduction and internal plate fixation became more common in the treatment of proximal tibial fractures in the early 1990s, infection rates as high as 80% were reported (Mallik et al. 1992, Young and Barrack 1994). Due to high risk for infection in early ORIF, the staged procedures were introduced. In the staged management protocol, the soft tissue envelope is first allowed to recover before performing the definitive fixation. This may be achieved with a temporary external fixator or a brace. Also, in bicondylar fractures, a dual incision technique has reduced the need for extensive soft tissue dissection relative to one large anterior approach. With these new techniques, infection rates have been reduced. Nevertheless, deep infection rates of up to 24% have been reported especially after bicondylar fractures (Table 3) (Barei et al. 2004, Rademakers et al. 2007, Colman et al. 2013, Morris et al. 2013, Ruffolo et al. 2015).
Table 3. Incidence of deep surgical site infection after ORIF of tibial plateau fracture.

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Fracture type (AO /OTA)</th>
<th>n</th>
<th>Intervention</th>
<th>Deep SSI rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barei et al. (2004)</td>
<td>C3 type</td>
<td>83</td>
<td>Dual plating</td>
<td>8.4</td>
</tr>
<tr>
<td>Rademakers et al. 2007</td>
<td>B/C type</td>
<td>202</td>
<td>Plate or screw fixation</td>
<td>5.4</td>
</tr>
<tr>
<td>Colman et al. (2013)</td>
<td>B/C type</td>
<td>309</td>
<td>Plate</td>
<td>7.8</td>
</tr>
<tr>
<td>Morris et al. (2013)</td>
<td>C type</td>
<td>302</td>
<td>Plate</td>
<td>14.2</td>
</tr>
<tr>
<td>Ruffolo et al. (2015)</td>
<td>C3 type</td>
<td>140</td>
<td>Dual plating</td>
<td>23.6</td>
</tr>
</tbody>
</table>

Few studies have focused on risk factors of wound infection after operative treatment of proximal tibia fractures. Colman et al. (2013) showed that prolonged operative time and open fractures increase the risk for deep surgical site infection after plate fixation of tibial plateau fractures. Another recent study showed that smoking, open fracture, dual incisions, and compartment syndrome requiring fasciotomies were risk factors for infection when treating bicondylar fractures (Morris et al. 2013).

### 2.8.2 COMPARTMENT SYNDROME

Tibial plateau fracture comprises a risk for compartment syndrome necessitating four-compartment fasciotomies of the leg. The diagnosis of compartment syndrome is usually clinical, but also direct compartment pressure measurement can be used. A difference of <30 mmHg from diastolic blood pressure is usually used as objective evidence of compartment syndrome (McQueen and Court-Brown 1996). The reported incidence of compartment syndrome and fasciotomy has ranged from 7% to 27% after Schatzker IV–VI fractures (Barei et al. 2004, Stark et al. 2009, Acklin et al. 2012, Morris et al. 2013, Ruffolo et al. 2015, Gamulin et al. 2017). In the studies that have included all plateau fracture types, the incidence has been lower, ranging from 1% to 5% (Manidakis et al. 2010, Colman et al. 2013, Urruela et al. 2013). The use of a single skin incision technique to perform four-compartment fasciotomy does not seem to lower the infection risk (Bible et al. 2013)
2.8.3 MALUNION AND NONUNION

Malunion of the articular surface or the metaphyseal-shaft junction can occur after operative treatment of tibial plateau fractures. Stable fixation will reduce the risk of this complication. A recent study showed that 32% of patients had a step or gap of more than 2 mm at the articular surface in postoperative CT scan (Meulenkamp et al. 2017). Malreductions were mainly seen at the posterior quadrants of the lateral tibial plateau. Fluoroscopic reduction alone resulted significantly more often in malreduction relative to submeniscal arthrotomy and direct visual reduction (17% vs. 41%). If the mechanical axis is affected, an osteotomy to restore the mechanical axis may be indicated (Figure 8). In older patients, a total knee arthroplasty may be the best salvage procedure, but constrained implants with extensions may be necessary (Marczak et al. 2014, Softness et al. 2017).
Figure 8. Radiographs of a 31-year-old woman who sustained a bicondylar fracture after a bicycle fall (a). After 7 weeks of conservative treatment, a severe displacement was found (b). Corrective osteotomy and plate fixation were performed to restore the mechanical axis (c).
Nonunions are seldom reported complications after proximal tibia fracture, probably because of the good healing potential of the metaphyseal bone compared with the diaphysis. Rademakers et al. (2007) reported two nonunions in a series of 202 Schatzker I–VI fractures, and both were due to postoperative infection. Urruela et al. (2013) found two nonunions after treatment of 96 Schatzker I–VI fractures; one was due to infection and the other due to fixation failure. Manidakis et al. (2010) had a nonunion rate of 2% in their study with 101 proximal tibia fractures. However, one study with 140 bicondylar tibial fractures treated with ORIF showed 14 (10%) nonunions, and only six of these were nonseptic (Ruffolo et al. 2015). Another study with high-energy AO/OTA type A and C fractures treated with hybrid external fixator found that A-type fractures had significantly longer healing times and higher risk of nonunion than C-type fractures (Savolainen et al. 2010).

2.8.4 POSTTRAUMATIC OSTEOARTHRITIS

Posttraumatic OA develops in 9–44% of patients following tibial plateau fracture (Rasmussen 1972, Volpin 1990, Honkonen 1995, Rademakers et al. 2007). Patients with tibial plateau fractures have five times higher risk of needing a total knee arthroplasty (TKA) than a matched cohort population (Wasserstein et al. 2014). This risk is related to the patient’s age and to the complexity of the fracture. Only 7% of patients with a plateau fracture will develop OA needing TKA in a 10-year follow-up after injury versus 2% of patients without a fracture. Compared with TKA performed on patients with primary OA, TKA performed to treat posttraumatic OA or malunion after ORIF is often more technically demanding due to previous surgeries and scarring (Lunebourg et al. 2014). The choice of implant should take into account the stability of the knee and existing bony defects. The most common implants used are valgus/varus constrained, hinged, and PCL constrained prosthesis (Softness et al. 2017). There is controversy in the literature on the clinical outcomes after TKA performed for posttraumatic OA. In one prospective matched cohort study, no difference was found in KSS and WOMAC scores between patients with primary OA versus posttraumatic OA after ORIF (Lizaur-Utrilla et al. 2015). By contrast, another retrospective matched cohort study reported significantly lower postoperative KOOS scores for patients with posttraumatic OA relative to primary OA after TKA (Lunebourg et al. 2014). The complication rate after TKA performed for posttraumatic OA after ORIF is higher than TKA performed for primary OA (Bala et al. 2015, Lizaur-Utrilla et al. 2015, Scott et al. 2015). The most commonly reported complications include infections, stiffness, and ruptures of patella tendon due to exposure difficulty in knees with significant scar tissue.
Some authors have suggested that in certain patients TKA could be the primary procedure to treat proximal tibia fracture (Figure 9) (Malviya et al. 2011, Parratte et al. 2011, Haufe et al. 2016). Immediate postoperative mobilization with the possibility of full weight-bearing is one of the main advantages, especially for geriatric patients. Some of the main indications for considering primary arthroplasty include treatment of geriatric patients with poor bone quality and pre-existing OA likely to end up requiring TKA (Malviya et al. 2011, Parratte et al. 2011, Kini and Sathappan 2013). Only a few retrospective case series (≤30 patients) have been published, and mean age of the patients in these series has ranged from 78 to 81 years (Malviya et al. 2011, Parratte et al. 2011, Boureau et al. 2015, Haufe et al. 2016). Implant type and level of constraint should be determined based on pre-operative radiographs. If the fracture line likely compromises the medial or lateral collateral ligaments, a rotating hinge prosthesis is recommended (Parratte et al. 2011). Fractures in elderly patients are typically caused by low-energy injury with less soft tissue damage. The mean surgical delay to perform TKA has varied from 4 to 7.5 days (Malviya et al. 2011, Parratte et al. 2011, Boureau et al. 2015). The overall complication rate is 9.5–33%, and the most commonly reported complications include infections and wound complications, stiffness, and periprosthetic fractures (Softness et al. 2017). In one study with 30 patients, two patients died due to complications related to further surgical treatment of complications of the TKA: one prosthetic infection and one periprosthetic fracture (Haufe et al. 2016). Despite permitting immediate weight-bearing, TKA for the treatment of acute tibial plateau fracture has entailed considerable loss of patient autonomy (Boureau et al. 2015).

Figure 9. Radiographs of a 73-year-old woman who sustained a bicondylar AO C3 type fracture after a same-level fall at home (a). The patient was treated with primary TKA (b).
2.9 OUTCOME MEASUREMENT INSTRUMENTS

There are several specific and validated patient-reported outcome measures of lower limb function. Yet, there is no scoring system that has been specifically designed to evaluate the follow-up of patients after knee fractures (McNamara et al. 2015). In studies conducted in the 1970s to 1990s, non-validated scoring systems were often used (Rasmussen 1973, Honkonen 1994). In more recent long-term studies from the 21st century, several different knee-specific outcome measurement instruments have been used: American Knee society score (AKSS), HSS knee score, Short Musculoskeletal Functional Assessment (SMFA), Oxford knee score, IOWA knee score, Western Ontario and McMaster Universities Osteoarthritis index (WOMAC), and Knee injury and Osteoarthritis Outcome Score (KOOS). KOOS was developed as an extension of the WOMAC to assess both short- and long-term symptoms and function.

2.10 OUTCOME AFTER OPERATIVE TREATMENT OF PROXIMAL TIBIA FRACTURES

Results of tibial plateau fractures are difficult to evaluate given the wide range and severity of injury and the advancement of management techniques over the years. Recent long-term studies of plateau fractures, however, indicate that satisfactory knee function can be obtained with even severe injuries. There is controversy regarding the effect of patient’s age, fracture type, and achieved reduction on the end result. A summary of functional results achieved in different studies is shown in Table 4.
Table 4. Functional outcome after treatment of proximal tibia fracture.

<table>
<thead>
<tr>
<th>Author et al. (year)</th>
<th>Treatment period</th>
<th>FU-time (years)</th>
<th>No. of fractures included in the study</th>
<th>Fracture type</th>
<th>Intervention</th>
<th>Functional outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type I = 4</td>
<td></td>
<td>Physical function 70</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type II = 16</td>
<td></td>
<td>Role physical 65</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type III = 5</td>
<td></td>
<td>Bodily pain 64</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type IV = 8</td>
<td></td>
<td>General health 71</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type V = 3</td>
<td></td>
<td>Vitality 57</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type VI = 11</td>
<td></td>
<td>Social function 85</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Medial 7</td>
<td></td>
<td>Excellent 76 (70%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bicondylar 32</td>
<td></td>
<td>Good 27 (25%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fair 6 (5%)</td>
</tr>
<tr>
<td>Manidakis et al. (2010)</td>
<td>2003–2006</td>
<td>1.7 (1–5.8)</td>
<td>125</td>
<td>Schatzker</td>
<td>ORIF 72</td>
<td>AKSS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type I = 31</td>
<td></td>
<td>Good 86 (69%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type II = 42</td>
<td></td>
<td>Fair 30 (24%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type III = 21</td>
<td></td>
<td>Poor 8 (7%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type IV = 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type V = 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type VI = 16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dreumel et al. (2015)</td>
<td>2004–2010</td>
<td>6.2 (2.9–9.8)</td>
<td>71</td>
<td>Schatzker</td>
<td>ORIF with plate/</td>
<td>KOOS*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type I = 10</td>
<td>or screw fixation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type II = 39</td>
<td></td>
<td>Pain 89.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type III = 3</td>
<td></td>
<td>Other symptoms 91</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type IV = 4</td>
<td></td>
<td>Daily function 89.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type V = 17</td>
<td></td>
<td>Sports 72.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type VI = 23</td>
<td></td>
<td>Quality of life 75</td>
</tr>
</tbody>
</table>

*Mean values, range 0–100, 100 is the highest score

**Mean values, range 0–100, 0 is the highest score
Stevens et al. (2001) reported 54 consecutive tibial plateau fractures treated with open reduction and internal fixation. Of these, 47 patients (85%) participated in the study. Five of the 47 (11%) fractures had postoperative malreduction (≥4 mm step-off or depression). No correlation existed between fracture type or adequacy of fracture reduction and WOMAC scores. Of patients aged <40 years, 24 (92%) of 26 received SF-36 scores comparable to the healthy age-matched population. The corresponding figures for patients aged ≥40 years were 12 (57%) of 21 patients. In the age groups <40 years and ≥40 years, 68% and 48%, respectively, were able to return to full-time employment. The study concluded that age at time of injury is the main factor influencing outcome, with fracture type having much less influence.

Rademakers et al. (2007) treated 202 tibial plateau fractures with ORIF. The treatments of 10 patients who had arthrodesis, TKR, or corrective osteotomy were considered failures and excluded from the final evaluation. Overall, 109 (54%) patients participated in the final follow-up visit. Their mean Neer score was 88.6 (56–100). The mean HSS Knee score was 84.8 (19–100). Patients without signs of posttraumatic OA had significantly higher Neer and HSS Knee score than patients with moderate or severe OA. Patients with malalignment of >5° had significantly more moderate to severe grade OA than those with an anatomic knee axis. Age did not appear to impact the results. The study also concluded that unicondylar fracture had significantly better Neer Score, 93 (40–100), than bicondylar fractures, 87 (42–100).

Manidakis et al. (2010) evaluated 156 patients with tibial plateau fractures. Thirty-one patients (20%) were lost to follow-up or died. Excellent reduction and alignment were achieved in 71 (57%) of 125 cases, but no definition for ‘excellent’ was provided. The authors concluded that the best results occurred in patients with unicondylar fractures and the worst results in patients with bicondylar fractures with diaphyseal-metaphyseal dissociation.

Urruela et al. (2013) reported the results of 94 patients with 96 Schatzker I–VI fractures treated with ORIF between 2005 and 2011. The most common fracture type was Schatzker II (50%). Only 63% (60/96) were able to participate in the one-year follow-up. At 12 months, 76% of the patients had returned to their pre-injury employment. No correlation was found between Schatzker classification and patient’s age or functional or radiological results. Also the postoperative articular step-off and residual depression at 12 months were not associated with decreased functional outcome.

Van Dreumel et al. treated 96 patients with Schatzker I–VI tibial plateau fractures surgically with plate and/or screw fixation, achieving anatomical reduction (step-off or gap < 1 mm) in 87.5% (van Dreumel et al. 2015). Most of the fractures were Schatzker type II (40.6%). Of the patients, 74% completed the KOOS questionnaire survey. No difference was found in functional outcome (KOOS subscores and total score) after anatomical or nonanatomical reduction. Of the patients participating
REVIEW OF THE LITERATURE

In the study, 64% were able to return fully to their previous work after a mean of 6.8 months.

2.11 REHABILITATION AND WEIGHT-BEARING PROTOCOLS AFTER OPERATIVE TREATMENT

The goal of operative treatment is to allow early mobilization with full range of motion exercises. Often a hinged brace is used even though there is little data in the literature to support its benefit.

Patients are usually instructed after tibial plateau fracture to avoid weight-bearing activity for the first 10 weeks, then allowing only partial weight-bearing for the following 2 weeks. Despite apparent willingness to comply with the weight-bearing protocols, patients often do not follow weight-bearing restrictions (Haller et al. 2013). There is no scientific evidence in the literature to support these weight-bearing restrictions, and good prospective, randomized studies are totally missing (Haller et al. 2013). A retrospective study with 32 patients with B-type lateral plateau fractures, treated operatively with locking plate, compared immediate and delayed weight-bearing; no difference was found in radiographic fracture displacement or complication rate (Haak et al. 2012). Another study investigated the stability of seven Schatzker II tibial plateau fractures treated with conventional plate fixation using radiostereometric analysis (Solomon et al. 2011). Patients were allowed immediate 20 kg partial weight-bearing for the first 6 weeks, followed by progression to full weight-bearing in the next 6 weeks. The study showed that use of a raft of subchondral screws with buttress plate was able to maintain the reduction for up to one year of follow-up with this protocol.

Another retrospective study with 42 AO/OTA B- and C-type fractures concluded that commencing weight-bearing against instruction in the first 6 weeks resulted in failure of reduction in 80% of patients compared with 25% of patients who started weight-bearing after 10 weeks (Ali et al. 2002).
3. AIMS OF THE STUDY

This study had the following aims:

1. To determine the medium-term functional and radiographic outcomes of operatively treated AO B3.1 lateral tibial plateau fractures and to evaluate whether surgery- and patient-related factors influence these outcomes.

2. To determine fracture- and surgery-related factors that could influence the development of posttraumatic OA after medial tibial plateau fracture and to evaluate functional outcome and the type of concomitant injuries associated with these fractures.

3. To determine whether the occurrence of concomitant injuries preoperatively detected using MRI correlates with arthroscopic findings during the treatment of lateral tibial plateau fractures.

4. To identify the most important patient- and surgery-related risk factors for deep SSI following operative treatment of proximal tibia fractures.
4. PATIENTS AND METHODS

Patients were treated at Töölö Hospital, the level I trauma center of Helsinki University Hospital. The local Ethics Committee approved the study, and informed consent was obtained from each patient (I–III). The study protocols were approved by the Institutional Review Board (I–IV). All studies were conducted in adherence with the principles of the Declaration of Helsinki.

4.1 IDENTIFICATION OF THE STUDY POPULATION

All patients with a surgically treated proximal tibial fracture at our institution were identified by querying the hospital surgical database for diagnoses coded with the International Classification of Diseases, Ninth and Tenth Revision (ICD-9, ICD-10) for proximal tibial fractures (823.0, 823.1, S82.1) and procedure codes (NOMESCO) for external (NGJ70) or internal fixation (NGJ62, NGJ64) of proximal tibial fractures from 2002 to 2013. Eligible surgical procedures were restricted to those performed primarily at our institution in patients aged 16 years and older.

Study I consisted of patients with split-compression lateral plateau fractures who were treated operatively with plate fixation between January 2002 and December 2008.

Study II consisted of patients with medial plateau fractures who were operatively treated between January 2002 and December 2008.

Study III was a prospective study that enrolled 50 consecutive patients who were surgically treated for lateral tibial plateau split-depression fractures between April 2009 and February 2012.

Study IV consisted of patients who had operatively treated proximal tibia fractures with plate fixation between January 2004 and December 2013. Patients with deep surgical site infection were identified and a control group was randomly selected from the noninfected cohort.
4.2 STUDY DESIGN

Study I was a retrospective cohort study of 123 consecutive patients with split-compression lateral plateau fracture (AO/OTA type B3.1) treated operatively with plate fixation during a 7-year period. Of these patients, 73 were available for clinical, functional, and radiographic follow-up examination; seven had died, one had undergone a total knee arthroplasty, one had suffered a pathological fracture, and 41 were lost to follow-up (11 were untraceable, 22 refused to participate, three had emigrated, and five had a language barrier).

Study II was a retrospective cohort study of 63 consecutive patients with operatively treated medial plateau fracture (AO/OTA type 41-B1.2, B1.3, B3.2, and B3.3) during a 7-year period. Of the 63 patients, 41 were able to participate in a follow-up visit. Included patients had clinical, radiographic, and functional assessment at the end of follow-up, except for two patients who underwent total knee arthroplasty and were not included in the clinical and functional evaluations. Seven patients completed functional evaluation information forms, but were unable to attend the follow-up visit. Fifteen patients were excluded from the study due to no follow-up data; 8 had died, 2 had severe dementia or schizophrenia, and 5 were lost to follow-up.

Patient demographics, mean follow-up times, and injury mechanisms are presented in Tables 5 and 6. Fractures were classified according to AO/OTA classification.

Table 5. Demographics of patients in Studies I and II.

<table>
<thead>
<tr>
<th></th>
<th>Study I</th>
<th>Study II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years, mean (range)</td>
<td>48 (17-77)</td>
<td>47 (16-78)</td>
</tr>
<tr>
<td>Female gender</td>
<td>56%</td>
<td>38%</td>
</tr>
<tr>
<td>BMI (kg/m²), mean</td>
<td>25.8</td>
<td>27.6</td>
</tr>
<tr>
<td>Follow-up time, years (range)</td>
<td>4.5 (1.6-8.5)</td>
<td>7.6 (4.7-11.7)</td>
</tr>
</tbody>
</table>
PATIENTS AND METHODS

Table 6. Mechanism of injury in Studies I–III.

<table>
<thead>
<tr>
<th>Injury mechanism</th>
<th>Study I (n=73)</th>
<th>Study II (n=63)</th>
<th>Study III (n=50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same level fall</td>
<td>32 (44%)</td>
<td>28 (44%)</td>
<td>27 (54%)</td>
</tr>
<tr>
<td>Sports-related</td>
<td>11 (15%)</td>
<td>8 (13%)</td>
<td>10 (20%)</td>
</tr>
<tr>
<td>Automobile collision with pedestrian</td>
<td>11 (15%)</td>
<td>2 (3%)</td>
<td>2 (4%)</td>
</tr>
<tr>
<td>Fall from height &gt;1 m</td>
<td>7 (10%)</td>
<td>2 (3%)</td>
<td>5 (10%)</td>
</tr>
<tr>
<td>Bicycle accident</td>
<td>3 (4%)</td>
<td>9 (14%)</td>
<td>3 (6%)</td>
</tr>
<tr>
<td>Road traffic accident</td>
<td>3 (4%)</td>
<td>14 (22%)</td>
<td>2 (4%)</td>
</tr>
<tr>
<td>Assault</td>
<td>6 (8%)*</td>
<td>1 (2%)</td>
<td></td>
</tr>
</tbody>
</table>

*Including 2 tsunami victims

**Study III** was a prospective study of 50 consecutive patients with split-compression lateral plateau fracture (AO/OTA type B3.1) treated surgically in a 3-year period. Indications for operative treatment included articular displacement or step-off >2 mm, condylar widening >5 mm, malalignment >5°, or instability in full extension. Study exclusion criteria were presence of OA (Kellgren-Lawrence grade > 1), an open fracture, or a pathological fracture. All patients were subjected to a preoperative multidetector computer tomography (CT) scan and magnetic resonance imaging (MRI) of the affected knee for evaluation of fracture morphology and concomitant injuries. The mean age of the patients was 50 years (range 23–86) and 54% were female. To identify and treat clinically relevant concomitant injuries, all patients underwent knee arthroscopy prior to open reduction and internal fixation (ORIF) within the same procedure. During arthroscopy the integrity of both menisci and cruciate ligaments was evaluated and cartilage defects were recorded. Results of arthroscopy were compared with MRI findings. The follow-up time was one year.

**Study IV** was a case-control study of 652 consecutive patients with proximal tibia fracture treated operatively with plate fixation in a 10-year period. Medical records were assessed for signs and symptoms of surgical site infection (SSI). Infections were classified as deep when all three of the following criteria were met simultaneously: clinical signs of SSI (swelling, redness, drainage, or wound dehiscence), positive bacterial cultures of wound specimens, and osteosynthetic material palpable or visible in the wound. Thirty-four (5.2%) of the 652 patients fulfilled the above-mentioned criteria and were classified as having a deep infection. The mean age of the patients was 55 years (range 16–84) and 35% were female. A control group was randomly selected in a 1:4 ratio from the cohort of patients who had undergone plate fixation, but did not subsequently develop SSI. The minimum follow-up time was one year. Potential patient- and surgery-related risk factors for infection were assessed by reviewing medical, microbiological, surgical, and radiology records.
We collected the demographic data and possible patient co-morbidities, injury mechanism (high-energy injury defined as a fall from a height >1 m or a motor vehicle accident), severity of open fractures (Gustilo grade I–III), and fracture type (AO/OTA classification system). Also recorded were use of a temporary spanning external fixator, pin-plate overlapping, tourniquet use, four-compartment fasciotomy, dual incision approach, bicondylar plating, concomitant arthroscopic examination, and use of bone graft. The duration of external fixation in situ, timing of the definitive surgery, duration of the surgery, and timing of the fasciotomy closure were recorded. Timing of antibiotic prophylaxis (suboptimal timing was defined as antibiotic given more than 60 minutes before the incision, after the incision, or less than 5 minutes before or after tourniquet inflation) and use of a drain were assessed. Additionally, blood leukocyte counts, C-reactive protein levels, and causative pathogens were noted at infection onset.

4.3 OPERATIVE TREATMENT IN STUDY III

Following arthroscopy, ORIF was performed using an anterolateral incision, and an arthrotomy was done beneath the lateral meniscus. Depression of the articular surface was elevated under direct visual control, and the bone defect was filled with either autograft (16 patients) or synthetic bone material (22 patients) depending on the preference of the attending surgeon. Fixation was achieved using an angular stable locking plate with a raft of subchondral screws (LCP Proximal Tibia Plate 4.5/5.0; Synthes, Elmira, NY, USA).

The postoperative management protocol included early mobilization using a hinged knee orthosis for 12 weeks. All patients were instructed to avoid weight-bearing activity for the first 10 weeks, and then allowed only partial weight-bearing for the following 2 weeks.

4.4 RADIOLOGICAL EVALUATION

All patients (Studies I and II) had preoperative computer tomography for accurate evaluation of fracture morphology. Conventional standing knee radiographs were taken to evaluate the stage of posttraumatic OA according to the Kellgren-Lawrence classification (grade 0 to 4) at the end of follow-up. Radiographs were obtained with the knees extended and the tibias in neutral rotation. Standing knee radiographs were obtained also from the contralateral uninjured knee for comparison. The maximal depression of the tibial articular surface was measured from anteroposterior and lateral view radiographs at the follow-up visit. Full-length radiographs of the lower extremities were taken to evaluate the mechanical axis at the end of follow-up. In
Study II, additionally, computed tomography (CT) (GE Discovery CT750 HD, General Electric Medical Systems, Milwaukee, WI, USA) of the injured knee was obtained at the end of follow-up to measure the depression of the joint surface. Axial 1.25-mm-thick reconstructions and 2-mm sagittal and coronal reformation were used for the analysis. The images were independently evaluated on clinical PACS workstations (IMPAX DS 3000, version 4.5, Agfa-Gevaert N.V., Mortsel, Belgium) by two musculoskeletal radiologists and mean measurement values were used.

The stage of posttraumatic OA was assessed according to the Kellgren-Lawrence classification as follows: Grade 1: unlikely narrowing of the joint space, possible osteophytes; Grade 2: small osteophytes, possible narrowing of the joint space; Grade 3: multiple, moderately sized osteophytes, definitive joint space narrowing; and Grade 4: multiple, large osteophytes, severe joint space narrowing, sclerosis and/or deformity.

In Study III, all patients were subjected to a preoperative multidetector CT scan and an MRI of the affected knee for evaluation of fracture morphology and concomitant injuries. The MR images were obtained with a 1.5-T Signa MRI Echospeed (GE Healthcare, Milwaukee, WI, USA). The standard clinical sequences were coronal T1-weighted fast-spin echo, T2-weighted fast-spin echo with fat saturation, sagittal T2-weighted fast-spin echo, sagittal PD-weighted spin echo, and axial proton density fast-spin echo with fat saturation.

4.5 OUTCOME EVALUATION

Clinical assessment

All patients included in Studies I–III had a clinical assessment at the end of follow-up. Valgus and varus laxity were evaluated using manual testing in extension and at 30 degrees of flexion. To assess anterior laxity, the Lachman, anterior drawer, and pivot shift tests were applied. Posterior laxity was evaluated using the posterior drawer test. Range of motion was measured using a goniometer. Results were compared with those of the uninjured contralateral knee.

Functional assessment

All patients in Studies I–III completed two validated functional outcome measurement tools: the Modified Lysholm knee score (Briggs et al. 2009) and the Western Ontario and McMaster Universities Osteoarthritis index (WOMAC) (Roos et al. 1999).
4.6 STATISTICAL ANALYSES IN STUDIES I–IV

An independent biostatistician conducted the statistical analyses for Studies I, II, and IV. In all studies, p-values of less than 0.05 were considered statistically significant.

**Study I.** Statistical analyses were performed using SAS System for Windows, version 9.2 (SAS Institute Inc., Cary, NC, USA). Associations between categorical variables were tested with the Chi-square test. Kruskal-Wallis or Mann-Whitney U-tests were used to test differences in continuous and ordinal variables between the levels of categorical variables. The correlation coefficients were calculated using Spearman rank-order correlations.

**Study II.** Statistical analyses were performed with SAS System for Windows, version 9.4 (SAS Institute Inc., Cary, NC, USA). The differences in categorical variables between patients with or without posttraumatic OA were analyzed with Chi-square test or Fisher’s exact test. The mean ages between patient groups were compared using two-sample t-test. The Mann-Whitney U-test was used to assess the difference in non-normally distributed continuous variables between patients. Receiver-operating characteristics (ROC) analysis and Youden’s (sensitivity+specificity-1) index were used to find the optimal cut-off value for depression measured from preoperative CT scans in predicting posttraumatic OA. The maximum value of Youden’s index was used as a criterion for selecting the optimal cut-off value.

**Study III.** Based on the recorded variables, sensitivity was calculated using the proportion of meniscal ruptures correctly diagnosed by MRI, compared with the number of actual lesions found by arthroscopy. These same categories were also analyzed to calculate specificity, using the proportion of diagnoses not indicating meniscal lesions compared with the cases that did not have actual meniscal lesions. Negative predictive value, positive predictive value, and accuracy were also calculated.

**Study IV.** Statistical analyses were performed using SAS System for Windows, version 9.4 (SAS Institute Inc., Cary, NC, USA). Differences in categorical variables between the infected and noninfected groups were analyzed using cross-tabulation. The Mann-Whitney U-test was applied to evaluate the difference in the length of the external fixator treatment between groups. Univariate logistic regression analysis was used to assess significant risk factors for deep SSI. Significant risk factors (p<0.05) in the univariate analyses and diabetes as a clinically important factor were included in the multivariable model. Independent risk factors for infection were
identified by multivariable logistic regression analysis using a stepwise procedure. In addition, multivariable analysis was performed including one or two of the injury severity indicators (bicondylar plating, AO classification, external fixation usage, time to definitive fixation) at a time in the multivariable logistic regression model to avoid multicollinearity problems and to see the real effects of the injury severity indicators. Results of logistic regression analyses were expressed using odds ratios (ORs) with corresponding 95% confidence intervals (CIs).
5. RESULTS

5.1 STUDY I: PREDICTORS OF OSTEOARTHRITIS FOLLOWING LATERAL TIBIAL PLATEAU FRACTURES

Of the 73 patients, 55 (75%) had no or only mild (Kellgren-Lawrence grade 0-2) posttraumatic OA and 18 (25%) had severe (grade 3-4) posttraumatic OA. Altogether 44% (13/29) of the patients with >2 mm articular depression on the articular surface postoperatively had developed severe (Kellgren-Lawrence grade 3-4) OA compared with 11% (5/44) of those with depression ≤2 mm (p=0.001). Articular surface depression of >2 mm was also associated with more pain at night and at standing (p=0.02) and pain while sitting (p=0.01). Articular depression >2 mm was additionally associated with poorer WOMAC functional scores (8 vs. 14) (p=0.02). None of the patients had an articular depression >7 mm.

Of the patients with valgus malalignment >5 degrees, 50% (6/12) had developed severe (Kellgren-Lawrence grade 3-4) OA compared with 5% (1/20) of those with a normal mechanical axis (p=0.006). The mechanical axis at follow-up had no correlation with WOMAC or modified Lysholm scores. The radiological results are shown in Table 7.

Table 7. Radiological results of patients with lateral tibial plateau fracture.

<table>
<thead>
<tr>
<th>Articular Depression</th>
<th>Patients with grade 0–2 OA at follow-up n=55 (%)</th>
<th>Patients with grade 3–4 OA at follow-up n=18 (%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–2 mm</td>
<td>39 (53)</td>
<td>5 (11)</td>
<td>0.001</td>
</tr>
<tr>
<td>3–7 mm</td>
<td>16 (22)</td>
<td>13 (18)</td>
<td></td>
</tr>
<tr>
<td>≥5° varus</td>
<td>0</td>
<td>2</td>
<td>0.028</td>
</tr>
<tr>
<td>2–4° varus</td>
<td>9</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>± 1°</td>
<td>20</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2–4° valgus</td>
<td>19</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>≥5° valgus</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

Functional results of patients with lateral plateau fractures are shown in Table 8. Age at time of operation correlated with stage of posttraumatic OA; the older the patient, the more severe the OA at follow-up (p=0.002, R=0.36). Older patients also had poorer WOMAC functional scores (p=0.039, R=0.24). Minor medial
collateral ligament (MCL) laxity was found in 13 patients (18%), and 4 patients (5%) had anterior cruciate ligament (ACL) laxity. MCL laxity did not have an effect on functional outcome scores, but ACL laxity resulted in lower modified Lysholm scores (p=0.011).

Factors not associated with radiological results were BMI at time of trauma (p=0.57), type of void filler used (p=0.54), experience of surgeon (resident or specialist) (p=0.08), and use of angular stable plate or buttress plate (p=0.24).

Table 8. Functional results of patients with lateral and medial tibial plateau fractures.

<table>
<thead>
<tr>
<th></th>
<th>Patients with lateral plateau fracture (n=73)</th>
<th>Patients with medial plateau fracture (n=39)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>WOMAC Pain</td>
<td>10 (0–66)</td>
<td>12 (0–60)</td>
</tr>
<tr>
<td>Stiffness</td>
<td>14 (0–61)</td>
<td>14 (0–77)</td>
</tr>
<tr>
<td>Function</td>
<td>10 (0–59)</td>
<td>12 (0–63)</td>
</tr>
<tr>
<td>Modified Lysholm score</td>
<td>80 (41–100)</td>
<td>80 (35–100)</td>
</tr>
<tr>
<td>Range of motion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal extension</td>
<td>70</td>
<td>36</td>
</tr>
<tr>
<td>Extension limitation 5–15</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>&lt; 20° flexion limitation</td>
<td>67</td>
<td>31</td>
</tr>
<tr>
<td>20–45 ° flexion limitation</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

*2 patients who underwent total knee arthroplasty were excluded

5.2 STUDY II: PREDICTORS OF OSTEOARTHRITIS FOLLOWING MEDIAL TIBIAL PLATEAU FRACTURES

Of the 41 patients, 24 (59%) had no or mild (Kellgren-Lawrence grade 0–2) posttraumatic OA and 17 (41%) had severe (grade 3–4) OA. Initial articular depression measured from preoperative CT scans was a significant predictor of posttraumatic OA (p=0.009). The optimal cut-off value for depression was ≥3.4 mm in predicting posttraumatic OA (sensitivity 0.81, specificity 0.75). Factors not associated with development of posttraumatic OA were AO/OTA subtype of fracture (p=0.68), median articular depression at first postoperative x-ray (p=0.18), median articular depression at end of follow-up in CT (p=0.68), and median mechanical axis at end of follow-up (p=0.36).

Patients with mechanical axis > 4 degrees of varus had significantly more WOMAC pain (p=0.045), but no difference was present in other functional outcome scores. The difference in mechanical axis of the fractured leg compared with the uninjured leg was not associated with an increased risk of posttraumatic OA (p=0.10). Patients
with articular depression or step-off in the first postoperative radiographs had more WOMAC pain ($p=0.044$), but no difference in other functional outcome scores. Functional results of patients with medial plateau fractures are shown in Table 8.

**Additional injuries**

Permanent peroneal nerve dysfunction was found in six of the 63 patients. None of the patients had vascular injuries. Fasciotomy was performed on six patients due to clinical signs of compartment syndrome. At the time of fracture stabilization, LCL repair or reconstruction was performed on 10 patients (16%); 7 of the 20 (35%) with isolated medial plateau fracture (B1.2, B3.2) and 3 of the 43 (7%) with an oblique fracture type (B1.3, B3.3). Additionally, ACL avulsion fixation was performed on nine patients (14%). One patient had delayed ACL reconstruction and another patient had delayed ACL and PCL reconstructions.

**5.3 STUDY III: USEFULNESS OF MRI AND ARTHROSCOPY IN DIAGNOSTICS AND TREATMENT OF SOFT TISSUE INJURIES ASSOCIATED WITH LATERAL TIBIAL PLATEAU FRACTURES**

Arthroscopy identified medial meniscus tear in six patients (12%), lateral meniscus tear in 12 patients (24%), and ACL rupture in two patients (4%). PCL rupture was diagnosed clinically in two patients (4%). No lateral collateral ligament (LCL) ruptures were identified. Medial collateral ligament (MCL) stability testing preoperatively was not possible due to the lateral condyle fracture.

**Meniscal tears**

Of the 12 tears of the lateral meniscus, eight were bucket-handle tears, which were treated using open suture repair, and the rest were radial tears treated with resection (three arthroscopically and one in an arthrotomy). Also six tears of the medial meniscus were identified in arthroscopy, of which five were resected and one was considered clinically insignificant, not requiring treatment. Table 9 summarizes MRI sensitivity and specificity for detection of meniscal injuries.
RESULTS

Table 9. Diagnostic accuracy of MRI for detection of meniscal tears in patients with lateral tibial plateau fracture.

<table>
<thead>
<tr>
<th></th>
<th>Lateral meniscus tear (n = 12)</th>
<th>Medial meniscus tear (n = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>True positive</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>False positive</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>33%</td>
<td>67%</td>
</tr>
<tr>
<td>Specificity</td>
<td>76%</td>
<td>66%</td>
</tr>
</tbody>
</table>

MRI identified four of the 12 lateral meniscal tears, having an overall sensitivity of 33%. MRI diagnosed nine lateral tears among 38 menisci that did not contain a tear, and thus, specificity was 76%. MRI identified medial meniscal injuries in four of six patients, yielding an overall sensitivity of 57%. In all, 14 medial tears were diagnosed among 44 menisci that did not contain a tear; specificity was therefore 67%.

**Cruciate ligament ruptures**

In arthroscopy, one complete ACL rupture was found, which MRI had detected as a partial rupture. There was also one partial and combined ACL and PCL rupture in arthroscopic and clinical examination, which was detected as only a partial PCL rupture by MRI. One complete PCL rupture was correctly identified by both MRI and arthroscopy combined with clinical examination under anesthesia. All of these patients exhibited anteroposterior knee laxity in follow-up clinical examination, but had no subjective symptoms of instability and did not require operative intervention. MRI detected additionally one ACL rupture and one ACL avulsion injury, which were found to be normal on arthroscopy and stable during clinical examination.

**Collateral ligament ruptures**

One complete and seven partial LCL ruptures was detected by MRI, but none of these patients demonstrated varus instability at the time of operation or at the follow-up visit, and thus, they were considered stable. Four complete and three partial ruptures of the MCL were identified by MRI and all were treated nonoperatively. Three patients had MCL laxity on follow-up, but all of them were asymptomatic.
Cartilage lesions

There were full-thickness cartilage lesions (grade IV) on the weight-bearing surface in two patients: one on the lateral and the other on the medial femoral condyle. Both of these lesions were treated with microfracture technique. One of them was correctly visualized with MRI as a grade IV lesion, while the other went undetected. MRI detected additionally four grade IV cartilage lesions of the weight-bearing surface in three patients, which in arthroscopy were confirmed to be only grade II to III in severity and did not require surgical intervention.

5.4 STUDY IV: RISK FACTORS FOR DEEP SSI FOLLOWING PLATE FIXATION

Incidence and pathogens

The incidence of deep SSI was 5.2% (34 of 655 patients). There were 28 acute-onset (within 2 months of index surgery) and six late-onset (>6 months) infections. At the time of infection onset, 76% of patients with deep infection had a raised C-reactive protein value (>10 mg/L) and 44% had an elevated blood leucocyte count (>8.2 E/Ł). Deep infections were monobacterial in 20 of 34 patients (59%), and the three most prevalent pathogens were Staphylococcus aureus (n=9), Staphylococcus epidermidis (n=5), and Pseudomonas aeruginosa (n=2).

Treatment

Of the 28 acute-onset infection patients, 17 patients required muscle flap coverage and nine were treated successfully only with antibiotic therapy and debridement. Three patients with fulminant infections were treated eventually with an above-the-knee amputation. One elderly patient with multiple comorbidities had persistent infection and an elective above-the-knee amputation was planned, but the patient died due to other causes before the operation. Of the six late infections, five were treated with hardware removal and debridement. One elderly patient with an aggressive infection and nonunion with severe bone loss was treated with an above-the-knee amputation after one year from the index operation.
RESULTS

Risk factors for deep SSI

Patient- and surgery-related risk factors that significantly increased the risk of deep SSI are shown in Table 10. Since the patients who were initially treated with a temporary spanning external fixator had a higher risk of infection (p<0.001), the effect of external fixator and plate overlap was examined. In the infection group, 62% (13/21) of the patients had external fixator and plate overlap, whereas only 36% (12/33) of the non-infected group had overlap, however, this difference was not significant (p=0.07).

Table 10. Univariate logistic regression analyses for patient- and surgery-related risk factors for deep SSI.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Patients with infection n=34 (%)</th>
<th>Control patients n=136 (%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age ≥ 50 years</td>
<td>24 (71)</td>
<td>64 (47)</td>
<td>0.016</td>
</tr>
<tr>
<td>ASA grade 2–4</td>
<td>29 (88)</td>
<td>87 (64)</td>
<td>0.012</td>
</tr>
<tr>
<td>Obesity (BMI ≥ 30 kg/m²)</td>
<td>14 (42)</td>
<td>25 (19)</td>
<td>0.005</td>
</tr>
<tr>
<td>Smoking</td>
<td>15 (44)</td>
<td>33 (24)</td>
<td>0.026</td>
</tr>
<tr>
<td>Alcohol abuse</td>
<td>15 (44)</td>
<td>19 (14)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>AO type C vs. type B fracture</td>
<td>20/9</td>
<td>47/83</td>
<td>0.002</td>
</tr>
<tr>
<td>AO type A vs. type B fracture</td>
<td>5/9</td>
<td>6/83</td>
<td>0.004</td>
</tr>
<tr>
<td>Open fracture*</td>
<td>6 (18)</td>
<td>7 (5)</td>
<td>0.021</td>
</tr>
<tr>
<td>Four-compartment fasciotomy</td>
<td>13 (38)</td>
<td>12 (9)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Use of external fixator</td>
<td>21 (62)</td>
<td>33 (24)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Use of external fixator (bicondylar fractures only)</td>
<td>16/20 (80%)</td>
<td>24/47 (51%)</td>
<td>0.033</td>
</tr>
<tr>
<td>Operative time (mean, min)</td>
<td>211</td>
<td>171</td>
<td>0.031</td>
</tr>
<tr>
<td>Dual incision approach</td>
<td>18 (53)</td>
<td>39 (29)</td>
<td>0.009</td>
</tr>
<tr>
<td>Bicondylar plating</td>
<td>12 (35)</td>
<td>22 (16)</td>
<td>0.015</td>
</tr>
</tbody>
</table>

*All open fractures were classified as Gustilo grade III

In the multivariate analysis, the variables that remained independent predictors of deep infection are presented in Table 11.
Table 11. Independent risk factors in the multivariable logistic regression analysis for deep SSI.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>P-value</th>
<th>OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age ≥50 years</td>
<td>0.015</td>
<td>3.6 (1.3, 10.1)</td>
</tr>
<tr>
<td>Obesity (BMI ≥30 kg/m²)</td>
<td>&lt;0.001</td>
<td>6.5 (2.2, 18.9)</td>
</tr>
<tr>
<td>Alcohol abuse</td>
<td>&lt;0.001</td>
<td>6.7 (2.4, 19.2)</td>
</tr>
<tr>
<td>AO type C vs. Type B fracture</td>
<td>0.039</td>
<td>2.8 (1.1, 7.5)</td>
</tr>
<tr>
<td>AO type A vs. Type B fracture</td>
<td>0.42</td>
<td>2.1 (0.4, 12.3)</td>
</tr>
<tr>
<td>Use of external fixator</td>
<td>0.009</td>
<td>3.9 (1.4, 11.1)</td>
</tr>
<tr>
<td>Four compartment fasciotomy</td>
<td>0.017</td>
<td>4.5 (1.3, 15.7)</td>
</tr>
</tbody>
</table>
6. DISCUSSION

6.1 PREDICTORS OF OSTEOARTHRITIS AFTER LATERAL TIBIAL PLATEAU FRACTURES

The patients in this study had a good general outcome following surgical treatment of their injury. The mean WOMAC score at follow-up was similar to population-based normative values (Bellamy et al. 2011) and the mean modified Lysholm score was also good and comparable to other studies concerning operative treatment of lateral tibial plateau fractures (Horstmann et al. 2003, Siegler et al. 2011).

Another focus of the study was to evaluate how surgery- and patient-related factors influence the clinical and radiographic outcomes. Several previous studies have claimed that local residual irregularity of the articular surface is not an important factor in predicting functional outcome (Rasmussen 1973, Lansinger et al. 1986, Stevens et al. 2001, Weigel and Marsh 2002) or development of posttraumatic OA (Rademakers et al. 2007). However, two earlier studies have shown that step-offs in excess of 2.5–3 mm lead to lower clinical and functional results (Honkonen 1994, Singleton et al. 2017). In our study, patients with residual depression of the articular surface of >2 mm had significantly more severe (Kellgren-Lawrence grade 3–4) posttraumatic OA. Articular surface depression >2 mm was also associated with poorer WOMAC functional and pain scores. Although these functional results were statistically significant, the differences were small and may not be clinically relevant (Angst et al. 2001, Tubach et al. 2005).

Rademakers et al. (2007) showed that patients with mechanical axis malalignment of >5° after plateau fracture developed a moderate to severe grade of OA more often than patients with an anatomic knee axis as evaluated from standing knee radiographs (27% vs. 9%) over a mean 14-year follow-up. Another study revealed that patients with >5° of valgus after plateau fracture had poorer functional and clinical results (Honkonen 1994). One study found no correlation of mechanical axis with functional end result (Singleton et al. 2017). In the current study, patients with >5° valgus in mechanical axis had developed significantly more severe (Kellgren-Lawrence grade 3–4) posttraumatic OA already at medium-term follow-up. This suggests that the unfavorable consequences of such a mechanical disadvantage to the articular surface may begin at a very early stage.

Knee instability associated with fracture can be caused by ligamentous injury or bony deformation due to fracture. Knee instability has previously been noted to be an important factor influencing functional outcome and to be an indicator for operative treatment after tibia plateau fracture (Rasmussen 1973, Schatzker et al.
1979, Moore 1981). In our study population, 18% of patients had minor residual MCL laxity at follow-up, which was a similar level or less to what has previously been noted in other studies (Honkonen 1994, Ali et al. 2002). In the present study, residual MCL instability was not associated with functional outcome scores, whereas residual ACL laxity was associated with inferior modified Lysholm scores. This implies that concomitant ACL avulsions should be fixed at the time of injury if any dislocation is present.

Earlier, it has been noted that older age predicts worse functional outcome after tibia plateau fracture (Stevens et al. 2001). The present study also revealed that older patients had more advanced secondary OA and poorer WOMAC functional scores at follow-up than younger patients.

In a prospective randomized study of 119 patients with Schatzker I–VI type fracture, bioresorbable calcium phosphate cement was shown to be better than autogenous iliac bone graft in preventing fracture subsidence (Russell and Leighton 2008), when fixation was done with conventional plates or screws only. In our study, no difference was found in articular depression or mechanical axis according to void filler used. However, most of our patients were operated on using an angular stable plate, which may be a confounding factor.

6.2 PREDICTORS OF OSTEOARTHRITIS AFTER MEDIAL TIBIAL PLATEAU FRACTURES

Our first goal was to evaluate fracture- and surgery-related factors that could influence the development of posttraumatic OA. In this study, 17 of 41 patients (41%) developed severe Kellgren-Lawrence grade 3–4 posttraumatic OA after a mean follow-up of 7.6 years, and two of these patients had already undergone total knee arthroplasty. Earlier studies have shown that the development of posttraumatic OA may be caused by initial trauma to the tibial plateau cartilage (Roos 2005, Furman et al. 2006, Lotz 2010) or it an altered axial loading pattern to the tibial plateau caused by articular incongruence (Honkonen 1994, Parkkinen et al. 2014). In our study, the initial depression of the fracture, as seen on the preoperative CT scan, predicted the development of OA. However, the fracture subtype according to AO/OTA classification did not predict OA. The differences between the two groups in the quality of postoperative reduction were minimal, and the depression, measured from the first postoperative x-ray and CT scan, at the end of follow-up, did not predict the development of posttraumatic OA.

The other objective was to evaluate functional outcomes and the type of concomitant injuries associated with these fractures. The patients had generally good functional outcome after ORIF. Patients in the OA group had statistically worse WOMAC function and modified Lysholm scores. Patients with >4° of varus
malalignment or ≥2 mm of articular depression or step-off had significantly more WOMAC pain. Previous MRI studies have shown a high incidence of concomitant injuries among medial plateau fractures; one study reported that the incidence of complete LCL rupture was 57% in Schatzker IV fractures (n=7) (Gardner et al. 2005). Furthermore, unsatisfactory results have been reported after conservative treatment of complete (grade III) LCL injuries (Kannus 1989). In the present study, 10 patients (16%) had grade III LCL rupture at the clinical evaluation necessitating reconstruction and 9 patients (14%) had ACL avulsion fixed, and all of these were found to be clinically stable at the follow-up. A routine MRI is advisable when treating these fractures since there seems to be a high prevalence of ligament injuries demanding early operative treatment. One previous study noted that the severity of associated injuries tended to increase as the main fracture line moved laterally (Wahlquist et al. 2007). By contrast, we found that most of the LCL ruptures and peroneal nerve injuries were seen in isolated medial plateau fractures with an intact lateral plateau. Medial plateau fractures have also been suggested to entail an increased risk for vascular injury (Moore 1981). In one study, with 9 Schatzker type IV fractures, a routine arteriography was performed, but no vascular injuries were found (Bennet and Browner 1994). In the current study, which contained 63 patients with medial plateau fracture, no vascular injuries were seen.

6.3 USEFULNESS OF MRI AND ARTHROSCOPY IN DIAGNOSTICS AND TREATMENT OF SOFT TISSUE INJURIES ASSOCIATED WITH LATERAL TIBIAL PLATEAU FRACTURES

The purpose of this study was to determine whether the incidence of concomitant injuries preoperatively detected using MRI correlated with arthroscopic findings. Previous MRI studies have shown a high incidence of soft tissue injuries concomitant to lateral tibial plateau fractures (Barrow et al. 1994, Coletti et al. 1996, Gardner et al. 2005, Mustonen et al. 2008), whereas in arthroscopic studies the incidence has been lower (Gill et al. 2001, Kayali et al. 2008, Rossi et al. 2008). In this study, the incidence of concomitant injuries was lower than reported in earlier MRI studies. Most often, the concomitant injuries involved the menisci. Our study showed that, in the presence of a lateral condyle fracture of the tibia, the sensitivity and specificity of MRI are low for the diagnosis of meniscal injuries. In the absence of fracture, MRI has a sensitivity of 47–91% and specificity of 93–95% for diagnosis of a medial meniscus tear, and a sensitivity of 77–100% and specificity of 75–93% for a lateral meniscus tear (Sampson et al. 2008, Behairy et al. 2009). The reduced sensitivity and specificity of MRI in the presence of fracture may be due to distorted anatomy combined with the effects of intra-articular fracture fragments. Additionally, MRI image quality might be affected by pain-induced motion artifact.
In the current study, the incidence of meniscal lesions diagnosed arthroscopically (24% lateral meniscus and 12% medial meniscus tear) was similar to previous studies using ARIF (Gill et al. 2001, Kayali et al. 2008, Rossi et al. 2008). In these studies, meniscal tears have most often been on lateral menisci, and all of the medial meniscus tears needing intervention have been treated with resection. One study including Schatzker II fractures reported a higher number of associated meniscal lesions, finding 28 meniscal tears among 45 patients; yet, the study did not specify whether the lateral or medial meniscus was involved (Abdel-Hamid et al. 2006).

Another aim of the study was to evaluate the proportion of concomitant injuries that require arthroscopic intervention. One advantage of ARIF has been considered to be the identification and simultaneous repair of intra-articular soft tissue injuries (Fowble et al. 1993, Abdel-Hamid et al. 2006). In the current study, there were eight suturable bucket-handle tears, all on the lateral side, and these were treated with an open suture repair technique through the arthrotomy used for ORIF. Additionally, one lateral meniscus tear was resected through the arthrotomy, and three were resected arthroscopically. Medial meniscus injuries cannot be detected from an anterolateral open surgical approach. From the six medial meniscus tears, five were resected arthroscopically, and one required no operative intervention. Some of the medial meniscal tears may have occurred prior to the fracture since a population-based MRI study has shown degenerative asymptomatic meniscal tears to be highly prevalent (23%) among middle-aged and elderly adults, even in the absence of radiological signs of OA or pain (Englund et al. 2008). A study has also demonstrated that patients with degenerative medial meniscus tears and no knee OA received no benefit from partial meniscectomy relative to those with a sham surgical procedure (Sihvonen et al. 2013).

In the current study, we found no bucket-handle tears of the medial meniscus or tears that could have been repaired. It remains unknown whether the medial meniscal tears would have caused any clinical symptoms had they been left untreated arthroscopically at the time of fracture fixation. Additionally, none of the three cruciate ligament injury patients required surgical treatment, and only two patients with cartilage lesions were treated with microfracture. Therefore, arthroscopy did not offer significant advantages in the treatment of most of these injuries.

### 6.4 RISK FACTORS FOR DEEP SSI

The focus of the study was to identify risk factors for deep SSI following plate fixation of proximal tibial fractures using established criteria for deep infection. The study found several patient- and surgery-related risk factors for SSI in the univariate analysis. Age ≥50 years, BMI ≥30 kg/m², alcohol abuse, AO type C fracture, four-compartment fasciotomy, and use of temporary external fixation were
all independent risk factors for deep infection. The study also showed that deep infection in plated proximal tibial fractures carries substantial morbidity.

The rate of deep SSI was 5.2%, which is somewhat lower than reported in previous studies (8–24%) assessing risk factors for infection in patients with plated proximal tibial fractures (Colman et al. 2013, Morris et al. 2013, Ruffolo et al. 2015). This is probably due to the more rigorous definition of deep infection used in our study.

Some of the commonly recognized patient-related risk factors for SSI include obesity, smoking, and diabetes with complications (Karunakar et al. 2005, Suzuki et al. 2010, Wukich et al. 2010, Morris et al. 2013, Ovaska et al. 2013, Wukich et al. 2014). Obesity has previously been shown to increase the infection rate in the operative treatment of acetabular fractures (Karunakar et al. 2005, Suzuki et al. 2010), and also in the current study it was a risk factor for deep SSI in the treatment of proximal tibia fractures. Earlier studies of proximal tibia fractures have reported that patient age did not correlate with increased infection risk (Colman et al. 2013, Morris et al. 2013). We found that age ≥50 years was an independent risk factor for deep SSI. The current study also revealed that alcohol abuse was an independent risk factor for deep infection. Smoking was a significant risk factor in our univariate analysis, but not in the multivariable analysis. This may be due to strong interactions between smoking and other health-compromising behaviors since a recent study has shown tobacco use to be a risk factor for infection when treating bicondylar fractures (Morris et al. 2013). In accordance with previous studies of proximal tibia fractures, diabetes was not found to increase the infection rate in our study, which may also be explained by β-type error (Colman et al. 2013, Morris et al. 2013, Ruffolo et al. 2015).

Early attempts of plate fixation through a single midline incision were complicated by unacceptably high infection rates, up to 80% (Mallik et al. 1992, Young and Barrack 1994). There has been a marked decrease in infection rates since adopting the staged treatment modality (with a temporary spanning external fixator or a sling) and the dual incision approach (Barei et al. 2004, Egol et al. 2005, Morris et al. 2013). This allows the soft tissue envelope to recover before definitive fixation and also avoids extensive soft tissue dissection. Yet, there has been constant uncertainty about whether temporary spanning external fixator carries an increased risk of infection. A recent study found that use of an external fixator in proximal tibial fractures was associated with a higher infection rate than use of no external fixator, but it was not an independent risk factor of SSI (Colman et al. 2013). A similar result emerged in another study, where 81% of bicondylar fractures with infection had a temporary external fixator before ORIF (Morris et al. 2013). It has also been speculated that external fixator use may merely reflect injury severity and greater soft tissue trauma, which lead to a higher incidence of infection. In our study, the use of a temporary spanning external fixator was found to be an independent risk factor for infection, as was fracture severity (AO type C). External fixator pin site colonization has been
thought to be a potential risk factor for infection if the plate extends to the pin site area; yet, controversy exists on this subject. One study found no correlation between infection and overlapping of the fixator pin site with the plate (Laible et al. 2012), whereas another study noted that this increased the risk of infection (Shah et al. 2014). In our study, pin overlap was associated with higher infection risk, but the difference was not statistically significant. Based on our findings, we recommend pin placement away from the field of planned internal fixation to reduce the likelihood of pin site colonization interfering with definitive fixation. Our recommendation is also that pin sites should be debrided and covered until the wounds are closed after internal fixation to minimize the risk of contamination.

The reported incidence of compartment syndrome needing fasciotomy in the treatment of bicondylar fractures has ranged from 7% to 27% (Barei et al. 2004, Stark et al. 2009, Morris et al. 2013, Ruffolo et al. 2015). Performing internal fixation in the presence of an open fasciotomy has caused concern that it might increase the infection rate. One study with bicondylar fractures found that patients with fasciotomies performed prior to ORIF carried the highest likelihood of deep infection (Morris et al. 2013). Fasciotomy closure before definitive fixation has been shown to be associated with significantly fewer deep infections than internal fixation with open fasciotomy wounds (Ruffolo et al. 2015). However, another study showed no difference in infection rate whether the definitive fixation was done before, at the same time, or after fasciotomy closure (Zura et al. 2010). Performing single or dual incision fasciotomies in patients with tibial plateau or shaft fractures has not been shown to affect the infection rates (Bible et al. 2013). In our study, development of compartment syndrome leading to four-compartment fasciotomy was an independent risk factor for deep infection. The diagnosis of compartment syndrome in our clinic has been in nearly all cases only clinical, and compartment pressure measuring devices might be a useful supplement to clinical assessment in deciding when to perform fasciotomies (McQueen and Court-Brown 1996).

6.5 LIMITATIONS AND STRENGTHS OF THE STUDY

The principal weakness of Studies I and II was their retrospective nature; development of OA is multifactorial and data on variables are often limited. Moreover, being a medium-term follow-up study, the follow-up time in Study I was relatively short. Another limitation was that 33% of patients in Study I and 35% in Study II were lost to follow-up, yet this level is similar to other previous studies (Honkonen 1994, Rademakers et al. 2007, Siegler et al. 2011). Measurement of articular depression at the follow-up visit in Study I was performed from plain radiographs. This is challenging and can be associated with errors, and thus, is acknowledged as a limitation (Mustonen et al. 2005). Therefore, in Study II CT
was used to more reliably determine articular depression at the end of follow-up. In a prospective setting, the use of CT both postoperatively and at follow-up would enable even more reliable assessment of articular depression. Important strengths of Studies I and II were the selection of only one specific fracture type to minimize the effects of heterogeneous fracture patterns on these outcomes and the use of validated outcome measurement tools. To our knowledge, Study II is also the largest in the English literature examining the outcomes of medial tibial plateau fractures.

Study III may have limitations in the use of arthroscopy as the reference standard for the diagnosis of associated injuries, as intra-articular hematoma can reduce visibility. Also compression of the lateral plateau can restrict the view of the posterior horn of the medial meniscus, as providing valgus stress is difficult. To our knowledge, Study III is the first prospective study comparing the use of MRI with arthroscopy in the diagnosis of concomitant injuries in patients with split depression lateral plateau fracture of the tibia.

As deep SSIs are uncommon, a retrospective case-control study is an accepted design for analysis of risk factors for postoperative infection (Study IV).

A limitation is the reliance on data provided by medical charts since there may be underreporting, especially of patient-specific factors such as smoking. To control for these reporting deficiencies, the records from all other medical fields were also assessed. To the best of our knowledge, Study IV is the largest case-control study of risk factors for deep infection after proximal tibial fracture plate fixation that has utilized established criteria for deep infection.

6.6 FUTURE ASPECTS

Fracture classification is done nowadays based on CT scans, and surgical approaches should be planned accordingly (Luo et al. 2010). Fractures with the main involvement at the posterior column should be managed via the posterior approach. Fluoroscopy is not a reliable method to assess the reduction result (Krause et al. 2016, Meulenkamp et al. 2017). The reduction should also be verified with one of the following: direct visualization through an open approach, arthroscopy with or without fluid, or perioperative CT scan.

The importance for functional result of the exact reduction of certain plateau areas – e.g. the posterolateral central area, the reduction of which is very challenging and may necessitate more demanding approaches – remains unclear. Comminuted fracture patterns have usually involved the lateral plateau, but they have recently also been described on the medial side of elderly females, with diminished subchondral bone structure (Krause et al. 2016).
Postoperative CT scan should be the standard method for the evaluation of quality of the reduction in the future (Mustonen et al. 2005). The “ten-segment classification” could be a useful tool in distinguishing the different areas of the tibia plateau more thoroughly.

Open reduction and internal plate fixation provide the best anatomical reduction results. However, since good functional results have also been obtained with minimally invasive reduction and hybrid external fixation with C-type fracture, this fixation method should be considered more often for patients at high risk for deep SSI. Even though minimally invasive reduction probably leads to a less satisfactory articular surface reduction, it does not seem to provide an inferior functional result as long as the knee becomes stable and normal alignment is achieved postoperatively. Nevertheless, more studies are needed to determine the true significance of a specific anatomic articular reduction for the end result.

High-quality randomized control trials are required to identify the best fixation method for different types of plateau fractures. Locking plates are especially useful when there is a bicondylar fracture, which disconnects the condyles from the diaphysis of the tibia, since locking plates can be placed in a minimally invasive way distally. Remaining controversial is their role in preventing the loss of achieved reduction of articular surface relative to conventional plates.

Performing fasciotomies for compartment syndrome entails an elevated risk for deep SSI, and the role of vacuum-assisted closure in preventing this risk should be a focus of future studies.

The treatment of proximal tibia fractures remains a challenge for orthopedic surgeons. With the aging of the population, we are likely to see more complex fracture patterns also involving the medial plateau. Careful assessment of the fracture with the use of CT scan to guide the selection of approach is essential. The use of newer posterior approaches and arthroscopy-assisted techniques, when necessary, is important to achieve good anatomical reduction, leading to the best long-term results.
7. CONCLUSIONS

On the basis of these clinical studies, the following conclusions can be drawn:

1. Restoration and maintenance of articular congruity (<2 mm depression) and mechanical axis (<5 degrees of valgus) of the knee after plate fixation of lateral tibial plateau fractures seem to have a role in preventing posttraumatic arthritis, but do not appear to predict clinical outcome in medium-term follow-up.

2. With ORIF of medial tibial plateau fractures, good functional results can be expected, but posttraumatic OA is common (44%). The initial articular depression at preoperative CT scans seems to predict the development of OA, probably reflecting the severity of chondral damage at the time of fracture. Lateral collateral ligament injuries are common, especially in isolated medial plateau fractures. Restoration of mechanical axis and articular congruence is important as mechanical axis >4 degrees of varus and ≥2 mm articular depression or step-off are associated with worse WOMAC pain scores.

3. MRI has low sensitivity and specificity in the diagnosis of concomitant injuries in the lateral tibial plateau fracture setting. Nearly all of the clinically relevant concomitant injuries could be treated through the same lateral arthrotomy at the time of ORIF without the need for additional arthroscopy.

4. High morbidity is associated with deep SSI in plated proximal tibial fractures. Patients ≥50 years who are obese, have a history of alcohol abuse, or have AO type C fracture are at high risk for infection. Performing a fasciotomy increases the risk of deep infection and should be implemented with meticulous technique when deemed necessary.
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Espoo, November 2017
Markus Parkkinen
9. REFERENCES


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