Osteochondral Fractures After Patellar Dislocation
Characteristics, Risk Factors and Treatment Outcomes

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ABSTRACT

This dissertation examined trends in surgical techniques for patellar dislocation over the recent decades. The dissertation also focuses on the characteristics, risk factors and treatment outcomes of common concomitant injuries, osteochondral fractures, a potential area of development in the treatment of patellar dislocation.

Trends in patellar dislocation surgery were examined using a population-based register sample drawn from the Finnish National Hospital Discharge Register for the years 1997-2016 (Study I). Overall and annual incidences as well as the annual incidences of different types of procedure were calculated using population data from the Statistics Finland database. Trends in incidences were examined across the study period.

Osteochondral fractures were examined in a retrospective multicenter study sample drawn from the records of two large Finnish hospitals (Studies II, III and IV). The study sample consisted of all patients treated for patellar dislocation in the two hospitals during 2012–2018. In total, 135 patients with an intra-articular osteochondral fragment verified by magnetic resonance imaging (MRI) were included in the analysis. Demographic and clinical data were collected from electronic patient records and knee MRIs were examined to establish the characteristics of osteochondral fractures and the patellofemoral anatomy. Study II examined the characteristics of osteochondral fractures in different patient groups. Study III compared the anatomical measures of the patellofemoral joints of patients with an osteochondral fracture after patellar dislocation with those of propensity score-matched patients without osteochondral fracture. Study IV examined the outcomes of patellar dislocation patients with an osteochondral fracture treated according to the treatment protocol of the study hospitals. Patients were divided into groups according to the primary treatment approach and later surgery. Groups were compared on the characteristics of the injury, patellofemoral anatomy, and patient-reported outcomes.

The results showed that although the overall incidence of patellar dislocation surgery has remained stable over the past two decades, the surgical techniques used have shifted towards the reconstruction of damaged structures and modification of congenital anatomical risk factors for patellar dislocation (Study I).
Osteochondral fractures after patellar dislocation most commonly occurred in the medial facet of the patella (approximately two-thirds of cases) or in the lateral femoral condyle (one-third of cases (Study II). In women, patellar lesions were more common than in men. Osteochondral fractures sustained after primary patellar dislocation may be larger than those sustained after recurrent dislocation.

The prevalence of anatomical malformations related to patellar instability was very similar between the patellar dislocation patients with and those without an osteochondral fracture (Study III). However, the patterns of malformations differed between the groups, the non-osteochondral fracture patients showing more a severely high lying patella and deformed trochlea and the osteochondral fracture patients showing more severe patellar lateralization.

Lastly, although the primary treatment decision was definitive in the majority of the patellar dislocation patients with an osteochondral fracture, a relatively high proportion needed further surgery (Study IV). In the patients who underwent surgery in the primary phase, the osteochondral fragment was reimplanted in the majority of cases whereas in the patients who underwent surgery in the later phase, the fragment was removed. Additional stabilizing procedures were often performed in primary or later surgery. Patient-reported outcomes indicated generally acceptable results in all patient groups.

Our results show that the treatment of patellar dislocation, anatomical malformations, and concomitant injuries has evolved considerably during recent decades. However, patellofemoral problems in patients with osteochondral fractures after patellar dislocation include the risk of chronic patellar instability, cartilaginous injury, and degeneration of the patellofemoral articular cartilage in the long term. Hence, the treatment of these patients remains challenging. Further research is needed on individually tailored surgical procedures as well as standardized conservative treatment in patients with an osteochondral fracture after patellar dislocation. In addition, long-term outcomes pertaining to cartilage degeneration remain to be determined.
TIIVISTELMÄ

Tämän tutkimuksen tavoitteena oli tutkia polvilumpion sijoitetaanmenon leikkaushoidon kehitystä ja trendejä viimeisten kahden vuosikymmenen aikana. Lisäksi tässä tutkimuksessa paneuduttiin polvilumpion sijoitetaanmenon yhteydessä yleisen liitännäsvammojen, luurustomurtumien, kuiviluun, anatomisiin riskitekijöihin sekä hoidon tuloksiin. Polvilumpion sijoitetaanmenon liittyvän tutkimuskirjallisuuden lisääntytyä nopeaa vauhtia viime vuosien aikana, luurustomurtumien hoito on mahdollisesti seuraava keskeinen kehityksen osa-alue.


saavutettuja luurustomurtumapotilaiden hoidon tuloksia. Potilaat jaettiin ryhmiin perustuen luurustomurtuman jälkeiseen hoitolinjaan. Luurustomurtuman piirteitä, polvilumpio-reisiluunivelen anatomiaa ja potilaiden täyttämien vastekyselyjen tuloksia vertailtiin ryhmiin välillä.

Tämän tutkimuksen tulosten perusteella polvilumpion sijoitaanmenoon liittyvän leikkaushoidon kokonaisilmaantuvuus on pysynyt vakana viimeisen kahden vuosikymmenen ajan, mutta tehdyissä toimenpiteissä on tapahtunut muutos vaurioita korjaavan ja anatomisia poikkeavuuksia muovaavan kirurgian yleistyessä ajan myötä (Tutkimus I).


Polvilumpion sijoitaanmenon ja sen riskiin liittyvien anatomisten poikkeavuuksien sekä liitännäisvammojen kirurginen hoito on kehitetty merkittävästi viime vuosikymmenen aikana. Tästä huolimatta
luurustomurtumapotilaiden hoito asettaa edelleen merkittäviä haasteita polviongelman kaksijakoisuuden, polvilumpion mahdollisesti pysyvän epävakauden ja sijoiltaanmenon toistuvuuden sekä toisaalta pitkän aikavälin nivelrustovaurion, vuoksi. Jatkotutkimuksia tarvitaan potilaiden anatomian ja vamman laadun perusteella räätälöidyistä leikkaushoidoista sekä toisaalta vakioiduista kuntoutushoidoista. Lisäksi pitkän aikavälin seurantatutkimuksia rustovaurion etenemisestä luurustomurtuman hoidon jälkeen tarvitaan.
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# ABBREVIATIONS

<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>BMI</td>
<td>Body mass index</td>
</tr>
<tr>
<td>CDI</td>
<td>Caton-Deschamps index</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence interval</td>
</tr>
<tr>
<td>CT</td>
<td>Computed tomography</td>
</tr>
<tr>
<td>ICD-10</td>
<td>International Classification of Diseases, 10th revision</td>
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<tr>
<td>IQR</td>
<td>Interquartile range</td>
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<tr>
<td>ISI</td>
<td>Insall-Salvati index</td>
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<tr>
<td>LCL</td>
<td>Lateral collateral ligament</td>
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<tr>
<td>LPFL</td>
<td>Lateral patellofemoral ligament</td>
</tr>
<tr>
<td>LPTL</td>
<td>Lateral patellotibial ligament</td>
</tr>
<tr>
<td>MCL</td>
<td>Medial collateral ligament</td>
</tr>
<tr>
<td>MPFL</td>
<td>Medial patellofemoral ligament</td>
</tr>
<tr>
<td>MPTL</td>
<td>Medial patellotibial ligament</td>
</tr>
<tr>
<td>MRI</td>
<td>Magnetic resonance imaging</td>
</tr>
<tr>
<td>NCSP</td>
<td>Nomesco Classification of Surgical Procedures</td>
</tr>
<tr>
<td>NHDR</td>
<td>National Hospital Discharge Register</td>
</tr>
<tr>
<td>OCF</td>
<td>Osteochondral fracture</td>
</tr>
<tr>
<td>PCL</td>
<td>Posterior cruciate ligament</td>
</tr>
<tr>
<td>PTI</td>
<td>Patellotrochlear index</td>
</tr>
<tr>
<td>RCT</td>
<td>Randomized controlled trial</td>
</tr>
<tr>
<td>TT-TG</td>
<td>Tibial tubercle-trochlear groove distance</td>
</tr>
<tr>
<td>TT-PCL</td>
<td>Tibial tubercle-posterior cruciate ligament distance</td>
</tr>
<tr>
<td>US</td>
<td>Ultrasonography</td>
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This dissertation is based on the following original studies, which are referred to in the text by their Roman numerals.


AUTHOR’S CONTRIBUTION

Study I  The first author participated, along with the other members of research group, in the design of the study and interpretation of the findings. The author was responsible for the data analysis, illustrations, and preparation of the manuscript.

Study II  The first author had a major role in the design of the study and was responsible for the data gathering, statistical analysis and preparing the manuscript.

Study III  The first author was responsible for the design of the study, data gathering, statistical analysis and preparing the manuscript.

Study IV  The first author participated in the design of the study and was responsible for the data gathering, statistical analysis and preparing the manuscript.
1 INTRODUCTION

Patellar dislocation usually occurs in young and active populations (Askenberger et al., 2014; Atkin et al., 2000; Fithian et al., 2004; Nietosvaara et al., 1994). The annual incidence of patellar dislocations is 5.8 per 100,000 persons (Fithian et al., 2004). The incidence peaks at 29-120 cases per 100,000 persons per year between ages 9 to 17 (Askenberger et al., 2014; Fithian et al., 2004; Nietosvaara et al., 1994). Osteochondral fractures of the knee joint are common concomitant injuries during patellar dislocation. In previous studies, osteochondral fractures have been detected in 38-39% of pediatric patients after patellar dislocation (Nietosvaara et al., 1994; Seeley et al., 2013).

The main causes of patellar instability are anatomical malformations of the knee joint (Arendt et al., 2018; Arendt et al., 2017; Askenberger et al., 2016b; Dejour et al., 2018; Diederichs et al., 2010; Lewallen et al., 2015). These malformations include a high lying patella (patella alta), malalignment of the extensor mechanism and femoral trochlear dysplasia (Arendt et al., 2018; Arendt et al., 2017; Askenberger et al., 2016b; Dejour et al., 2018; Diederichs et al., 2010; Lewallen et al., 2015).

Primary patellar dislocations have usually been treated non-operatively, whereas surgery may be justified in recurrent dislocations or in primary dislocations with osteochondral fracture (Smith et al., 2015b; Stefancin et al., 2007). However, debate continues on the best treatment approach (Smith et al., 2015b). Recently, a meta-analysis of 16 randomized controlled trials (RCT) comparing outcomes of surgical and conservative treatment of primary patellar dislocation conducted during the years 1986-2016 concluded that surgical treatment may be preferable even in first-time dislocation (Yang et al., 2019a). In patients who underwent surgical treatment, Kujala anterior knee pain scale scores were higher, and the re-dislocation rate was lower when compared to those treated conservatively. With the rapid development in knowledge and treatment techniques for patellar dislocation over the past few decades, study populations and treatments have been heterogeneous. Moreover, the efficacy of different surgical techniques has been shown to vary (Askenberger et al., 2018; Bitar et al., 2012; Sillanpää et al., 2008b; Utting et al., 2008; Yang et al., 2019a). Hence, the conclusions of studies may not represent the true difference in efficacy between surgical and non-surgical approaches.
When considering treatment efficacy, it might not be enough to simply dichotomize treatments as surgical versus non-surgical. As knowledge on the risk factors of patellar dislocation has increased, techniques have been developed to address individual patients’ unique set of anatomical characteristics. This has meant that a one-size-fits-all surgical procedure may be insufficient as a basis for treatment recommendations.

Further, despite the expanding knowledge on patellar dislocation, concomitant osteochondral fractures have received relatively little attention in the literature. Thus, the characteristics and risk factors as well as injury mechanism of osteochondral fractures are rather poorly known. Lack of knowledge on the nature of the injury means that treatment is based on assumptions, established clinical practices and the personal assessments of physicians rather than solid research-based findings. As a result, no consensus exists on preferred treatments. However, given that cartilage damage of 1 cm² or more has been found to present a considerable risk for articular degeneration, the successful treatment of osteochondral fractures may be essential for long-term outcomes after patellar dislocation (Guettler et al., 2004).

Various management techniques for osteochondral fractures have been proposed (Guettler et al., 2004; Koëter et al., 2006; Lee et al., 2013; Li et al., 2019; Spahn et al., 2005; Walsh et al., 2008; Zhou et al., 2020b). The primary surgical procedure has been the reduction and reimplantation of the osteochondral fragment using biodegradable sutures or pins (Koëter et al., 2006; Li et al., 2019; Walsh et al., 2008; Zhou et al., 2020b). If reimplantation is not possible, the fragment is removed. In these cases, microfractures, subchondral drilling, or periosteal or abrasion chondroplasty of the fracture site may be considered (Lee et al., 2013; Spahn et al., 2005).

However, as the injuries in study samples have been highly heterogeneous, subgroup analyses comparing differing injury entities have not commonly been conducted and hence the efficacy of different techniques in different subgroups has not been thoroughly assessed (Guettler et al., 2004; Koëter et al., 2006; Lee et al., 2013; Li et al., 2019; Spahn et al., 2005; Walsh et al., 2008; Zhou et al., 2020b). To conduct such research would require a comprehensive analysis and classification of the injury in question.

Osteochondral fractures after patellar dislocation have received relatively little research attention (Nietosvaara et al., 1994; Seeley et al., 2013). Nietosvaara et al. (1994) and Seeley et al. (2013), in their studies of 15 and 46 patients, respectively, found that osteochondral fractures occurred in the medial facet of the patella in 69% and in the lateral condyle of the femur in 21% of cases (Nietosvaara et al., 1994;
Seeley et al., 2013). In the remaining 10%, the injury was located in both locations (Nietosvaara et al., 1994; Seeley et al., 2013). These studies did not examine differences in the injury pattern between patient subgroups by sex or age.

In addition to deficiencies in knowledge on the injury patterns of osteochondral fractures after patellar dislocation, the risk factors for these concomitant injuries are poorly known. Although the anatomical risk factors of patellar dislocation have been extensively reviewed, their associations with the risk of osteochondral fracture have not been assessed (Elías et al., 2002; Nietosvaara et al., 1994; Seeley et al., 2013). When compared to the normal knee joint, anatomical malformations related to patellar dislocation allow less restricted movement of the patella in relation to the femoral trochlea (Arendt et al., 2017; Dejour et al., 1994; Diederichs et al., 2010; Lewallen et al., 2015). As a result, anatomical malformations may reduce the forces on the articular surfaces of the patellofemoral joint. In theory, the occurrence of osteochondral fracture may require higher forces on articular surfaces. Thus, patellar dislocation with a concomitant osteochondral fracture may comprise an entity that differs, at least in part, from patellar instability related to anatomical malformations of the knee joint. In such cases, the differences in injury entities may be crucial when deciding on the optimal treatment for individual patients.

This dissertation examined the development and trends in surgical techniques for patellar dislocation over the past few decades using a population-based register sample. In addition, this research focused on the characteristics, risk factors and treatment outcomes of osteochondral fractures, a common concomitant injury that may be the next key area of development in patellar dislocation surgery. Osteochondral fractures were examined in a multicenter study sample drawn from two large Finnish hospitals.
2 REVIEW OF THE LITERATURE

2.1 Anatomy of the human knee joint

The knee joint is one of the largest joints in the human body. It consists of three bones, the femur, tibia, and patella (Figure 1). The tibiofemoral joint enables articulation between the femur and tibia. The posterior surface of the patella articulates with the trochlea of the femur, forming the patellofemoral joint. Hence, the knee joint actually consists of two distinct joints, the tibiofemoral joint and the patellofemoral joint. Alongside the patella, femur, and tibia, the fibula may also be considered as part of the knee joint, although it does not have a common articular surface with the femur and thus does not contribute to articular movement. However, it has a role in the mechanics of the knee joint as an insertion point for the stabilizing ligaments and musculature of the joint.

The tibiofemoral joint is a hinge joint that works as the weight-bearing component of the knee joint. The weight is carried by the medial and lateral condyles of the femur and tibia. The articular surfaces of the tibial condyles are concave with the intercondylar eminence separating the medial and lateral condyles. The femoral counterparts separated by the intercondylar fossa are convex. Knee flexion and extension are caused by motion of the tibiofemoral joint. In addition to flexion-extension, the tibiofemoral joint allows slight rotation of the tibia in relation to the femur. In full knee extension, the tibia is rotated slightly outwards, which causes the locking of the knee. Inward rotation of the tibia or outward rotation of the femur will unlock the knee, allowing flexing.

The femoral trochlea may be considered as an extension of the intercondylar fossa, forming a groove between the lateral and medial femoral condyles and their articular facets along the anterior side of the distal femur. The posterior surface of the patella articulates with the femur trochlea forming a slide joint. The patellar articular surface can be divided into the medial and lateral facet with the patellar ridge separating the two.

The articular surfaces of each bone are coated with cartilaginous tissue that serves as a shock absorber as well as a reducer of friction between the bones (Buckwalter et al., 1997). In addition, the outer edges of the medial and lateral parts of the
tibiofemoral joint are bordered by C-shaped fibrous connective tissue structures called the menisci. These provide additional shock absorption as well as depth in the tibial condyle sockets, thereby improving the stability of tibiofemoral motion (Renström et al., 1990).

Figure 1. Bony anatomy of human knee joint. A = femur, B = patella, C = tibia, D = fibula, E = patellofemoral joint, F = tibiofemoral joint. © Mikko Uimonen

Ligaments are fibrous connective tissue structures that connect bones to each other. Ligaments work as flexible cords allowing motion while simultaneously maintaining the connection between the bones. The knee joint is stabilized by a
sturdy fibrous capsule and several ligaments that ensure the correct posture of the joint. The joint capsule is a two-layer structure that surrounds the articulating structures of the joint. The outer layer consists of fibrous tissue with sensory and proprioceptive innervation (Kennedy et al., 1982; Ralphs et al., 1994). The inner layer excretes a viscous fluid, known as synovial fluid, inside the joint (Kennedy et al., 1982; Ralphs et al., 1994). The synovial fluid lubricates the cartilaginous surfaces decreasing the friction between surfaces (Ogston et al., 1953).

The lateral (LCL) and medial collateral (MCL) ligaments are the main ligaments that maintain the knee joint in the sagittal plane. The MCL is proximally attached to the medial femoral condyle and distally to the medial tibial condyle. In addition, the MCL is attached to the medial meniscus. The main function of the MCL is to resist the impact of valgising forces on the knee joint. The LCL, in turn, resists varising forces. Proximally, the LCL is inserted in the lateral femoral condyle and distally, the LCL is attached to the proximal tip of the fibula.

The main ligaments that maintain the knee in the coronal plane are the anterior (ACL) and posterior cruciate (PCL) ligaments. The cruciate ligaments derive their name from cruxiform arrangement in relation to each other. Proximally, the ACL is inserted in the medial wall of the posterior lateral femoral condyle. Distally, the ACL is inserted in the anterior part of the tibial intercondylar eminence. The PCL originates from the lateral edge of the medial femoral condyle. Distally, the PCL is inserted in the intercondylar section of the posterior proximal tibia below the articular surface. The ACL resists anterior movement of the proximal tibia in relation to the distal femur. The PCL, in turn, resists posterior tibial movement. In addition, the ACL has an important role in preventing internal rotation of the tibia.

Since the patella is articulated to the other bones only through the patellofemoral slide joint, it requires extensive stabilizing structures to prevent it from dislocating (Figure 2) (Earhart et al., 2013). In fact, patella is stabilized in its location by several ligament structures as well as the quadriceps femoris muscle. The medial and lateral patellofemoral and patellotibial ligaments (MPFL and LPFL) as well as the medial patellomeniscal ligament are the main ligaments stabilizing the patella in the lateral and medial directions (Hinckel et al., 2018). The medial and lateral patellofemoral ligaments attach the patella to the medial and lateral epicondyle of the femur, respectively. In a similar manner, the medial and lateral patellotibial ligaments attach the patella to the medial and lateral condyles of the tibia. In addition to the patellofemoral and patellotibial ligaments, the medial patellomeniscal ligament, which attaches the patella to the outer fibers of the medial meniscus provides the patella with additional medial stability.
Figure 2. Anterior view of the human knee joint. A = Vastus medialis muscle, B = Rectus femoris muscle, C = Vastus lateralis muscle, D = Medial collateral ligament, E = Lateral collateral ligament, F = Patella, G = Tibia, H = Fibula, I = Medial patellofemoral ligament, J = Lateral patellofemoral ligament, K = Medial patellotibial ligament, L = Lateral patellotibial ligament, N = Medial patellomeniscal ligament. © Mikko Uimonen
Proximally, stabilization is mainly provided by the quadriceps femoris muscle and its four parts, the rectus femoris, vastus lateralis, vastus intermedius and vastus medialis. The quadriceps muscle tendon is attached to the proximal edge of the patella. In addition, lateral fibers from the vastus lateralis muscle tendon are attached to the lateral proximal edge and medial fibers from the vastus medialis tendon to the medial proximal edge of the patella. Fibers branching from the quadriceps femoris tendon and traversing the knee joint from the medial and lateral sides of the patella with attachments to the sides of the patella, patellar ligament and proximal tibia form other layers stabilizing the medial and lateral sides of the patella. These fibrous layers are termed the medial and lateral retinaculum, respectively.

The patellar ligament attaches the inferior tip of the patella to the tibial tubercle. The patellar ligament is a strong, non-elastic ligament that mediates the forces on anterior tibia generated by the quadriceps femoris muscle. Thus, the patellar ligament may be considered an extension of the quadriceps femoris tendon. The quadriceps femoris muscle is the main muscle enabling knee extension. The structure in charge of extension movement of the knee joint, known as the extensor apparatus, consists of the quadriceps femoris muscle, femoral tendon, patella, and patellar ligament.

Flexion of the knee joint, in turn, is enabled by the collaboration of several muscles. Located in the posterior thigh, the hamstring muscles, comprising the biceps femoris, semitendinosus and semimembranosus muscles, are the main flexors of the knee joint. The biceps femoris muscle originates from the ischiatic tuberosity and is attached to the proximal fibula. The semimembranosus and the semitendinosus also originate from the ischiatic tuberosity. In comparison to the biceps femoris, these muscles are situated medially with the semitendinosus attaching to the pes anserinus, the cojoined tendons of three muscles of the thigh, which inserts onto the medial side of the proximal tibia, and the semimembranosus attaching inferoposteriorly to the medial tibial condyle. In addition to the hamstring muscles, the sartorius, gastrocnemius, plantaris, and popliteus muscles collaborate in the flexion of the knee joint. In addition, the slight internal rotation of the tibia, an essential motion which initiates the flexion movement after full extension of the knee joint, is caused by the popliteus muscle.
2.2 Biomechanics of patellar dislocation

During movement of the knee joint, the articular surface of the patella slides along the femoral trochlea. In knee flexion, the patella moves towards the distal end of the femur trochlea and in extension it moves towards the proximal trochlea. Alongside the femur trochlea, the trajectory of the patellar during knee movement is guided by the patellofemoral and patellotibial ligaments along with the quadriceps muscle (Hinckel et al., 2017; Hinckel et al., 2018; Hinckel et al., 2019; Panagiotopoulos et al., 2006).

In full knee extension, the patella lies slightly lateralized in relation to the trochlear groove (Kujala et al., 1989; O'Donnell et al., 2005). During the first 30 degrees of knee flexion, the patellar tracks medially. After 30 degrees of knee flexion, stabilizesarticular surface of the patella fully engages with the trochlear groove and the patellofemoral joint becomes congruent (Kujala et al., 1989). Thus, during the first 30 degrees of knee flexion the patellofemoral joint is vulnerable to maltracking and dislocating.

The structures stabilizing the patellofemoral joint can be divided into active, passive and static stabilizers (Balcarek et al., 2010; Earhart et al., 2013). The quadriceps femoris muscle is an active stabilizer of the patellofemoral joint. In addition to vertical stabilization, the oblique fibers of the vastus medialis and lateralis tendons actively guide the tracking of the patellar both laterally and medially. The passive stabilizers are the patellofemoral and patellotibial ligaments and the joint capsule. These structures do not actively modify the patellar tracking but rather provide boundaries within which the patella can move in relation to the femur trochlea at each point of the patellofemoral range of motion. In contrast, the trochlear groove and patellar ridge, which function as the static stabilizers, stabilize the patellofemoral tracking via direct contact with the patellofemoral articular surfaces. Thus, the stabilizing effect of the static stabilizers depends on the morphology of the trochlear at a certain point in the patellofemoral range of motion. (Earhart et al., 2013)

Lateral dislocation of the patella occurs when forces laterally directed on the patella exceed those directed medially. When the normal force center of the patella exceeds the lateral edge of the lateral condyle of the femur, the patella displaces onto the lateral side of the lateral femoral condyle. The usual mechanism of injury involves mild flexion of the knee joint with simultaneous valgus torsion and external tibial rotation which increase the lateral force on the patella (Crotty et al., 1998; Earhart et al., 2013; Kirsch et al., 1993; Spritzer et al., 1997). Contraction of the quadriceps
femoris muscle in this condition would further increase this force. During lateral dislocation of patella, the medial stabilizing structures, such as the MPFL, MPTL and medial retinaculum, are usually damaged, an event that may predispose to recurrence of the dislocation (Askenberger et al., 2016a; Felus et al., 2012; Sanders et al., 2001; Zheng et al., 2020).

### 2.3 Epidemiology of patellar dislocation

The reported incidence of patellar dislocation varies widely, ranging between 2.3 and 77 per 100 000 person-years (Fithian et al., 2004; Gravesen et al., 2018; Hsiao et al., 2010; Sanders et al., 2018; Sillanpää et al., 2008a; Waterman et al., 2012). The highest incidence was observed in a Finnish study by Sillanpää et al. (2008), who examined the incidence of patellar dislocation among male conscripts with a median age of 20 (Sillanpää et al., 2008a). The level of physical activity in this patient group may be higher than the general population mean and thus the incidence of patellar dislocation may be abnormally high. The peak incidence of patellar dislocation has consistently been reported to occur between ages 10 to 18 (Fithian et al., 2004; Gravesen et al., 2018; Sanders et al., 2018). Moreover, in adolescents, the incidence has been reported to be higher in females than males (Fithian et al., 2004; Gravesen et al., 2018). In a study comparing the incidence by age groups and sex, the peak incidence of 148 per 100 000 person-years was found to lie between ages 14-18, and was earlier in females than males (Sanders et al., 2018). Thereafter, the incidence declined rapidly to 54 and 18 per 100 000 person-years between ages 19-25 and 26-35 years in females and males, respectively (Sanders et al., 2018).

### 2.4 Risk factors for patellar dislocation

Patellar dislocation is a multifactorial phenomenon that is affected by several risk factors. These risk factors can be divided into anatomical, demographical and clinical factors and may, at least partially, overlap.

#### 2.4.1 Anatomical risk factors

The most studied and scientifically established risk factors of patellar dislocation are likely related to the anatomy of the knee joint. Anatomical risk factors for patellar
dislocation can be subsumed under three headings: patellar height, patellar lateralization, and trochlear configuration.

2.4.1.1 Patellar height

An abnormally high lying patella in relation to the femur trochlea, a condition known as patella alta (Figure 3), is one of the main anatomical risk factors for patellar dislocation (Arendt et al., 2018; Arendt et al., 2017; Dejour et al., 1994; Huntington et al., 2020; Lewallen et al., 2015; Parikh et al., 2018; Steensen et al., 2015). The risk derives from the increasing reduction in the patellofemoral contact surface as the location of the patella becomes higher (Diederichs et al., 2010; Simmons et al., 1992). This may impede the stability of the patella during the first 30 degrees of flexion of the knee joint. In addition, in patella alta, an even higher angle of flexion of the knee joint may be required for the patellofemoral joint to achieve congruence. Further, since the femoral trochlea is shallower in the superior parts, the stability provided by the trochlea is not as effective as in a knee in which the patella lies at normal height (Kujala et al., 1989; Yamada et al., 2007).

Figure 3. Normal riding patella (A) and patella alta (B). © Mikko Uimonen
2.4.1.2 Patellar lateralization

As stated above, the patella is already laterally sited when the knee is fully extended, and the patellofemoral joint does not reach congruence until flexion reaches 30 degrees (Kujala et al., 1989). The risk for dislocation owing to incongruence is pronounced if anatomical factors further increase patellar lateralization (Figure 4). The risk for patellar dislocation has been shown to be associated with patellar lateralization (Arendt et al., 2017; Dejour et al., 1994; Huntington et al., 2020; Kohlitz et al., 2013; Parikh et al., 2018; Steensen et al., 2015). A lateralized patellar location not only reflects the shortened distance from the normal patellar tracking to the lateral edge of the femur trochlea but also has broader implications. The location of the patellar during knee joint movement is determined by the sum of the forces on the patella. The location of the patellar in the mediolateral direction is the sum of the quadriceps femoris tendon alignment, tibial tubercle location, mediolateral ligament structures, and tibiofemoral valgus angle and torsion. The laterally situated tibial tubercle, externally rotated tibia and pronounced force of the vastus lateralis in relation to the vastus medialis increases the sum of the forces that push the patella in a lateral direction. Further, in severe valgus posture of the knee joint, so called knock-knee, the force vectors of the quadriceps muscle tendon and patellar ligament pull the patella in a lateral direction, predisposing the patellar to dislocation (Gillespie et al., 2015). It has been suggested that torsional malalignment of the tibiofemoral joint is associated with patellar instability (Cameron et al., 1996; Cooke et al., 1990; Steensen et al., 2015), although contradictory results have also been presented (Balcarek et al., 2019; Diederichs et al., 2013). The medial ligament structures, vastus medialis and lateral trochlear facet are the main resistors of the laterally directed forces on the patella. Thus, malalignment or damage in these structures may worsen the lateralization of the patella and hence increase the risk for dislocation.
2.4.1.3 Trochlear dysplasia

The main function of the trochlea is to guide the motion of the patellar during flexion and extension of the knee joint. The importance of the trochlear morphology in the risk for patellar dislocation has been repeatedly advocated (Arendt et al., 2018; Arendt et al., 2017; Askenberger et al., 2016b; Dejour et al., 1994; Kohlitz et al., 2013; Lewallen et al., 2015; Steensen et al., 2015; Yamada et al., 2007), and the risk is similar in both the pediatric and adult population (Askenberger et al., 2016b). The trochlear morphology has been shown to be the most accurate predictor of recurrence after primary patellar dislocation (Lewallen et al., 2015). The trochlear groove determines the tracking of the patellar in the congruent state of the patellofemoral joint. Since the groove is shallower in the superior part of trochlea (Kujala et al., 1989; Yamada et al., 2007), the support provided by the trochlea to the patella diminishes in knee extension, even when the anatomy of the knee is normal. In dysplastic trochlea, in which the trochlea may be convex and the trochlear groove is not properly developed due to hypoplasia or dysplasia of the medial and lateral condyles of the femur, trochlear support is further decreased (Yamada et al., 2007). In addition, the medial and lateral trochlear facets may be inadequately shaped or grown. A dysplastic trochlea allows the patella more freedom of movement in the mediolateral direction;
this in turn predisposes the patella to dislocation (Figure 5). In some patients, the presence of a bony spur at the cranial end of the trochlear articular surface may compromise the congruence of the patellofemoral joint at the beginning of knee joint flexion (Yamada et al., 2007). It has been reported that in patients with patellar instability, the trochlear groove may be located more medially than in control patients with no patellar instability (Hing et al., 2006).

![Figure 5. Axial cut magnetic resonance images of a normal trochlea (A) and dysplastic trochlea with flat trochlear groove (B). © Mikko Uimonen](image)

### 2.4.2 Demographic and clinical risk factors

In epidemiological studies, the incidence of patellar dislocations has been shown to be higher in females than males (Fithian et al., 2004; Gravesen et al., 2018). However, studies investigating the risk factors for recurrent dislocations have yielded inconsistent results on the association between sex and recurrence risk (Huntington et al., 2020). According to these studies, it seems that while patellar dislocation is more common in females, the risk of recurrent dislocations is very similar in both sexes (Huntington et al., 2020). Thus, after primary dislocation, sex did not influence dislocation risk in a selected sample of patients with a previous dislocation (Huntington et al., 2020).

The incidence of patellar dislocation has been found to peak between ages 10 and 18, thereafter declining with age (Fithian et al., 2004; Gravesen et al., 2018; Sanders et al., 2018). This finding suggests that adolescents and young adults may be at higher risk for patellar dislocation than older adults. Similarly, younger age has consistently
been found to be associated with higher risk for recurrent dislocations, with an odds ratio of 2.61 (95% confidence interval [CI] 1.90-3.57) (Huntington et al., 2020).

The association between age and dislocation risk might be at least partly explained by developmental and growth-related factors. Patients who still have open growth plates have been reported to have higher incidence for recurrent patellar dislocation than patients with closed growth plates (Arendt et al., 2018; Lewallen et al., 2015; Lewallen et al., 2013; Parikh et al., 2018), and an odds-ratio of 2.72 (95% CI 1.85-3.99) has been reported (Huntington et al., 2020). In a Swedish study of 9- to 15-year-old children and adolescents, joint laxity was shown to be at its highest in the youngest population and to decline with age (Jansson et al., 2004). Moreover, joint laxity was more prevalent in females, a factor that may contribute to the increased incidence of patellar dislocation in females than males (Jansson et al., 2004). However, laxity have not been found to associate with the risk for recurrent patellar dislocation (Huntington et al., 2020). This again may be due to selection bias, as among patients after primary dislocation, laxity may not be associated with recurrence.

The strongest predictor of patellar dislocation is likely to be a previous patellar dislocation (Fithian et al., 2004). Since in patients with previous patellar dislocations the prevalence of predisposing factors is inevitably higher than in the general population with no previous dislocations, the cumulative probability of patellar dislocation increases along with the severity of the patient’s predisposing factors. However, previous patellar dislocation itself may also be considered an independent risk factor for recurrence, as dislocation causes permanent injuries to the medial stabilizing structures of the patella, such as the MPFL, MPTL and medial retinaculum (Askenberger et al., 2016a; Elias et al., 2002; Felus et al., 2012; Sanders et al., 2001; Zheng et al., 2020). On the other hand, the presence or type and extent of an MPFL injury after primary patellar dislocation did not unambiguously predict recurrence risk (Huntington et al., 2020). This may indicate that medial stabilizing structures other than the MPFL also play an essential role in patellar stability.
2.5 Concomitant injuries in patellar dislocation

2.5.1 Injury to medial stabilizers and MPFL

In lateral patellar dislocation, the laterally directed forces exceed the strength of the medial stabilizing ligament and tendon structures, causing them to rupture and the patella to dislocate. It has been shown, using knee magnetic resonance imaging (MRI), that almost every patient has at least a partial MPFL rupture after patellar dislocation (Askenberger et al., 2016a; Felus et al., 2012; Sanders et al., 2001; Zheng et al., 2020). In addition, injuries to other medial structures, such as the medial retinaculum and vastus medialis tendon, are also present in the majority of patellar dislocation patients (Elias et al., 2002; Sanders et al., 2001). Hence, injury to medial supporting structures is a considerable risk factor for recurrent patellar dislocation.

Studies examining patterns of injury to the MPFL after patellar dislocation have shown that the MPFL was completely ruptured in approximately half of patients, and partially ruptured or stretched in the remainder (Askenberger et al., 2016a; Balcarek et al., 2010; Felus et al., 2012; Sanders et al., 2001; Zheng et al., 2015). The most common location of an MPFL injury, accounting for two-thirds of all cases, is the patellar insertion site of the ligament (Askenberger et al., 2016a; Felus et al., 2012). In most of these cases, patellar avulsion fractures may be detected (Felus et al., 2012). Multifocal MPFL injury, in which the injury may be detected in several diverse components of the MPFL, are also common, occurring in one-third of patients (Askenberger et al., 2016a; Felus et al., 2012).

The oblique fibers of the vastus medialis tendon, which causes medial upwards-directed pull towards the patella, are injured after patellar dislocation in approximately a half of cases (Elias et al., 2002; Seeley et al., 2012; Zhang et al., 2018). The majority of vastus medialis obliquus injuries are complete ruptures of the tendon (Zhang et al., 2018).

Complete and partial MPFL injuries as well as medial retinaculum injuries have been shown to be more common in males than females (Zheng et al., 2020). In addition, it has suggested that the MPFL injury pattern is associated with the bony anatomy of the knee joint (Balcarek et al., 2010). It has been shown that complete MPFL ruptures are associated with other concomitant injuries, such as chondral and osteochondral fractures and rupture or sprain of the vastus medialis obliquus, during patellar dislocation (Zhang et al., 2017; Zhang et al., 2018; Zheng et al., 2015).
2.5.2 Chondral and osteochondral injury

During patellar dislocation, when the patella moves laterally over the lateral femoral condyle, the prominent edges of the articular surfaces of the patellofemoral joint are subjected to high pressure. Further, in reduction, the lateral femoral condyle is subjected to high energy from the medial patellar facet. In both dislocation and reduction, the cartilaginous tissue covering the articular surfaces is predisposed to damage (Farr et al., 2012). Radiographic and arthroscopic studies have shown that in almost every patient after patellar dislocation, signs of injury may be detected in the articular cartilage or subchondral bone in the acute phase (Kirsch et al., 1993; Nietosvaara et al., 1994; Nomura et al., 2003b; Sallay et al., 1996; Virolainen et al., 1993). Such signs include, among others, fissures and striae in articular cartilage, contusion edema in subchondral bone, and chondral or osteochondral intra-articular loose fragments (Figure 6) (Adelani et al., 2008; Diederichs et al., 2010; Earhart et al., 2013; Elias et al., 2002; Guerrero et al., 2009; Kirsch et al., 1993; Nomura et al., 2004; Nomura et al., 2003b; Paakkala et al., 2010; Rillmann et al., 1999; Sanders et al., 2006; Spritzer et al., 1997; Virolainen et al., 1993; Zaidi et al., 2006). Typically, in accordance with the trauma mechanism, the injuries to articular surfaces are located in the patellar medial facet and lateral femoral condyle (Farr et al., 2012).

During recent decades, the use of MRI and arthroscopy have increased in popularity, improving the likelihood of detecting cartilaginous injuries after patellar dislocation. As a result, these injuries have been found to be more common than previously assumed (Farr et al., 2012). In MRI studies, subchondral bone contusion has been detected in up to 87-100% of patients after patellar dislocation (Sallay et al., 1996; Sanders et al., 2006). Further, using MRI, osteochondral fractures have been detected in 39-76% of patients (Kirsch et al., 1993; Nietosvaara et al., 1994; Virolainen et al., 1993). However, despite the high occurrence of cartilaginous lesions diagnosed using MRI, it has been shown that MRI detects only 32% of the cartilaginous lesions that are detected arthroscopically (Stanitski et al., 1998). This finding may reflect an even higher incidence of small chondral lesions after patellar dislocation. Indeed, in an arthroscopic study of 39 patellar dislocation patients, cartilaginous lesion was found in 95% of cases (Nomura et al., 2003b).

It has been proposed that the risk of articular surface lesions varies depending on patient demographics, anatomy and trauma energy (Farr et al., 2012). In a pediatric population, the incidence of osteochondral fractures was lower than in a patient population unrestricted by age (Kirsch et al., 1993; Nietosvaara et al., 1994; Virolainen et al., 1993). In addition, cartilaginous lesions have been found more often
in males than females, both in adolescents and in adults (Zheng et al., 2020). A study comparing the occurrence of cartilaginous lesions between patients with generalized joint laxity and patients with normal joints found that cartilaginous lesions occurred 2.5 times more often in patients with normal joints (Stanitski et al., 1998). Further, the finding of a lower incidence of osteochondral fractures after patellar dislocation in a pediatric compared to general population (Nietosvaara et al., 1994) may be at least partly explained by the aging-related decline in ligamentous laxity (Jansson et al., 2004).

Although osteochondral fractures are relatively common concomitant injuries after patellar dislocation, these injuries have not received conspicuous research attention. Previously, small case series have been published concerning on the characteristics of the injury (Nietosvaara et al., 1994; Seeley et al., 2013). In accordance with the hypothesized trauma mechanism, the studies by Seeley et al. and Nietosvaara et al. have shown that osteochondral fractures occur at the medial patellar edge or in the lateral femoral condyle (Nietosvaara et al., 1994; Seeley et al., 2013). Further, since previous studies have detected osteochondral fractures only in patients whose patella had relocated spontaneously after dislocation, it has been assumed that osteochondral fractures occur during spontaneous relocation rather than dislocation of the patella (Milgram, 1943; Nietosvaara et al., 1994; Rorabeck et al., 1976; Savarese et al., 1990; Scheller, 1974).

![Figure 6](image)

**Figure 6.** A) Chondral injury in the patellar lateral facet and the lateral trochlear facet shown as ragged articular cartilage. B) Osteochondral fragment next to the lateral femoral condyle. Contusion edema is shown by the intensified signal in the lateral femoral condyle. © Mikko Uimonen
2.5.3 Long-term manifestations and osteoarthritis

Numerous studies have shown that patellar dislocation predisposes to patellofemoral osteoarthritis in the long term (Franzone et al., 2012; Mäenpää et al., 1997c; Nomura et al., 2004; Nomura et al., 2005; Salonen et al., 2017; Sanders et al., 2017; Sillanpää et al., 2011; Vollnberg et al., 2012). The development of osteoarthritis has been observed independently of the occurrence of cartilaginous lesions in the primary phase. Cartilaginous degeneration has been observed in 22-96% patients, varying by the length of the follow-up period as well as by the criteria and methods of diagnosing degenerative lesions (Franzone et al., 2012; Nomura et al., 2004; Nomura et al., 2005; Salonen et al., 2017; Sillanpää et al., 2011; Vollnberg et al., 2012).

Nonetheless, chondral lesions with a diameter greater than 10mm have been found to cause redistribution of pressure towards the articular cartilage, increasing the burden around the lesion area (Guettler et al., 2004). This, in turn, may accelerate degeneration around the lesion areas. The presence of osteochondral fracture has been reported to be associated with an over 10-fold risk for patellofemoral osteoarthritis (hazard ratio 11.3, 95% CI, 5.0-26.6) (Sanders et al., 2017). In addition, trochlear dysplasia has also been found to predispose to patellofemoral osteoarthritis (hazard ratio 3.6, 95% CI 1.3-10.0) (Sanders et al., 2017).

Whether traumatic patellar dislocation with no recurrent dislocations or chronic patellar instability and recurrent dislocations presents a higher risk for osteoarthritis remains obscure (Franzone et al., 2012; Mäenpää et al., 1997c; Nomura et al., 2004; Nomura et al., 2005; Salonen et al., 2017; Sanders et al., 2017; Sillanpää et al., 2011). It has been shown over a 17- to 25-month follow-up that chondral degeneration is worse in patients after traumatic patellar dislocation than in patients with recurrent patellar dislocation (Nomura et al., 2005). The authors hypothesized that in recurrent dislocations, anatomical and other instability-related factors may allow the patella to dislocate with less impact on the articular cartilage. If so, the impact on the articular cartilage would be higher in traumatic patellar dislocations, causing more severe injury than in patients with recurrent dislocation. At an 8-year follow-up of patients with traumatic patellar dislocation but no anatomical malformations related to patellar instability, all the patients presented with recognizable chondral degeneration (Salonen et al., 2017). However, in the majority of cases, the degeneration was considered non-significant.

In studies comparing chondral degeneration between patients with traumatic and those with recurrent dislocation over the long term, degeneration has been found to be more severe in the recurrent dislocation patients (Franzone et al., 2012;
Mäenpää et al., 1997c). In a study by Sanders et al. (2017), who examined a total of 609 patients with a mean follow-up of 12 years, the hazard ratio for patellofemoral osteoarthritis was 7.8 (95% CI 3.9-17.6) in recurrent dislocation patients in relation to those with no recurrent dislocations (Sanders et al., 2017). Degeneration has found to be comparable in operatively and non-operatively treated patients (Franzone et al., 2012; Mäenpää et al., 1997c; Sanders et al., 2017; Sillanpää et al., 2011). However, although surgical techniques have advanced during the past few decades, studies on chondral degeneration in patients treated operatively using more recent techniques have not yet appeared.

2.6 Clinical and radiological examination

2.6.1 Clinical examination

Typically, patients may recall an unspecified twisting event of the knee along with a loud popping sound and the feeling of something breaking inside the knee joint, followed by rapid pain onset (Birk et al., 2001). After injury, the knee may collapse, and the patient be unable to place weight on the injured leg. In addition, the patient may recall a popping sensation caused by spontaneous reduction of the patella. After sustaining patellar dislocation, patients typically show up in the emergency care unit with a reduced patella, either spontaneously reduced or reduced by paramedics in the field. The dislocation and spontaneous reduction of the patella may occur so rapidly that the patient may not even be aware of it. Thus, it is not unusual for patients to be unable to tell if they have actually experienced a patellar dislocation, especially in first-time dislocations. If the patella has not yet been reduced, the reduction should be performed immediately, using sedatives if necessary. After reduction, the pain is usually instantly relieved.

Since patients’ trauma history is often unclear and they may recall the injury inaccurately, the clinical examination should be conducted carefully. Swelling and hematomas around the knee joint may be indicative of injury. Intra-articular effusion may be present, and, if so, is usually a sign of hemorrhage inside the joint. The most common cause of intra-articular hemorrhage in the pediatric population and the third most common cause after anterior cruciate ligament and meniscal ruptures in adults is patellar dislocation (Askenberger et al., 2014; Olsson et al., 2016). Increasing pressure inside the joint may worsen the pain, and thus aspiration of the
knee joint may be considered (Stefancin et al., 2007). Inspection of the aspirate may be suggestive of intra-articular fractures if droplets of fat are detected in the aspirated fluid (Stefancin et al., 2007). In addition, it has been proposed that a higher amount of intra-articular blood effusion after patellar dislocation is associated with more severe injury in the medial stabilizing structures or the occurrence of an osteochondral fracture (Mäenpää, 1998; Mäenpää et al., 1997a; Vainionpää et al., 1990). On the other hand, a lower intra-articular effusion might reflect a milder intra-articular trauma during patellar dislocation, possibly indicating the presence of anatomical risk factors and hence a higher risk of recurrent dislocation.

Palpation of the knee is essential to identify possible injury sites. In patellar dislocation, pain is typically located at the medial patellar edge and lateral edge of the lateral femoral condyle (Birk et al., 2001). In addition, the medial retinaculum and site of the insertion of the MPFL in the medial femoral epicondyle may be tender, suggesting rupture in these structures (Birk et al., 2001). It may be possible to palpate defects in the MPFL or medial retinaculum structures, although this may have limited diagnostic value (Stefancin et al., 2007).

Patellar motion should be assessed. In MPFL and medial retinacular injuries, the end point of lateral movement may be not be detected and, in severe injury with anatomical risk factors, the patella may be involuntarily dislocated during the examination (Stefancin et al., 2007). Crepitation of the patella may be suggestive of injury to the patellofemoral articular cartilage.

In the primary phase, the range of motion of the knee joint may be limited owing to pain in the motion extremities (Birk et al., 2001). Severe intra-articular effusion may also limit the range of motion (Stefancin et al., 2007). To rule out injuries in the collateral and cruciate ligaments, the stability of the knee joint should be tested. In addition, meniscal provocation tests may provide information on meniscal tears.

2.6.1.1 Clinical instability tests

Numerous clinical tests to identify patellar instability have been introduced. In their systematic review of clinical tests of patellar instability conducted, Smith et al. (2008) identified 18 tests (Smith et al., 2008a). Only five of these tests were evaluated for sensitivity and specificity, and the patient populations did not primarily consist of patellar instability patients but rather of patients suffering from anterior knee pain. Thus, the applicability and importance of the available tests for the clinical assessment of patellar instability remain unclear. However, they may have a role in constructing an overall picture of the problematics of patellar instability.
In the apprehension test (Sallay et al., 1996; Smith et al., 2008a), the patient lies supine with leg relaxed in slight flexion and the examiner pushes the patella laterally. The test result is positive if the patient involuntarily contracts the quadriceps muscle to prevent the patella from dislocating. Verbal expression of anxiety is also considered as a positive test result. The apprehension test reflects deficiency in the stabilizing structures of the patella.

Malalignment of the extensor mechanism may be clinically assessed using the J-sign and Q-angle tests (Smith et al., 2008a). In the J-sign test, the patient sits on the edge of the examination table with knees bent. The patient is then asked to extend the knees to full extension. Lateral patellar motion as the patella disengages from the trochlear groove when completing the knee extension is considered as a positive result: the higher the lateral deviation of the trochlear groove from the force vector between the quadriceps tendon and tibial tubercle lateral, the more prominent the lateral motion of the patella. Severe J-sign was associated with poorer functional outcomes, including residual instability, after surgical stabilization of the patella (Zhang et al., 2019).

The Q angle is the angle between the lines radiating from the center of the patella to the tibial tubercle and to the superior iliac spine measured with the patient supine on the examination table (Figure 7) (Kantaras et al., 2001; Smith et al., 2008a). The 0-degree angle represents the ideal alignment, as the force vector from the quadriceps muscle to the tibial tubercle via the patella is completely straight. Conversely, the larger the angle, the higher the laterally directed force vector during contraction of the quadriceps muscle. In an extensive valgus alignment of the knee joint, the Q angle is invariably greater if the medial stabilizing structures are intact.
Ligamentous laxity and hypermobility may have an effect on the severity of an articular cartilage injury and on the probability of osteochondral fracture after patellar dislocation as well as on the risk for recurrent dislocations (Nomura et al., 2006; Stanitski, 1995). In addition, generalized joint laxity has been shown to impair the outcome of surgical stabilization after patellar dislocation (Sacks et al., 2019). Laxity may be assessed by applying the criteria proposed by Beighton and Horan (Beighton et al., 1969; Sacks et al., 2019). These criteria include five mobility tests, of which four assess the mobility of upper and lower limbs bilaterally and one

Figure 7. Q angle of normal knee joint is close to 0° (A) whereas in valgus knee the Q angle is larger (B). © Mikko Uimonen
assesses the forward bending of the upper body. Each positive test for laxity adds 1 point to the overall score. A higher score indicates higher laxity. The total score varies from 0 to 9, and 4 points or higher is interpreted as indicating hypermobility (Beighton et al., 1969; Grahame et al., 2008; Sacks et al., 2019).

2.6.2 Radiological evaluation

Although, in clinical examinations, patients suffering from patellar dislocation present with several typical findings, the accuracy of these tests and clinicians’ diagnoses in emergency units has been found to be poor. It has repeatedly been shown that only 11-27% of patients with patellar dislocation are actually suspected of having patellar dislocation (Frobell et al., 2007; Kirsch et al., 1993; Quinn et al., 1993). Instead, they are usually thought to have meniscal or cruciate ligament injuries (Frobell et al., 2007; Kirsch et al., 1993). Thus, it is essential to refer patients with signs of severe knee injury for a radiographic examination.

2.6.2.1 X-ray

X-ray imaging is usually the first-line examination and should be performed in the primary phase in the emergency care unit (Sillanpää et al., 2012). In knee injury patients, the utility of X-ray imaging lies in the examination of bony injuries to the knee, such as fractures and dislocations. X-ray imaging of the knee joint in knee injuries includes the coronal and sagittal views of the knee joint as well as the Laurin projection, which is an axial view of the patellofemoral joint with the knee bent in 45 degrees of flexion (Figure 8) (Sillanpää et al., 2012). In cases of a solitary patellar dislocation, the X-ray of the knee joint is usually normal with no signs of bony injury. In patients with an osteochondral fracture or MPFL avulsion fracture, the fragment may be seen in the X-ray, if the fragment is ideally located (Duthon, 2015; Haas et al., 2012). However, the absence of loose fragments in the X-ray does not eliminate the possibility of a fracture. On the other hand, an X-ray may indicate severe intra-articular effusion.
Figure 8. Standard projections of a knee X-ray after patellar dislocation. A) Sagittal view, B) Coronal view and C) Laurin projection. In this patient, osteochondral fragments are detectable in the sagittal and coronal views. © Mikko Uimonen

2.6.2.2 Computed tomography

The increasing availability of computed tomography (CT) imaging in larger emergency care units has led to interest in the applicability of CT in the case of knee
injuries. Like the X-ray, the CT scan has its strengths in detecting bony injuries whereas in soft tissue lesions CT may not provide information that is sophisticated enough to guide treatment. However, CT has been shown to be accurate in locating intra-articular osteochondral fragments and the donor site after patellar dislocation (Peltola et al., 2011). The CT scan may be at its the most beneficial in the examination of severe knee injuries involving intra- and extra-articular fragmentation when planning surgical treatment.

2.6.2.3 Ultrasonography

Thus far, ultrasonography (US) has not become an established imaging modality in cases of patellar dislocation. However, a few studies have suggested that US has its uses in patellar dislocation diagnostics (Le Corroller et al., 2009; Zhang et al., 2015). The main advantage of US, according to its proponents, is its ability to detect MPFL and medial retinacular injuries (Le Corroller et al., 2009; Zhang et al., 2015). US has been found to be equal to MRI in sensitivity and specificity when assessing partial and complete MPFL injuries (Zhang et al., 2015). Interobserver agreement has also been found acceptable (Zhang et al., 2015). Further, unlike MRI, it is suggested that US is useful as it enables dynamic assessment of the MPFL. In dynamic assessment, the torn ends of the MPFL separate improving the examiner’s ability to detect MPFL rupture. However, US does not detect bony lesions and its usefulness in cartilaginous injuries has not been confirmed.

2.6.2.4 Magnetic resonance imaging

MRI may be considered the gold standard of the non-invasive diagnostics tools. MRI is superior to the other imaging modalities in cases of patellar dislocation as it enables accurate assessment of concomitant bony as well as soft tissue injuries after patellar dislocation (Figure 9) (Earhart et al., 2013). In addition, since clinical examination does not always lead to a correct diagnosis, MRI is typically able to confirm or reject an initial diagnosis of patellar dislocation (Frobell et al., 2007; Kirsch et al., 1993; Quinn et al., 1993; Saragaglia et al., 2020). Moreover, MRI is invaluable in the assessment of anatomical risk factors for patellar dislocation (Earhart et al., 2013). Thus, MRI has a crucial role in determining the treatment of patellar dislocation.

MRI is not usually a primary phase imaging modality as its availability in emergency departments in Finnish health care units is poor. In addition, a solitary
patellar dislocation rarely, if ever, requires immediate surgical treatment after patellar reduction. MRI is usually conducted within four weeks of acute trauma while in cases of more chronic patellar instability the interval may be longer. Referrals for MRI are administered in the orthopedic unit.

In patients with patellar dislocation, MRI reveals the typical characteristics of the injury. The most consistently observed sign of patellar dislocation, in almost all patients, is the so-called kissing contusion (Figure 9), the bruising of bone in the lateral femoral condyle, which is indicated by edema in the subchondral bone (Earhart et al., 2013; Elias et al., 2002; Kirsch et al., 1993; Paakkala et al., 2010; Spritzer et al., 1997; Virolainen et al., 1993; Zaidi et al., 2006). In addition, in approximately half of patients a similar sign may be observed in the subchondral bone of the medial part of the patella (Earhart et al., 2013; Elias et al., 2002; Kirsch et al., 1993; Spritzer et al., 1997). Kissing contusions during patellar dislocation are caused by high impact directed by the medial facet of the patellar on the lateral femoral condyle. This sign is visible in MRI even if no actual fracture has occurred.

An observable primary finding after patellar dislocation is joint effusion with intra-articular blood clots (Diederichs et al., 2010; Earhart et al., 2013; Schweitzer et al., 1992). In addition, MRI may show hemarthrosis with associated fat drops, which is suggestive of osteochondral injury (Earhart et al., 2013). Kissing contusions and effusion, however, soon disappear and are thus only observable immediately after dislocation (Diederichs et al., 2010; Earhart et al., 2013). A concave impression deformity in the medial patella has been found to be 100% specific to patellar dislocation and may be observed in 44% of patients (Elias et al., 2002).

Injuries to the medial stabilizing structure are another common sign of prior patellar dislocation that can be observed using MRIs. As well as femoral kissing contusions, injury to the medial stabilizers may be observed in almost every patient (Elias et al., 2002; Kirsch et al., 1993). Continuity of the MPFL may be inspected with MRI, although it may not be distinguishable from the other medial retinacular layers (Earhart et al., 2013). A wavy form or total disruption of medial retinacular fibers as well as the leakage of synovial fluid through the medial retinaculum indicate complete rupture of the medial stabilizers, whereas a partial tear is characterized by fiber irregularity, partial discontinuity, and edema around the medial retinaculum (Diederichs et al., 2010; Elias et al., 2004; Sillanpää et al., 2009). Furthermore, the region of the MPFL injury may be assessed using MRI (Guerrero et al., 2009; Seeley et al., 2012). The injury region has been shown to play a role in predicting future patellar instability (Sillanpää et al., 2009). Elevation of the vastus medialis obliquus tendon in the coronal or sagittal cut indicates at least a partial rupture or sprain of
the tendon (Elias et al., 2002; Seeley et al., 2012; Zhang et al., 2018). Edema and hemorrhage in the tendon or the surrounding tissues are also indicative of injury to this tendon (Elias et al., 2002; Seeley et al., 2012).

Cartilaginous lesions are common findings after patellar dislocation, occurring in 30-96% of patients (Ahmad et al., 2009; Elias et al., 2002; Guerrero et al., 2009; Nomura et al., 2004; Nomura et al., 2003b; Rillmann et al., 1999; Sanders et al., 2006). Assessment of chondral and osteochondral injuries may be performed using MRI, as it is comparable in accuracy to arthroscopic assessment, especially in detecting more severe lesions (Von Engelhardt et al., 2010). MRI allows possible loose fragments, either chondral or osteochondral, to be identified and their origin located (Adelani et al., 2008; Diederichs et al., 2010; Elias et al., 2002; Kirsch et al., 1993).

Figure 9. Axial cut magnetic resonance images. Image A shows an osteochondral fracture (white arrow) and intact MPFL. Image B shows MPFL rupture close to patella insertion (gray arrow) and signs of a kissing contusion in the femoral lateral condyle. Both images show intra-articular effusion in the knee. In B the effusion also extends outside the joint capsule. © Mikko Uimonen

2.6.2.5 Assessment of anatomical risk factors

The assessment of anatomical risk factors is crucial in planning the treatment approach after patellar dislocation. Since the patient’s knee joint anatomy may enable prediction of the risk for recurrent dislocation, anatomical characteristics should be considered when deciding on treatment (Arendt et al., 2018; Lewallen et al., 2013; Parikh et al., 2018). MRI is the preferred imaging modality for the anatomy of the knee joint, as it shows the cartilaginous surfaces, and hence a more accurate picture
of the morphology the patellofemoral joint. Anatomical parameters and abnormal value thresholds are presented in Table 1.

**Table 1.** Abnormal value thresholds for anatomical parameters suggested by the literature.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Abnormal value threshold</th>
<th>References</th>
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<tbody>
<tr>
<td><strong>Patellar height</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISI</td>
<td>&gt;1.30</td>
<td>Miller et al. (1996)</td>
</tr>
<tr>
<td>CDI</td>
<td>&gt;1.20</td>
<td>Dejour et al. (1994)</td>
</tr>
<tr>
<td>PTI</td>
<td>&lt;0.50</td>
<td>Barnett et al. (2009)</td>
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<tr>
<td></td>
<td></td>
<td>Biedert et al. (2006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Biedert et al. (2017)</td>
</tr>
<tr>
<td><strong>Patellar lateralization</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT-TG, mm</td>
<td>&gt;15.0</td>
<td>Arendt et al. (2017)</td>
</tr>
<tr>
<td>TT-PCL, mm</td>
<td>&gt;20.0</td>
<td>Daynes et al. (2016)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seitlinger et al. (2012)</td>
</tr>
<tr>
<td><strong>Trochlear morphology</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulcus angle (°)</td>
<td>&gt;145.0</td>
<td>Pfirrmann et al. (2000)</td>
</tr>
<tr>
<td>Lateral trochlear inclination angle (°)</td>
<td>&lt;11.0</td>
<td>Carrillon et al. (2000)</td>
</tr>
<tr>
<td>Trochlear depth, mm</td>
<td>&lt;3.0</td>
<td>Pfirrmann et al. (2000)</td>
</tr>
<tr>
<td>Trochlear facet asymmetry ratio</td>
<td>&lt;0.40</td>
<td>Pfirrmann et al. (2000)</td>
</tr>
<tr>
<td>Trochlear condyle asymmetry ratio</td>
<td>&gt;1.10</td>
<td>Pfirrmann et al. (2000)</td>
</tr>
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</table>

ISI = Insall-Salvati index, CDI = Caton-Deschamps index, PTI = Patellotrochlear index, TT-TG = Tibial tubercle-trochlear groove distance, TT-PCL = tibial tubercle-posterior cruciate ligament distance.

**Patella alta**

Several measurement techniques have been introduced to assess the vertical location of the patella in relation to the femur trochlea. The most commonly applied measurement techniques are probably the Insall-Salvati index (ISI) (Insall et al., 1971), the Caton-Deschamps index (CDI) (Caton et al., 1982) and the
patellotrechlear index (PTI) (Biedert et al., 2006) (Figure 10). These are all sagittal plane measurements from the cut in which the patellar diameter is the highest.

The ISI is the ratio of the length of the patellar ligament to the diameter of the patellar. ISI values over 1.3 have been regarded as indicating patella alta (Miller et al., 1996). Since the patellar ligament is a non-elastic structure, the ISI does not vary by the angle of flexion of the knee joint (Biedert et al., 2017). The ISI may also be measured from the sagittal X-ray (Biedert et al., 2017). The ISI has been criticized for its inability to take the location of the tibial tubercle into account (Mayer et al., 2012). In patients with a distally located tibial tubercle, the ISI may indicate patella alta even in cases where the patella is in the the ideal position.

The CDI is a ratio between the distance from the lowest boundary of the patellar cartilage to the superior anterior edge of the tibia and the vertical length of the patellar articular cartilage (Caton et al., 1982). The threshold value for abnormal CDI has been reported to be 1.20, with higher values indicating patella alta (Dejour et al., 1994). Compared to the ISI, the CDI is not dependent on the position of the tibial tubercle but instead on the tibial articular plate, which, given the variation in patient anatomy, may be considered a more stable reference point than the tibial tubercle (Mayer et al., 2012). In addition, as with the ISI, the CDI is also independent of the knee angle of flexion angle (Biedert et al., 2017; Caton et al., 2010; Dean et al., 2016). However, the size of the patellar articular surface may influence the CDI, as it may indicate patella alta in patients with a small patella.

The PTI is calculated by dividing the length of the contact of trochlear surface with the patella by the total length of the patellar articular surface (Biedert et al., 2006). PTI values exceeding 0.50 are considered as indicative of patella alta (Barnett et al., 2009; Biedert et al., 2006; Biedert et al., 2017). The PTI value represents the proportion of the patellar articular surface that is congruent with the trochlea. Thus, it may be the most useful measure of patellar height in relation to the trochlea. However, the PTI may be affected by the knee flexion angle during the measurement. Nonetheless, when conducted correctly, the PTI has been shown to be reliable (Ali et al., 2009; Barnett et al., 2009) and is thus the most preferred measure of patella alta (Ali et al., 2009; Barnett et al., 2009; Diederichs et al., 2010; Earhart et al., 2013; Weber et al., 2016).
Figure 10. The measurements of the vertical location of the patellar in the side view of the knee joint as follows: ISI = B / A; CDI = D / C; PTI = E / C. © Mikko Uimonen
The most commonly used measures of patellar lateralization are probably the transversal distance between the tibial tubercle and the trochlear groove (TT-TG) (Dickens et al., 2014) and the transversal distance between the tibial tubercle and the posterior cruciate ligament (TT-PCL) (Seitlinger et al., 2012). These measures are examined with MRI from the axial view (Figure 1).

The TT-TG is measured using two axial cuts, a cut which shows the point of attachment of the patellar ligament to the tibial tubercle and the first axial cut below the lowest patellar edge, showing the trochlear groove (Brady et al., 2018). The reference line is drawn according to the posterior boundaries of the femoral condyles in the trochlear cut. Perpendicular to the reference line, lines are drawn via the deepest point of the trochlear groove and via the center of the patellar ligament in the cut showing the site of attachment to the tibial tubercle. The distance between these two lines yields the TT-TG. TT-TG values above 15 millimeters are considered to be abnormal (Arendt et al., 2017).

The TT-PCL is measured using three axial cuts (Brady et al., 2018; Seitlinger et al., 2012). First, the reference line is drawn along the posterior edges of the tibial condyles in the cut just below the tibial articular facet. The most medial point of the PCL is assessed from the most distal cut showing the PCL. The site of attachment of the patellar ligament to the tibial tubercle is assessed as in the TT-TG. Lines perpendicular to the reference line are drawn via the medial bound of the PCL and via site of attachment of the patellar ligament. The TT-PCL is the distance between these two lines. The abnormal value threshold of the TT-PCL has been shown to be 20 millimeters, higher values being regarded as abnormal (Daynes et al., 2016; Seitlinger et al., 2012).

Comparison of the TT-TG and the TT-PCL in their relative usefulness and predictability of the recurrence of dislocations has favored the TT-TG (Brady et al., 2017; Camp et al., 2016; Daynes et al., 2016; Heidenreich et al., 2017). However, the TT-TG has been criticized for its inability to distinguish between knees with patellar instability and those with no instability (Caplan et al., 2014). Since measuring patellar lateralization statically does not capture the whole picture of dynamic patellar movement during knee flexion, a single patellar lateralization measure may not be sufficient (Carlson et al., 2017). Combining of TT-TG and TT-PCL has been proposed to achieve a fuller understanding of the patellar tracking (Daynes et al., 2016; Heidenreich et al., 2017). It has been shown that knee joint flexion due to slight rotation of the femur in relation to the tibia in the early phase of knee flexion
induces variance in the TT-TG values (Marquez-Lara et al., 2017). In addition, the TT-TG has been shown to represent tibial torsion rather than lateralization of the tibial tubercle (Tensho et al., 2015). The TT-PCL in turn is not affected by this rotation as all the measurement points are in the tibia. The TT-PCL thus yields a pure representation of the lateralization of the tibial tubercle. Recently, to adjust the variability of the TT-TG and the TT-PCL caused by the size of the knee joint, ratios that between these measures and the width of the trochlea or patella have been introduced (Camp et al., 2016). These ratios have been found to be more accurate in predicting patellar instability than the TT-TG or TT-PCL alone (Camp et al., 2016). On the other hand, the TT-TG has been shown to be associated with patient age and femur size (Pennock et al., 2014), although the opposite results have also been reported (Balcarek et al., 2011).

Patellar lateralization is also related to the mechanical angle of the knee joint, as excessive valgus deformity transfers the force vector directed to the patella laterally (Gillespie et al., 2015). In addition, torsional malalignment of the knee joint may cause lateralization of the patellar tracking (Cameron et al., 1996; Cooke et al., 1990; Steensen et al., 2015), although torsional malalignment has not been unambiguously associated with instability (Balcarek et al., 2019; Diederichs et al., 2013). When planning surgical stabilization of the patella, assessment of the biomechanical basis of patellar lateralization is essential to provide the most appropriate treatment technique. The mechanical angle may be assessed using X-ray imaging of the lower limb. Torsional malalignment, in turn, may be assessed with MRI of the lower limb.
Figure 11. Upper image shows the measurement of the tibial tubercle-trochlear groove (TT-TG) distance and the lower image shows the measurement of the tibial tubercle-posterior cruciate ligament (TT-PCL) distance. © Mikko Uimonen

**Trochlear morphology**

When compared to patellar height and lateralization, addressing the trochlear morphology is more complicated owing to the complexity of its three-dimensional form. The depth of the trochlear groove, the angle between the trochlear facets, proportional sizes of the medial and lateral condyles and trochlear facets, and the inclination angle of the lateral facet may all be assessed using MRI.

Traditionally, trochlear dysplasia patterns have been classified according to Dejour et al. (Balcarek et al., 2010; Dejour et al., 1994) (Figure 12). The Dejour classification is a four-class system from A to D. Type A dysplasia is characterized by an enwidened sulcus angle (over 145 degrees). In type B, the trochlea is even
flatter, with a bony spur, known as the supratrochlear spur, on the superior part of the trochlea. The criteria for type C trochlear dysplasia are medial trochlear hypoplasia and lateral convexity of the lateral facet. Type D is characterized by a flattened trochlea, severe trochlear asymmetry and a supratrochlear spur. In type D dysplasia, the supratrochlear spur forms a convex cliff which separates the medial and lateral trochlear facets. Types B and D are considered as severe dysplasia. However, since the Dejour classification is based on a visual assessment of the trochlear anatomy, it involves a certain amount of subjectivity, which hampers the reliability of the assessment. To remedy this flaw, parametric methods for evaluating the trochlear anatomy have been introduced (Arendt et al., 2017; Yamada et al., 2007).

Figure 12. The Dejour classification for trochlear dysplasia. Class A is characterized by a shallow trochlea. In class B, the trochlea is flat with a supratrochlear spur. In class C dysplasia, the medial condyle is hypoplastic. Class D is characterized by a flat trochlea with severe trochlear asymmetry and a supratrochlear spur. The supratrochlear spur is illustrated in the figure as the medial part of the articular cartilage of the class D dysplastic trochlea. © Mikko Uimonen
Examination of the trochlear morphology is conducted at the first axial cut below the inferior edge of the patella (Figure 13) (Carrillon et al., 2000; Charles et al., 2013; Pfirrmann et al., 2000). The reference line is drawn according to the posterior bounds of the femoral condyles. Trochlear condyle asymmetry is calculated by dividing the perpendicular distance from the reference line to the most anterior tip of the lateral trochlear facet by the corresponding distance to the most anterior tip of the medial trochlear facet. Trochlear depth may be calculated by subtracting the distance to the deepest point of the trochlear groove from the mean distance to the highest tips of the lateral and medial facet. The sulcus angle is the angle drawn between the lateral and medial trochlear facet, and trochlear facet asymmetry may be calculated as the ratio between the lengths of the medial and lateral facets. The lateral trochlear inclination angle is the angle between the line drawn according the lateral facet and the reference line. (Arendt et al., 2017; Yamada et al., 2007) The following abnormal values of trochlear morphology measurements have been reported: sulcus angle over 145 degrees (Pfirrmann et al., 2000), lateral trochlear inclination angle less than 11 degrees (Carrillon et al., 2000), trochlear depth less than 3.0 millimeters (Pfirrmann et al., 2000), trochlear facet asymmetry ratio less than 0.4 (Pfirrmann et al., 2000) and trochlear condyle asymmetry over 1.1 (Pfirrmann et al., 2000).

Due to the complexity of the trochlear morphology, it might be impossible to predict instability by measuring only one parameter. Trochlear dysplasia is a multiform problem which may manifest in several different ways. Due to dysplasia, the congruence of the patellofemoral joint may be endangered, at least in some parts of the patellofemoral range of motion if not entirely. Thus, although parametric evaluation of the trochlear anatomy has increased in popularity, typifying the trochlear anatomy according to the Dejour classification may still have utility in assessment of the trochlea.
Figure 13. Trochlear configuration measurements as follows: trochlear depth = \([(A + C) / 2] - B\); trochlear facet asymmetry ratio = \(D / E\); trochlear condyle asymmetry ratio = \(C / A\); sulcus angle = \(F\); lateral trochlear inclination angle = \(G\). © Mikko Uimonen

2.7 Treatment of patellar dislocation

Thus far, the majority of patients with primary patellar dislocation have been treated non-surgically, although contradictory approaches have been proposed (Mehta et al., 2007; Sillanpää et al., 2012). If a radiological examination reveals a large osteochondral fragment, surgery may be indicated in the acute phase, although the occurrence of an osteochondral fracture is not a definitive indication of surgery (Mehta et al., 2007). Patients with small osteochondral fragments may be treated non-surgically. In addition, in rare cases with severe patellofemoral malformation presenting a clear pattern of risk factors for recurrent dislocation, surgical stabilizing may be chosen in the primary phase. Surgical treatment is usually offered to patients
with recurrent dislocations if severe symptoms, pain and loss of functionality continue (Stefancin et al., 2007).

Although the treatment of patellar dislocation has attracted enormous research interest, manifested in the large number of studies and meta-analyses during recent decades, consensus has not yet been reached on the optimal treatment approach. During the 2010s, at least 16 meta-analyses comparing surgical and non-surgical management of patellar dislocation were published (Cheng et al., 2014; Erickson et al., 2015; Fuller et al., 2018; Hing et al., 2011; Lee et al., 2018a; Longo et al., 2017; Migliorini et al., 2020b; Nwachukwu et al., 2016; Pagliazzi et al., 2019; Saccomanno et al., 2016; Smith et al., 2015b; Smith et al., 2011; Wang et al., 2016; Xing et al., 2020; Yang et al., 2019a; Zheng et al., 2014). All but two of these concluded that, as measured by the mean rate of recurrent dislocations after initial treatment, surgical management is superior (Fuller et al., 2018; Xing et al., 2020). Functional outcomes, in turn, have shown no such obvious trend. Six of the meta-analyses reported functional outcomes favoring surgical treatment (Longo et al., 2017; Migliorini et al., 2020b; Nwachukwu et al., 2016; Pagliazzi et al., 2019; Smith et al., 2015b; Yang et al., 2019a), although in two of these, the difference between surgically and non-surgically managed patients leveled out during the long-term follow-up (Longo et al., 2017; Pagliazzi et al., 2019). A further six meta-analyses concluded that functional outcomes did not differ by management approach (Cheng et al., 2014; Erickson et al., 2015; Fuller et al., 2018; Hing et al., 2011; Wang et al., 2016; Zheng et al., 2014). In one meta-analysis, non-surgical treatment was shown to yield a better functional outcome (Xing et al., 2020). On the other hand, compared to non-surgical treatment, surgical treatment was linked to a higher risk of patellofemoral osteoarthritis during a long-term follow-up (Erickson et al., 2015; Smith et al., 2011). The meta-analyses showed a high rate of overlap and many of the studies included in them were reported to be of low quality. Hence, in addition to yielding at least partly conflicting results, the quality of the evidence produced in many studies is low. Furthermore, with the rapid increase in research on the treatment of patellar dislocation during recent decades, new treatment techniques and practices have been developed. Consequently, the highly heterogeneous treatment techniques described in the existing randomized studies on the treatment of patellar dislocation do not represent the latest knowledge (Apostolovic et al., 2011; Ji et al., 2017; Moiz et al., 2018; Mostrom et al., 2014; Palmu et al., 2008; Petri et al., 2013; Regalado et al., 2016; Sillanpää et al., 2009a). Finally, as patients with patellar dislocation vary widely anatomically, applying the same surgical technique to all may not provide an adequate picture of the efficacy of surgical treatment.
Nowadays, many surgical techniques are available that address patients’ individual clinical and anatomical characteristics. It seems that if a surgical approach is chosen, the operation should be planned based on the characteristics of the individual patient rather than by applying a one-fits-all method.

### 2.7.1 Non-surgical treatment

Thus far, no recommended non-surgical management regimens have been established for patellar dislocation patients (Dixit et al., 2017; Moiz et al., 2018; Smith et al., 2010), although several diverse methods and combinations of these have been introduced and applied in clinical practice. However, since different non-surgical approaches have not been compared in a randomized design, knowledge on the most effective non-surgical treatment is yet to be determined. Previous research has not been able to reliably show the actual effect of non-surgical treatment in relation to patients’ natural history and recovery (Dixit et al., 2017; Moiz et al., 2018; Smith et al., 2010). Current non-surgical treatment regimens are largely based on expert opinion rather than research (Dixit et al., 2017).

Previously, in clinical practice, primary phase treatment often involved bracing to immobilize the knee at least to some degree. In studies comparing immediate mobilization, with or without a light knee brace, to 6 weeks immobilization with a cast have shown that complete immobilization for a long period reduces recurrent dislocations (Mäenpää et al., 1997b). It has been hypothesized that immobilization enables medial structures to heal more comprehensively (Mehta et al., 2007). However, knee stiffness and limited motion range, which are a cost of this benefit have been shown to bother patients for up to 13 years afterwards (Mäenpää et al., 1997b). Moreover, it is unknown if the reduction in recurrent dislocations is truly related to the decreased functionality of the knee. Conflicting results, proposing that the duration of immobilization or bracing has no marked influence on the risk of recurrent patellar dislocation, have also been presented (Kaewkongnok et al., 2018). Currently, the immobilization regimen most likely applied involves a knee brace or patellar stabilization brace that allows free motion of the knee joint and hence gradual mobilization. Bracing is usually used during the first 3 to 6 weeks after patellar dislocation (Dixit et al., 2017; Moiz et al., 2018; Smith et al., 2010).

The cornerstone of the non-surgical management of patellar dislocation is early physiotherapeutic treatment and muscle strength exercises aimed at muscular stabilization of the patella (Dixit et al., 2017; Moiz et al., 2018; Smith et al., 2010).
The main muscles involved are the quadriceps femoris, especially vastus medialis, and gluteal muscles (Dixit et al., 2017). The quadriceps is the main extensor of the knee joint and during the contraction, the patella is pulled towards the femoral trochlea more firmly, presumably to improve patellar stability. In addition, the obliquus fibers of the vastus medialis attached to the medial upper edge of the patella pull the patella in a medial direction, thereby enhancing the medial supportive forces and restricting lateral patellar movement. However, general quadriceps femoris training has been found to be more effective than training directed at the vastus medialis muscle (Smith et al., 2015a). In addition, closed kinetic chain exercises of the quadriceps femoris muscle have been found to be more effective than open kinetic chain exercises (Stensdotter et al., 2003). However, although the gluteal muscles do not have a direct effect on the patella, weakness in these muscles may predispose to internal hip rotation and valgus torsion in mild knee flexion, further predisposing the patella to dislocate. The assumption behind gluteal muscle training is that strengthening the gluteal muscles increases the external rotation of the femur and thus improves knee joint posture, in turn further improving patellar stability (Colvin et al., 2008).

After non-surgical management, a relatively high proportion of patients sustain recurrent dislocation, reported re-dislocation rates varying between 27-33% (Magnussen et al., 2017; Moiz et al., 2018; Smith et al., 2010). Functional outcomes assessed by patient-reports have been good (Moiz et al., 2018; Smith et al., 2010). However, when compared to an age-matched population, patients’ self-report scores have been lower even after successful non-surgical treatment of patellar dislocation with no recurrent dislocations (Magnussen et al., 2017; Moiz et al., 2018). While it has been shown that lower age is related to higher re-dislocation risk (Huntington et al., 2020), comparisons of results between adult and pediatric populations suggest that pediatric patients may achieve superior functional outcomes as measured on the Tegner scale (Buchner et al., 2005; Nikku et al., 1997; Palmu et al., 2008). Further, in studies comparing outcomes in patients differing in the location of their MPFL injury, those with an MPFL injury close to the femoral insertion site had a poorer subjective functional outcome as well as a higher recurrent dislocation rate after non-surgical treatment than those with an MPFL injury close to the patellar insertion site (Kang et al., 2013; Sillanpää et al., 2009b). It has been hypothesized that this finding is related to the improved healing capacity of the MPFL owing to the intersection of its ligamentous fibers with fibers of the vastus medialis obliquus muscle at the patellar insertion site as well as the larger area of insertion of the MPFL in the patellar than in femur (Kang et al., 2013).
Reliable data on the efficacy of the different non-operative interventions in relation to recurrent dislocations and functionality have not thus far been presented. Since studies on the non-surgical treatment of patellar dislocation are characterized by widely varying treatment protocols, including treatment duration and intensity and the interventions used, such as immobilization, bracing etc., conclusions on the efficacy of this type of treatment cannot be drawn (Dixit et al., 2017; Mehta et al., 2007; Moiz et al., 2018; Smith et al., 2010). Further, outcome measures have also been heterogeneous, further hampering the comparability of studies. As previously stated, and as evidenced by the number of meta-analyses published on the issue, non-surgical treatment has been compared to surgical treatment numerous times (Cheng et al., 2014; Erickson et al., 2015; Fuller et al., 2018; Hing et al., 2011; Longo et al., 2017; Migliorini et al., 2020b; Nwachukwu et al., 2016; Pagliazzi et al., 2019; Saccomanno et al., 2016; Smith et al., 2015b; Smith et al., 2011; Wang et al., 2016; Xing et al., 2020; Yang et al., 2019a; Zheng et al., 2014). Notwithstanding, these studies present a diversity of non-surgical approaches and may thus not provide a complete picture of the effectiveness of non-surgical versus surgical treatment in cases of patellar dislocation. Moreover, the efficacy of non-surgical treatment has not been compared to natural healing and recovery after patellar dislocation. Lastly, no eligible evidence on the differences between different non-surgical treatment interventions has been presented (Moiz et al., 2018). It remains obscure whether the efficacy of non-surgical treatment is related to the type or dosage of treatment or to the possible non-compliance of patients.

2.7.2  Surgical treatment

2.7.2.1  Evolution of patellar dislocation surgery

In the 20th century, surgery for patellar dislocation underwent radical change as a result of increasing research and new techniques involving anatomical modification of the patellofemoral joint. The initiation of modern patellar stabilizing surgery can be traced to the late 19th century, when, in 1888, the Swiss orthopedist Roux introduced a new technique for stabilizing the patella in which medial support of the patella was enhanced by medial transfer of the lateral part of the patellar tendon (Arendt et al., 2013; Goldthwait, 1896; Hauser, 1938; Roux, 1887). The technique was soon modified by Goldthwait, an American orthopedist, after which it became widely known as the Roux-Goldthwait procedure (Arendt et al., 2013). In 1922,
Galeazzi et al. published a technique involving reconstruction of the medial patellotibial ligament using a semitendinosus muscle tendon graft (Galeazzi, 1922). Later, in 1938, Hauser and his colleagues introduced a procedure involving the medial and distal transfer of the tibial tubercle along with lateral retinaculum release and imbrication of the vastus medialis tendon (Arendt et al., 2013; Hauser, 1938). In the Hauser procedure, the tibial tubercle was locked into its new location by a so-called bony clasp. In 1964, Trillat published an alternative to the Hauser technique of medial transfer of the tibial tubercle in which the proximal tibial tubercle was transferred medially with nail fixation (Arendt et al., 2013; Trillat et al., 1964). The distal part of the tibial tubercle was left intact to act as a hinge. As the procedure was originally developed, although not published, by Elmslie, it was termed the Elmslie-Trillat procedure (Arendt et al., 2013).

While the techniques developed by Roux and Goldthwait, Galeazzi, Hauser, and Elmslie and Trillat were probably the most applied procedures in patellar dislocation surgery across the 20th century, remodeling of the femur trochlea was also introduced in the early 20th century, when Albee et al. (1915) introduced trochleoplasty, which involved elevation of the lateral trochlear facet (Albee, 1915). However, trochleoplasty remained a relatively rare treatment until, with improved radiologic technologies, increased interest began to be shown in trochlear morphology. Following the large-scale morphological studies by Brattström et al, Malghem, and Dejour and Walch during the 1960s to 1980s, trochleoplasty techniques underwent rapid development (Brattström, 1964; Dejour et al., 1990; Malghem et al., 1989). During the 1970s and 1980s, Masse et al. developed new trochleoplasty technique involving deepening of the trochlear sulcus that was subsequently modified by Dejour et al. (Amis et al., 2008; Dejour et al., 1990; Masse, 1978; Von Knoch et al., 2006).

Techniques for MPFL reconstruction were introduced in the 1990s, first by Gomez et al., who used a synthetic polyester graft (Gomes, 1992) and by Avikainen et al., who used an adductor magnus tendon graft (Avikainen et al., 1993). As several studies showed good outcomes after MPLF reconstruction, it has since become the most studied and recommended surgical treatment for patellar dislocation (Buchner et al., 2005; Camanho et al., 2009; Christiansen et al., 2008b; Nomura et al., 2000; Nomura et al., 2003a).

In addition to MPFL reconstruction, femoral osteotomies for correcting excessive valgus posture of the knee joint as well as torsional malalignments have also been introduced during recent decades (Cameron et al., 1996; Dickschas et al., 2012; Marti et al., 2000; Puddu et al., 2000). These procedures have provided an
alternative to osteotomies of the tibial tubercle in patients with lateralized tracking of the extensor mechanism due to axial malalignment of the knee (Cameron et al., 1996; Dickschas et al., 2012; Marti et al., 2000; Puddu et al., 2000).

Towards the end of the 20th century, with the development of arthroscopic technology, mini-invasive interventions have rapidly increased in popularity (Dainer et al., 1988). Arthroscopy was originally mainly used in debridement procedures and capsular releases, but has since also been applied in reconstructive procedures, such as repair of the medial retinaculum and MPFL, and in the reimplantation of osteochondral loose fragments (Askenberger et al., 2018; Dainer et al., 1988; Dandy et al., 1994; Khemka et al., 2016; Lee et al., 2013; Mariani et al., 2011; Schöttle et al., 2006; Shtarker et al., 2018; Sillanpää et al., 2008c).

To summarize, the last few decades have shown an acceleration in research interest and in the application of various surgical stabilizing techniques in cases of patellar dislocation. Procedures such as femoral or tibial osteotomies, trochleoplasty, tibial tubercle transfer and MPFL reconstruction have been widely disseminated, whether as wholly new techniques or as improvements in older ones (Avikainen et al., 1993; Cameron et al., 1996; Dejour et al., 1990; Dickschas et al., 2012; Longo et al., 2016; Marti et al., 2000; Masse, 1978; Puddu et al., 2000; Servien et al., 2007).

### 2.7.2.2 Surgical patellar stabilization techniques

**MPFL reconstruction**

The rationale for MPFL reconstruction is to repair the injured medial stabilizing structures (Nomura et al., 2003a). Nowadays, the consensus is that MPFL reconstruction is an acceptable surgical approach in practically every patient referred for surgical treatment of patellar dislocation. Several MPFL reconstruction techniques have been introduced, although the basis of the procedure remains largely the same. Currently, tendon autografts are the most commonly used grafts in MPFL reconstruction, as synthetic grafts have not been found to have any advantages over these autografts (Nha et al., 2019; Nomura et al., 2000). Typically, gracilis, semitendinosus, or adductor magnus muscle tendons are used due to their easy accessibility (Christiansen et al., 2008a; Deie et al., 2005; Han et al., 2011; Monllau et al., 2017; Schöttle et al., 2005a; Toritsuka et al., 2011; Wagner et al., 2013). Other autografts have also been reported (Bitar et al., 2012; Fink et al., 2014; Muccioli et al., 2020).
The strength of the attachment of the graft to the patella as well as to the femur has a crucial role in determining the success of the reconstruction procedure. Several patellar fixation techniques have been proposed, varying from double and single patellar tunnel techniques to suture anchor and interference screw techniques (Figure 14) (Anbari et al., 2008; Christiansen et al., 2008a; Han et al., 2011; Panni et al., 2011; Ronga et al., 2009; Russ et al., 2015; Schöttle et al., 2005a; Schöttle et al., 2009; Schöttle et al., 2010; Song et al., 2014b; Steiner et al., 2006; Toritsuka et al., 2011). In the classical double tunnel approach, the graft is threaded through two tunnels drilled obliquely through the patella from the medial facet to the anterior or lateral side of the patella, forming a loop as the graft passes through one tunnel and emerges from the other (Christiansen et al., 2008a; Ercan et al., 2020; Panni et al., 2011). In the single tunnel method, the graft is threaded through just one tunnel from the medial to the lateral side of the patella with the other end of the graft returning medially along the anterior patellar facet (Ercan et al., 2020). To avoid or decrease the risk of patellar fracture involved in the drilling of tunnels in the patella, alternative fixation methods have been developed (Christiansen et al., 2008a; Hapa et al., 2012; Mikashima et al., 2006; Panni et al., 2011; Schiphouwer et al., 2017; Shah et al., 2012). The graft may be attached to the medial patella using either suture anchors or interference screws, or by transosseous sutures. A suture anchor is screwed to the edge of the medial patellar and the graft attached to the anchor by integrated sutures (Heo et al., 2019; Kang et al., 2019; Song et al., 2014b; Yoon et al., 2020). In interference screw fixation, the graft end is threaded into a drilled screw socket after which the interference screw is screwed into the socket, fixing the graft to the hole (Russ et al., 2015). Transosseous suture fixation is conducted by drilling two K-wire tunnels transversally from the medial to lateral edge of the patella. Suture loops are threaded along the tunnels to the medial side and the graft is passed through the loops. The lateral ends of the suture loops are tied at the lateral side of the patella, pulling the graft against the medial patellar edge (Lenschow et al., 2013). Fixation in the medial epicondyle of the femur is usually done with interference screws or suture anchors (Migliorini et al., 2020a; Sanchis-Alfonso et al., 2017). Concern has been expressed about the durability of the newer fixation methods that do not involve tunneling. However, the outcomes of these methods have been comparable or even superior to the tunneling techniques; while the redislocation rate has been similar irrespective of the fixation technique, functional outcomes and complication rates have been more favorable with these newer techniques (Heo et al., 2019; Kang et al., 2019; Yoon et al., 2020).

MPFL reconstruction has proven effective in improving functional outcomes as well as health-related quality of life and redislocation rates in patients with recurrent patellar dislocation (Fisher et al., 2010; Smith et al., 2007; Stupay et al., 2015). In addition, MPFL reconstruction has been shown to improve articular cartilage status and degeneration outcomes (Kita et al., 2014; Nomura et al., 2007). Further, outcomes reported in studies have improved over time, suggesting advances in knowledge and surgical techniques (Stupay et al., 2015). The influence of patient anatomy on the outcomes of MPFL reconstruction has received research interest recently, although the findings have been inconsistent. Patella alta and increased
patellar lateralization have been associated with worse outcomes in some studies (Kita et al., 2015; Sappey-Marinier et al., 2019; Valkering et al., 2017; Wagner et al., 2013) while others have found no such association (Bartsch et al., 2018; Kita et al., 2015; Matsushita et al., 2013; Valkering et al., 2017; Wagner et al., 2013). Severe trochlear dysplasia has been proposed to predict worse outcomes after isolated MPFL reconstruction (Kita et al., 2015), while ligamentous laxity has not been found to consistently predict residual instability after MPFL reconstruction (Hiemstra et al., 2019a; Howells et al., 2012). In addition, investigation of the influence on outcomes of the site of femoral insertion of the MPFL graft have yielded inconsistent results, some studies indicating worse clinical outcomes with a non-anatomic location (Hopper et al., 2014; Larson et al., 2014; Tscholl et al., 2018) and others no influence on outcomes (Hiemstra et al., 2019a; Servien et al., 2011).

**Other ligament and retinacular procedures**

Along with MPFL reconstruction, MPFL repair techniques have also been introduced during recent decades (Davis et al., 2002; Garth Jr et al., 2000; Sallay et al., 1996). However, repair has not achieved results that would have led to large-scale use of the technique. A high redislocation rate has been reported after MPFL repair, especially in MPFL injuries located close to the site of femoral insertion (Arendt et al., 2011; Camp et al., 2010). When compared to conservative treatment, MPFL repair has not been found to provide any additional benefits with respect to the redislocation rate or functional outcomes (Christiansen et al., 2008b). However, some authors have suggested comparable outcomes of repair with MPFL reconstruction if patients are carefully selected and additional anatomical risk factors for recurrent dislocations have been addressed and, if needed, treated (Camp et al., 2010; Dragoo et al., 2017). In one study of 23 patients, MPFL repair was found to be superior to MPFL reconstruction with regard to functional outcomes, while no recurrent dislocations were observed in either the repair or reconstruction groups in a follow-up of at least 2 years (Tompkins et al., 2014). However, since evidence for the wider use of MPFL repair remains scarce, it has not been adopted in everyday practice.

In addition to MPFL repair, repair of the medial retinaculum by suturing has also been used to re-stabilize the patella. However, in studies comparing the outcomes of medial retinaculum repair and conservative treatment after primary patellar dislocation, have not found substantial benefits favoring retinacular repair in either redislocation rates or functional outcomes (Apostolovic et al., 2011; Palmu et al.,
On the other hand, comprehensive remodification of the medial retinaculum, i.e., medial retinaculumplasty, has been proposed as an alternative to MPFL reconstruction, especially in patients with open physes (Ji et al., 2012; Li et al., 2020; Ma et al., 2012). Outcomes after medial retinaculumplasty have been found promising, with no redislocation in patient populations after surgery (Ji et al., 2012; Li et al., 2020; Ma et al., 2012; Ma et al., 2013). Imbrication of the vastus medialis have also been proposed as an affordable technique in patellar dislocation patients with no prominent anatomical risk factors (Lee et al., 2012; Zeichen et al., 1999).

Reconstruction or repair of the medial patellotibial ligament (MPTL) has not received as much attention as reconstruction or repair of the MPFL. However, as the force vector of the MPTL is directed between the patellar ligament and MPFL, the outcome of reconstruction and modification of the MPTL could be comparable to that of a combination of medial transfer of the tibial tubercle and MPFL reconstruction or repair. Zaffagnini et al. (2014) found that MPTL reconstruction produced relatively good results (Zaffagnini et al., 2014). The use of MPTL reconstruction, however, remains marginal.

After the adoption of arthroscopic technology in knee surgery, release of the lateral retinaculum was introduced to decrease the tension laterally directed on the patella. As the early outcomes seemed promising and the procedure was easy to perform, lateral release became a routine concurrent procedure in arthroscopic knee joint debridement after patellar dislocation (Arendt et al., 2013; Dandy et al., 1994; Dandy et al., 1989; Dejour et al., 1994; Donell et al., 2006; Schonholtz et al., 1987). However, while lateral release has been shown to reduce the force required to dislocate the patella laterally, its adequacy has been questioned (Christoforakis et al., 2006).

**Trochleoplasty**

The rationale for trochleoplasty is patellar instability related to trochlear dysplasia. In trochleoplastia, the trochlea is reshaped in order to improve stability and tracking of the patella during motion of the knee joint (Amis et al., 2008). Nowadays, the trochleoplasty techniques most likely applied are those presented by Masse and Dejour, Bereiter and Goutallier (Longo et al., 2018). The technique presented originally by Masse et al. and later modified by Dejour et al. is the so called V-shape trochleoplasty (Dejour et al., 1990; Masse, 1978). In this technique, after making a suprapatellar incision, the subchondral bone under the trochlea is reduced and
modified to form a “V” shape (Figure 15). The cartilaginous trochlear facets are then compressed and attached to the remodeled subchondral bone bed forming V-shaped articular surfaces of the subchondral bone. Bereiter et al. described a more comprehensive U-shaped trochleoplasty after a lateral parapatellar incision, (Bereiter et al., 1994). Approached laterally, the articular cartilage, along with a thin flake of bone, is detached from the trochlear subchondral bone, after which the subchondral bone is remodeled into the desired shape (Figure 16). Lastly, the trochlear articular cartilage is reattached to the remodeled subchondral bone bed by a wide vicryl band strung along the deepest part of the trochlear groove. Goutallier et al. came up with a different approach in which a recession wedge trochleoplasty was performed to manage protrusion of the upper trochlea (Figure 17). In their technique, a superiorly widening coronal wedge of subchondral bone under the proximal trochlea is removed and the trochlea twisted posteriorly (Goutallier et al., 2002). As a result, the supratrochlear spur is eliminated, and the angle between the quadriceps muscle force and patellar ligament is increased, thereby decreasing the patellofemoral compression force. In the literature on patellar dislocation surgery, the most commonly applied trochleoplasty technique is the U-shaped trochleoplasty (63%) followed by the V-shaped trochleoplasty (32%). Recession wedge trochleoplasty has been used only marginally (4.8%) and has been proposed for use only as an adjunct procedure along with the other patellar stabilizing techniques (Longo et al., 2018; Thaunat et al., 2011). The arthroscopic technique has also been applied in trochleoplasty procedures (Blønd et al., 2014).

Studies examining outcomes after the trochleoplasty procedure for patellar dislocation have shown considerable improvement in functionality and subjective instability symptoms (Camathias et al., 2016; Donell et al., 2006; Fucentese et al., 2011; Hiemstra et al., 2019b; Longo et al., 2018; McNamara et al., 2015; Ntagiopoulos et al., 2013; Schöttle et al., 2005b; Smith et al., 2008b; Utting et al., 2008; Von Knoch et al., 2006). In addition, the rates of recurrent dislocations after trochleoplasty have been very low, as in the majority of studies no recurrent dislocations have been observed even after a medium to long-term follow-up (Hiemstra et al., 2019b). Even in studies which have observed recurrence after trochleoplasty, the recurrence rates have been around one in ten patients (Hiemstra et al., 2019b). However, knee pain outcomes have not been as consistently good, as trochleoplasty may not have lessened or may even have exacerbated the pain (Fucentese et al., 2011; Schöttle et al., 2005b; Von Knoch et al., 2006). In addition, limitations on the range of motion of the knee have been reported after trochleoplasty (Song et al., 2014a). Better outcomes have been reported in patients
with more severe trochlear dysplasia (Fucentese et al., 2011). Thus, to ensure a favorable benefit-disadvantage ratio, it may be justified to target trochleoplasty to patients with severe trochlear dysplasia.

Figure 15. Illustration of V-shaped trochleoplasty by Masse and Dejour. A) Subchondral bone (black triangle) is removed and the bone is remodeled into a V shape. B) Articular cartilage is compressed and reattached to the remodeled subchondral bone. © Mikko Uimonen

Figure 16. Bereiter U-shaped trochleoplasty. A) Articular cartilage along with the thin flake of subchondral bone is lifted and the subchondral bone reshaped with osteotomies and a bone shaver (black area). B) After shaping the subchondral bone, the articular cartilage is reattached along the trochlear groove with a wide vicryl band. © Mikko Uimonen
Transfer of tibial tubercle

Transfer of the tibial tubercle and thus transfer of the patellar ligament attachment site may be performed to alter the direction of force of the quadriceps femoris as well as to correct patella alta (Servien et al., 2007). In lateralized patellar tracking, usually observed by an abnormally long TT-TG distance, the tibial tubercle may be transferred medially, whereas in patella alta the tibial tubercle is transferred distally to also pull the patella lower (Figure 18). Historically, tibial tubercle transfer can be considered the first stabilizing surgical technique developed for treating patellar instability (Servien et al., 2007). Several additional techniques and their modifications have been developed (Servien et al., 2007) since the original techniques introduced over a hundred years ago by Roux and Goldthwait and by Hauser and Elmslie and Trillat (Arendt et al., 2013; Goldthwait, 1896; Hauser, 1938; Roux, 1887). However, the main idea of the tibial tubercle transfer has remained the same. At its simplest, the tibial tubercle along with the patellar ligament is detached from the anterior tibia using an oscillating saw, after which the tubercle is transferred either medially or distally or both, depending on the patient’s anatomy and desired outcome, and re-attached to the tibia using titanium screws (Servien et al., 2007).
The results of studies on the outcomes of tibial tubercle transfer have indicated improved functional outcomes and a low rate of recurrent dislocations in the short to medium term (Dabby et al., 1999; Diks et al., 2003; Koëter et al., 2007; Pritsch et al., 2007; Servien et al., 2007; Tsuda et al., 2012). Patellar height is easily corrected by tibial tubercle distalization (Magnussen et al., 2014). Concern about patellofemoral arthritis after tibial tubercle transfer in the longer term has been raised (Arnbjornsson et al., 1992; Crosby et al., 1976; Marcacci et al., 1995). The hypothesis has been that, after the procedure, the force directed on the patellofemoral articular surfaces increases, and may thus predispose to chondral degeneration (Servien et al., 2007). However, results on degeneration in the long term have not been consistent, with some studies showing no increased risk for degeneration after tibial tubercle transfer (Pritsch et al., 2007; Tsuda et al., 2012). A typical complication after tibial tubercle transfer is pain due to the fixation screws, which are often removed a few years after the primary operation (Servien et al., 2007).

**Figure 18.** Illustration of distal transfer of tibial tubercle due to high riding patella. A) High riding patella. B) Tibial tubercle along with patellar ligament is detached from tibia. C) The detached tibial tubercle is attached more distally with two screws. As a result, the vertical location of the patellar is repositioned to a more favorable location lower down in relation to the femur trochlea. © Mikko Uimonen

**Femoral osteotomies**
Femoral osteotomies have become alternatives to tibial tubercle transfer in patients with a lateralized patella due to axial malalignment of the knee joint. In practice, femoral osteotomy involves cutting the femur from distal metaphyseal area and realigning it to desired position (Frings et al., 2019; Frings et al., 2018a; Nha et al., 2018; Wilson et al., 2018). In cases of patellar instability, typical procedures are a rotational or varus-producing osteotomy. Internal rotation of the femur in relation to the tibia may cause lateralized patellar tracking. To correct excessive internal rotation, the distal femur is rotated externally and re-fixated using fixation plates (Dickschas et al., 2012; Frings et al., 2019; Zhang et al., 2019). Valgus knee posture may be corrected by a varus-producing femoral osteotomy, in which a medially widening wedge is removed from the femur in order to alter the posture towards varus (Frings et al., 2018a; Nha et al., 2018; Wilson et al., 2018).

Since the use of femoral osteotomies has only relatively recently become more popular in patellar dislocation surgery, the number of studies examining the outcomes of these procedures is low (Dickschas et al., 2012; Frings et al., 2019; Frings et al., 2018a; Imhoff et al., 2019; Nha et al., 2018; Wilson et al., 2018). Moreover, the number of patients in these studies has been small. However, the short-term results have been promising, as functionality and pain symptoms have consistently showed improvement (Dickschas et al., 2012; Frings et al., 2019; Frings et al., 2018a; Imhoff et al., 2019; Nha et al., 2018; Wilson et al., 2018). In addition, the re-dislocation rate has been zero in adult populations (mean age 23-30) with a follow-up of 1-4 years (Dickschas et al., 2012; Frings et al., 2019; Frings et al., 2018a; Imhoff et al., 2019; Nha et al., 2018). However, in one study conducted with an obese adolescent population (mean age 16, mean BMI 31), the re-dislocation rate was 20% after a follow-up of 4.3 years (Wilson et al., 2018).

2.7.2.3 Management of chondral and osteochondral lesions

Chondral and osteochondral lesions are common concomitant injuries after patellar dislocation (Farr et al., 2012). These injuries play a central role in prognosis and long-term outcomes after patellar dislocation, since cartilaginous lesions have been found to increase the risk for degeneration (Sanders et al., 2017). Thus, appropriate treatment of chondral injuries is key in long-term outcomes even in the absence of recurrent episodes of patellar dislocation.

Treatment of lesions in cartilaginous articular surfaces has traditionally depended on the characteristics of the lesion. Reciprocal bone contusions on both sides of the
patellofemoral joint, i.e., kissing contusions, small impression fractures of subchondral bone, and cartilaginous fissures, are treated conservatively (Stefancin et al., 2007). The management of intra-articular loose fragments, however, has recently become a topic of debate. Based on the established understanding of cartilage-to-bone and bone-to-bone healing, the primary aim in the treatment of osteochondral fractures have been reimplantation of the loose fragment whereas in solitary chondral fractures with no bony component the loose fragment have been removed (Kramer et al., 2007). This practice is based on the belief that the healing capacity of cartilage to bone is poor due to the low mitotic activity of chondrocytes which leads to failure of attempts at reimplantation (Campbell, 1969; Mankin, 1982). On the other hand, bone-to-bone healing is known to involve good healing capability and thus if the fragment contains bone, reimplantation is more likely to succeed (Dines et al., 2008; Morris et al., 2016; Nakayama et al., 2014). Although solitary chondral fractures have been believed to heal poorly and have low reattachment potential after reimplantation, case series showing successful reimplantation of intra-articular loose fragments have recently been published (Chan et al., 2014; Churchill et al., 2019; Morris et al., 2016; Nakamura et al., 2004; Nakayama et al., 2014). However, no major breakthrough in chondral fracture reimplantation has yet been seen.

Traditionally, reimplantation in osteochondral fractures has been considered possible if the loose fragment is larger than 1cm² (Kramer et al., 2007). In practice, technological advances have enabled the reimplantation of even smaller fragments although, no studies on the reimplantation of osteochondral fractures smaller than 1cm² have been published thus far. Several reimplantation techniques for osteochondral fractures have been introduced during recent decades in the wake of accumulating knowledge and technological developments. Sutures, pins, and compression screws have been used reattachment procedures (Gkiokas et al., 2012; Kramer et al., 2007; Lee et al., 2013; Li et al., 2019; Malecki et al., 2019; Ng et al., 2017). Bioabsorbable materials have at least partly overtaken the older materials, such as titanium in compression screws and pins. In addition, advances in arthroscopic technology have enabled mini-invasive reimplantation of fragments in osteochondral fractures (Lee et al., 2013).

In cases with a removed loose fragment, either chondral or osteochondral, additional procedures, such as microfracturing, abrasion arthroplasty, mosaicplasty and chondral transplantation, may be considered in order to improve healing of the fracture site (Kramer et al., 2007). In microfracturing and abrasion arthroplasty, the fracture site is debrided using a shaver, curette and K-wires in order to enhance the natural healing capability of subchondral bone and cartilage (Kramer et al., 2007).
The bone marrow is exposed to enable pluripotent stem cells to initiate recovery of the cartilaginous surface. However, the new articular cartilage formed during healing is not the original hyaline type of cartilage but fibrocartilage scar tissue which is inferior to hyaline cartilage in its mechanical properties (Buckwalter, 1998). Thus, techniques aiming to restore hyaline cartilage are nowadays more favored. In mosaicplasty, multiple osteochondral cylinder grafts obtained from the non-weight-bearing articular surface of the knee joint are implanted in the weight-bearing lesion area to at least partly restore hyaline cartilage in that area (Hangody et al., 2001; Nho et al., 2008). Autologous chondrocyte implantation techniques have also been presented (Brittberg et al., 1994). In these techniques, a chondrocyte biopsy is used to grow chondrocytes in in vitro laboratory conditions. The implantation is performed weeks to months later, after sufficient chondrocyte volume has been obtained. Owing to its promising results in restoring cartilaginous surface, autologous chondrocyte implantation has been attracting increasing interest (Bartlett et al., 2005; Bentley et al., 2003; Harris et al., 2010; Knutsen et al., 2007; Peterson et al., 2010; Siebold et al., 2014).

2.7.2.4 Current concepts

Since knowledge on natural history and risk factors as well as management techniques and technologies has evolved enormously over the past few decades, the general consensus on the optimal surgical technique has shifted in focus to the anatomy of the individual patient. As the repertoire of techniques is now wider than ever, tailoring according to the patellofemoral anatomy of the patient may be an advantage when planning the most appropriate surgical management (Chotel et al., 2014).

In the research field, this is reflected in studies assessing the influence of anatomical factors on the outcomes of different surgical techniques (Frings et al., 2018b; Lee et al., 2018b; Martin et al., 2019; Matsushita et al., 2014; Tecklenburg et al., 2010; Zaffagnini et al., 2019). In addition, studies on combined surgical procedures have recently increased in number (Blond et al., 2014; Feller et al., 2014; Koch et al., 2011; Lobner et al., 2017; Mulliez et al., 2017; Purushothaman et al., 2012; Tscholl et al., 2020; Yang et al., 2019b). These studies have shown promising results. Thus, patellar dislocation surgery seems to be developing in a direction away from the “one-fits-all” solution.
3 AIMS OF THE STUDY

The aims of this dissertation research were to examine trends in patellar dislocation surgery and the characteristics, risk factors and treatment outcomes of osteochondral fractures after patellar dislocation.

The specific aims of the individual studies were:

Study I: To investigate trends in the surgical treatment of patellar dislocations in Finland between the years 1997 and 2016 using nationwide register data on surgical procedures.

Study II: To describe patterns of osteochondral fractures in the knee joint after patellar dislocation.

Study III: To examine and compare the presence of anatomical risk factors for patellar dislocation in patients with and without concomitant osteochondral fracture after patellar dislocation.

Study IV: To characterize and examine the utility of the primary treatment approaches and their relation to outcomes in patients with osteochondral fracture following patellar dislocation in two hospitals.
4 MATERIALS AND METHODS

4.1 Patients

4.1.1 Study I

Study I was performed using register data from the Finnish National Hospital Discharge Register (NHDR, National Institute of Health and Welfare, Finland). All private and public sector hospitals in Finland are required to record information on hospital admissions (both inpatient and outpatient) and treatment events in the NHDR. The register data on surgical treatment in Finland have been found to be both accurate and comprehensive (Huttunen et al., 2014; Mattila et al., 2008; Sund, 2012). Information on patient age and sex, length of hospital stay, patient’s domicile, and diagnoses and procedures performed during hospital stay is also saved in the NHDR.

The present patient sample consisted of all patients who had undergone surgery for patellar dislocation between 1 January 1997 and 31 December 2016. Eligible patients were identified using diagnosis codes S83.0, M22.0 and M22.3 of the International Classification of Diseases, 10th revision (ICD-10, World Health Organization). Codes from the NOMESCO Classification of Surgical Procedures (NCSP) (Finnish version) were used to identify specific procedure types. Information on age, sex, diagnoses and the surgical procedures performed was obtained from the NHDR.

As the same procedure codes may apply to diverse procedures, we attempted to mitigate bias in patient selection by combining the procedure code with the diagnosis of patellar dislocation. Furthermore, to better focus on the most relevant procedures, only those that were performed more than 100 times during the study period were included in the final analysis. Finally, 16 procedure codes were selected for review.

The selected procedure codes were classified by type as presented in Table 2. Since the coding used in patellar dislocation surgery is not fully specific, assignment to procedure classes was made based on clinical experience.
Table 2. Classification of procedure codes and descriptions of the procedures in each class.

<table>
<thead>
<tr>
<th>Class</th>
<th>Procedure codes</th>
<th>Includes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ligament reconstruction or repair</td>
<td>NGE60</td>
<td>Medial patellofemoral ligament or medial patellotibial ligament reconstruction or repair</td>
</tr>
<tr>
<td></td>
<td>NGE65</td>
<td></td>
</tr>
<tr>
<td>Extensor realignment</td>
<td>NGL66</td>
<td>Tibial tubercle transfer</td>
</tr>
<tr>
<td></td>
<td>NGL30</td>
<td>Patellar tendon shift</td>
</tr>
<tr>
<td></td>
<td>NGK99</td>
<td>Imbrication of vastus medialis</td>
</tr>
<tr>
<td>Trochleoplasty</td>
<td>NGG00</td>
<td>Trochleoplasty</td>
</tr>
<tr>
<td>Femoral osteotomies</td>
<td>NFK30</td>
<td>Varus-producing osteotomy of femur</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Torsional osteotomy of femur</td>
</tr>
<tr>
<td>Reimplantation of osteochondral fractures</td>
<td>NGF30</td>
<td>Open or arthroscopic reimplantation of osteochondral fractures</td>
</tr>
<tr>
<td></td>
<td>NGF35</td>
<td></td>
</tr>
<tr>
<td>Debridement</td>
<td>NGA30</td>
<td>Arthroscopy</td>
</tr>
<tr>
<td></td>
<td>NGD05</td>
<td>Loose fragment removal</td>
</tr>
<tr>
<td></td>
<td>NGF00</td>
<td>Plica resection</td>
</tr>
<tr>
<td></td>
<td>NGF25</td>
<td>Menisci debridement</td>
</tr>
<tr>
<td>Capsular release</td>
<td>NGE10</td>
<td>Lateral capsular release</td>
</tr>
<tr>
<td></td>
<td>NGE15</td>
<td></td>
</tr>
<tr>
<td>Unspecified procedures</td>
<td>NGH20</td>
<td></td>
</tr>
</tbody>
</table>

4.1.2 Studies II, III and IV

Studies II, III and IV were conducted as multicenter studies in two separate hospital districts (Central Finland Hospital, Jyväskylä; Tampere University Hospital, Tampere) in Finland with a combined population of approximately 800,000 (StatisticsFinland, 2020). The study sample consisted of all patients treated for patellar dislocation in the study hospitals during 2012-2018. Patients were identified from electronic patient records using ICD-10 diagnosis codes S83.0 (Acute patellar dislocation) and M22.0 (Recurrent patellar dislocation). The medical records of all the identified patients were screened for inclusion. The inclusion criteria were a diagnosis of patellar dislocation and an osteochondral fragment verified by MRI. An
osteochondral fragment was defined as an intra-articular loose fragment cleaved from the articular surface of the patellofemoral or tibiofemoral joint and containing components of both cartilage and bone. Exclusion criteria are presented in Table 3.

Table 3. Exclusion criteria.

<table>
<thead>
<tr>
<th>Exclusion criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous surgery for patellar dislocation</td>
</tr>
<tr>
<td>Previous major traumas of knee joint (ligament ruptures, intra-articular fractures etc.)</td>
</tr>
<tr>
<td>Magnetic resonance imaging not performed in the study hospitals</td>
</tr>
<tr>
<td>Loose fragment containing only either cartilage or bone</td>
</tr>
<tr>
<td>Extra-articular medial patellofemoral ligament avulsion fractures</td>
</tr>
<tr>
<td>Chondral or osteochondral impression fractures without loose fragment</td>
</tr>
<tr>
<td>Round-shaped osteochondral fragment interpreted as an old fracture (e.g., did not occur in the most recent dislocation)</td>
</tr>
</tbody>
</table>

The search of electronic patient records yielded a total of 2,373 patients with a diagnosis of patellar dislocation who had been treated in the study hospitals during the study period. The patient records of these patients were screened for inclusion. The flow-chart of patient selection (exclusions shown in the right column) is presented in Figure 19. After exclusions, a total of 135 patellar dislocation patients with osteochondral fracture were included in the analysis. One patient with missing data on treatment was excluded from Study IV.
Figure 19. Flow-chart on patient selection.

2373 patients with patellar dislocation diagnosis (S83.0 or M22.0)

192 patients with erroneous diagnosis excluded

51 patients that had previous knee surgery due to patellar dislocation or other major traumas of knee joint

992 patients that had not undergone MRI in study hospitals

1080 patients with no intra-articular loose fragments (including extra-articular MPFL-avulsion fragments and impression fractures without loose fragments)

42 patients with chondral fragment

8 patients with round shaped fragment

135 patients with osteochondral fracture

99 patients with osteochondral fracture after primary patellar dislocation

36 patients with osteochondral fracture after recurrent patellar dislocation
Demographic data were collected retrospectively from patient records. Information on the occurrence of previous patellar dislocations was collected from patient records to verify the correct diagnosis of primary or recurrent dislocation. If a patient had experienced several episodes of patellar dislocations, the first episode in which an osteochondral fracture occurred was selected for the final analysis.

In Study III, a control group of patellar dislocation patients with no osteochondral fractures was selected from the pool of all the patients deemed eligible. The eligibility criterion for patients in the control group was the absence of any intra-articular loose bodies as indicated by MRI. The number of patients in the control group was determined by adding 20% to the number of patients with an osteochondral fracture to obtain representative matched pairs of osteochondral fracture patients and patients with no osteochondral fractures.

In Study IV, the treatment outcomes of the patients with osteochondral fractures were examined by a mailed self-report questionnaire battery. Questionnaires were returned using prepaid return envelopes. The questionnaire battery included the following patient-reported outcome measures (PROMs): Kujala score, Quality of Life subscale of the Knee injury and Osteoarthritis Outcome Score (KOOS), Tegner activity scale and visual analogue scale (VAS) pain items. In addition to the PROMs, patients were sent a questionnaire on demographic characteristics.

4.1.2.1 Patient reported outcome measures (Study IV)

The Kujala anterior knee pain score is a widely used 13-item questionnaire on knee pain and functionality (Bennell et al., 2000; Crossley et al., 2004; Green et al., 2014; Ittenbach et al., 2016; Kujala et al., 1993). The total score ranges from 0 to 100 indicating poor to good functionality.

The KOOS is an instrument developed to evaluate the long-term consequences of knee injury and related conditions (Roos et al., 1998a; Roos et al., 1998b; Salavati et al., 2011). To measure knee condition-related quality of life, the four-item Quality of Life subscale of the KOOS (KOOS QoL) was used in this study. The items each have five response categories scored from 0 to 4, and the total score is calculated by summing the item scores and converting the result into a scale from 0 to 100. A higher score indicates better knee condition-related quality of life. The Finnish version of the KOOS was used (Multanen et al., 2018).

The Tegner activity scale is a one-item scale that is used to grade patients’ activity capabilities in relation to work and sports (Tegner et al., 1985). The Tegner scale consists of a single item scored from 0 to 10. Patients are asked to select from ten
response categories the one that best represents their activity capability level. A higher score indicates a higher level.

Patients pain outcomes were examined by five items on a 100-millimeter VAS: overall pain, pain during movement, pain during rest, daily pain, and nightly pain. The responses were examined and presented to within an accuracy of one millimeter. A higher score indicates more severe pain. The VAS scales are widely used in the assessment of musculoskeletal pain (Boonstra et al., 2008; Kelly, 2001; Langley et al., 1985).

4.1.2.2 Protocol for referrals to MRI

According to the protocols in both study hospitals, MRIs are conducted after referral from the orthopedic department, to which the patient is referred after primary care and assessment by a physician in the emergency department. The guidelines in the study hospitals specify that all primary patellar dislocation patients should be referred for MRI. However, the decision on referral to the orthopedic unit rests with the physician in the emergency department. If the knee injury is considered non-severe, the patient may not primarily be referred to the orthopedic unit. Further, if the patient did not seek further treatment in the study hospitals, MRI may not have been performed in these hospitals. In addition, patients with insurance may prefer private sector hospitals despite referral to a publicly funded orthopedic department. In these patients, further diagnostics and MRIs may be implemented in the private sector.

4.1.2.3 The protocol for treating osteochondral fractures after patellar dislocation in the study hospitals

Osteochondral fracture size and location and previous history of patellar instability play a key role when determining treatment in the primary phase. An osteochondral fracture larger than 1cm² in the central part of an articular surface is a relative indicator for surgery in the primary phase. Prior to all surgical procedures, the condition of cartilage surfaces and possible defects in the patellofemoral joint cartilage are inspected using arthroscopy. The primary target, along with stabilizing the patellar, is to restore the cartilage surface by reimplanting the osteochondral fragment into its site of origin using pins, screws, nails, and sutures. If reimplantation fails, the fragment is removed. Cartilage-restoring chondroplasties, such as microfracturing, mosaicplasty and osteochondral grafting are not performed in the
primary phase. With a few exceptional cases in the beginning of the study period, MPFL reconstruction was routinely performed. Bony stabilizing procedures are not generally used in primary phase surgery.

Conservative treatment is the primary approach in the majority of patients with osteochondral fracture smaller than 1cm² that is located close to the edge of the surface of the patellofemoral joint. However, surgery may be a choice in primary treatment if the patient has a history of patellar dislocations or shows obvious patellar instability in a clinical examination. MPFL reconstruction is performed in practically all of these patients. Bony stabilizing procedures, such as trochleoplasty, tibial tubercle osteotomy or femoral osteotomy, are performed in patients with a positive J-sign in a clinical examination and apparent patellofemoral deformity in knee MRI. A small osteochondral fragment located in a non-weight-bearing part of the patellofemoral joint may be removed arthroscopically without cartilage restoration procedures.

After primary treatment, whether conservative or surgical, the patient may seek further treatment if the symptoms of the injured knee persist and affect daily living in the longer term. Surgery may be an option in the late phase, if a patient presents with knee pain related to chondral injury or an intra-articular loose fragment or has sustained recurrent patellar dislocations. In later phase surgery, arthroscopic debridement of the patellofemoral cartilage surface is performed to remove any loose or ragged material. Cartilage restoration techniques may be used in patients with an chondral lesion that has not healed in the central part of the articular surface. Persistent patellar instability is managed on the same principles as in the primary phase.

4.2 Radiographic analysis

Radiological examination was performed based on MRIs of injured knees. Characteristics of osteochondral fractures, anatomical measures of the knee joint, and skeletal maturity were assessed from the images. Skeletal maturity was determined from MRI of the distal femur. Maturity was defined as an opening in the growth plates of less than 5 millimeters or complete epiphyseal fusion in any section of the distal femur (Dvorak et al., 2007). All radiological measures and other parameters were examined by two independent observers. The final measurement values were calculated as the mean of the measurements of the two observers.
Discrepancies in categorical variables between observers were resolved by double-checking the conflicting variables and reaching a consensus.

### 4.2.1 Imaging properties

MRI scans were conducted using 1.5T or 3T magnet strength scanners. Coils were used to improve the precision of the images. Proton density and T2-weighted turbo spin-echo sequences were used. Slice thickness varied between 2.5 and 3.5 millimeters whereas slice increments varied between 2.8 and 4.0 millimeters. The scan was performed with patient’s knee at 20-30 degrees of flexion.

### 4.2.2 Characteristics of osteochondral fracture

The location and size of the osteochondral fracture were assessed from MRIs. Lesion location was categorized by anatomical region. The patella was divided into three regions: medial articular facet, patellar ridge, and lateral facet. The articular surface of the femur was, accordingly, also divided into three regions: lateral trochlear facet, trochlear groove, and medial trochlear facet. An osteochondral fracture in the patellar ridge or trochlear groove was defined respectively as a lesion that extends to the highest edge of the patellar ridge or deepest part of trochlear groove.

The size of the osteochondral fracture was estimated by measuring three dimensional diameters of the loose fragment. The square area of the osteochondral fracture was calculated by multiplying the longest diameter by the second longest. Further, if there were several osteochondral fragments, the total fracture area was estimated by summing the areas of all fragments.

### 4.2.3 Anatomical measurements of the knee joint

Anatomical parameters related to patellar instability were measured from MRIs. Patellar height parameters, which included the ISI (Insall et al., 1971), CDI (Caton et al., 1982) and PTI (Biedert et al., 2006), were measured from the sagittal plane, where the vertical length of the patella was longest. Lateralization of patellar tracking was examined by measuring TT-TG (Dickens et al., 2014) and TT-PCL (Seitlinger et al., 2012). The trochlear configuration was examined from the first axial plane below the lower bound of the articular surface of the patella. The trochlear sulcus
angle (Pfirrmann et al., 2000), trochlear depth (Pfirrmann et al., 2000), trochlear facet asymmetry ratio (Pfirrmann et al., 2000), trochlear condyle asymmetry ratio (Pfirrmann et al., 2000), and lateral trochlear inclination angle (Carrillon et al., 2000) were measured. The measures are illustrated in Figures 10, 11 and 13. Inter-rater reliability of anatomy measurements between two observers for each measure was tested by calculating intraclass correlation coefficients (ICC). ICC values over 0.75 indicate good reliability (Koo et al., 2016). The observed ICC values varied between 0.75 and 0.89 with the lowest value in the sulcus angle measure.

4.3 Statistical analysis

Statistical analyses were performed using R statistical software (versions 3.6.1 – 4.0.3).

4.3.1 Study I

To calculate the total and annual incidences of surgical procedures for patellar dislocation, annual procedure rates were proportioned against register data on annual population statistics extracted from the Statistics Finland database (StatisticsFinland, 2020). The total incidence of surgical operations for patellar dislocation and the individual incidences of specific procedure types were calculated separately. When calculating the total incidence of surgical procedures, each operative session was counted as one procedure even if more than one NHDR procedure code was recorded as part of the same operation. In the calculations of individual procedure types, each procedure code was counted whether or not more than one code were recorded in a single operative session.

Total incidence was calculated per 100 000 person-years and annual incidence per 100 000 persons per year. Since the NHDR data is based on the whole population of Finland, no statistical estimation methods were used and thus the calculated incidences represent the true incidences.

4.3.2 Study II

Differences in the location and size of osteochondral fractures were examined in subgroups according to sex, skeletal maturity and their occurrence in primary versus
recurrent cases of patellar dislocation. To examine differences in location, Chi-square tests were performed for each subgroup. Since the Shapiro-Wilk test and histograms revealed that patient age and osteochondral fracture size were not normally distributed, further analyses were performed using non-parametric tests. To examine differences in the sizes of osteochondral fractures, Mann-Whitney U-tests were performed for each subgroup. The ages of patients with osteochondral fracture in the different locations were compared using the Kruskal-Wallis test. The association between patient age and osteochondral fracture size were examined by calculating Spearman correlation coefficients.

4.3.3 Study III

Anatomical parameters of the knee joint were compared between the patellar dislocation patients with osteochondral fracture and a propensity score-matched sample of patients with no osteochondral fracture. Propensity scores were calculated by age, sex, skeletal maturity, and primary versus recurrent dislocation. Matching was conducted by applying the nearest neighbor method with caliber width set to 0.15. The post-matching covariate balance was assessed by calculating z-differences between groups. A z-value less than ±1 was considered as acceptable (Kuss, 2013).

The Shapiro-Wilk test and visual assessment using histograms were used to assess the normality of the anatomical parameter distributions in both groups. Since all the anatomical parameters followed a normal distribution, further analysis was conducted using a parametric statistical approach. Mean parameter values with 95% CIs were compared between groups. Additionally, a sensitivity analysis was conducted in patients with primary patellar dislocation.

The parameters that showed eligible evidence of a difference between groups, were selected for further analysis. The criterion for difference was a control group mean value outside the 95% CI of the osteochondral fracture group mean value. Predictive logistic modeling was used to determine the limit values and 95% CIs of the differing anatomical parameters that showed a 50% probability for the occurrence of an osteochondral fracture. Univariable logistic regression models were constructed by setting the occurrence of an osteochondral fracture as a dependent variable and the anatomical parameter as an independent variable.

In addition, abnormality threshold values obtained from previous radiologic-anatomic studies were used to examine the proportions of patients with abnormal
values. The abnormal value thresholds are presented in Table 1 (page 43). The osteochondral fracture and control groups were compared using Chi-square test.

Lastly, the mean parameter values and 95% CIs were compared between patients with a patellar and femoral osteochondral fracture to examine association of parameter values with injury location.

4.3.4 Study IV

Patients were divided into three groups according to the primary treatment approach: primary surgery, late surgery, and conservative treatment. The primary surgery group consisted of the patients who had undergone knee surgery during the first 90 days after sustaining an osteochondral fracture in connection with patellar dislocation. The patients who had undergone surgery over 90 days after sustaining an osteochondral fracture were classified as the late surgery group. The patients who did not undergo surgical treatment for patellar dislocation or osteochondral fracture formed the conservative treatment group. The three groups were compared on their demographic, clinical and injury characteristics, and outcomes. The results were presented as counts along with percentages or medians with inter-quartile ranges (IQR). Due to the small sample size, statistical testing and estimation methods were not used.

4.4 Ethical considerations

Ethical approval was not obtained as, according to the Medical Research Act (488/1999), it is not required for register-based studies in Finland. Permission to conduct the study was obtained from the Institutional Review Board of each of the two study hospitals (research permit ID: R19529). The present studies did not affect the treatment of the patients. In Study IV, information and consent forms were mailed to the patients along with the questionnaires. Answering the questionnaires was voluntary. To participate in the study, patients were required to sign an informed consent form. The questionnaires and signed consent were returned using prepaid return envelopes.
5 RESULTS

5.1 Study I

The NHDR data yielded a total of 9,702 surgical procedures following diagnosis of a patellar dislocation during the study period. These operations were performed on 8,333 patients, of whom 61% were female (n = 5,071). Patient ages at time of surgery ranged between 4 and 88 years, with a median of 23 (inter-quartile range [IQR] 18-34). The age and sex distributions remained stable across the study period (Figure 20).

Figure 20. Annual distribution of patients by age and sex during the study period. Points indicate median age at time of surgery and whiskers the interquartile range. Bars show the annual count of males and females undergoing surgery. © Springer Nature, published with a permission from Springer Nature, originally published in Knee Surgery, Sports Traumatology and Arthroscopy (Study I)
The overall incidence of surgical procedures for patellar dislocation during the study period was 8.9 per 100 000 person-years. The annual incidence remained rather stable over the study period (Figure 21), varying from 8.9 in 1997 and 10.1 in 2016.

At the beginning of the study period, debridement was the most commonly performed procedure. The number of these procedures remained stable across the study period. Ligament reconstruction procedures rapidly increased after 2009 and were the most prevalent procedures at the end of the study period (Figure 22, Table 4). Alongside ligament procedures and although lower in number, femoral osteotomy and trochleoplasty as well as reimplantation of osteochondral fragments increased in number towards the end of the study period. The most prominent increase occurred in the incidence of femoral osteotomies, which rose by 227%, with the most prominent change after the year 2011. Trochleoplasty showed a U-shaped curve with a decrease during the beginning of the study period that turned into an increase after 2014. Reimplantation of osteochondral fragments increased steadily throughout the study period, rising to 152%. The incidence of extensor realignment procedures, showed a rather modest change, increasing by 2%. On the other hand, capsular release procedures and unspecified procedures clearly decreased during
study period. After the year 2001, capsular releases had decreased by 82% by the end of the study period. Unspecified procedures (NGH20) decreased steadily across the study period, showing a total decrease of 79% from the beginning to end of the study period.

Figure 22. Annual incidence of each procedure type during the years 1997-2016. © Springer Nature, published with a permission from Springer Nature, originally published in Knee Surgery, Sports Traumatology and Arthroscopy (Study I)
Table 4. Incidence and percentage change by procedure type.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Incidence per 100,000 persons</th>
<th>Total change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1997</td>
<td>2016</td>
</tr>
<tr>
<td>Ligament reconstruction or repair</td>
<td>1.11</td>
<td>6.00</td>
</tr>
<tr>
<td>Femoral osteotomy</td>
<td>0.00</td>
<td>0.36</td>
</tr>
<tr>
<td>Extensor realignment</td>
<td>0.89</td>
<td>0.91</td>
</tr>
<tr>
<td>Trochleoplasty</td>
<td>0.25</td>
<td>0.45</td>
</tr>
<tr>
<td>Debridement</td>
<td>4.68</td>
<td>5.31</td>
</tr>
<tr>
<td>Reimplantation of osteochondral fracture</td>
<td>0.64</td>
<td>1.62</td>
</tr>
<tr>
<td>Capsular release</td>
<td>0.91</td>
<td>0.25</td>
</tr>
<tr>
<td>Unspecified procedures</td>
<td>3.03</td>
<td>0.64</td>
</tr>
</tbody>
</table>

5.2 Study II

After screening, a total of 134 patellar dislocation patients with osteochondral fracture verified by MRI were identified and included in the final analysis. Of these patients, 99 (74%) had an osteochondral fracture after primary and the rest (n = 35; 26%) after recurrent patellar dislocation dislocation. Females were slightly in the majority (n = 74; 55%) with a median age of 17 (IQR 14-22) years. The majority of the patients were skeletally mature (n = 88; 66%). Of the patients who had a diagnosis of patellar dislocation but had not undergone MRI, 62% were female and their median age was 24 (IQR 19-33) years.

Osteochondral fractures of the patella were more common than those of the femur. with 85 (63%) occurring in the patella (Figure 23). Of these patellar osteochondral fractures, 62 (46%) were located in the medial facet and the rest (n = 22; 16%) in patellar ridge. In 46 (34%) patients, the osteochondral fracture was located in lateral femoral condyle. No patients had an osteochondral fracture in the lateral facet of the patella or in the medial trochlear facet or trochlear groove. Four patients (3%) had an osteochondral fracture in both the femur and patella.
The sizes of the osteochondral fractures were highly dispersed, with a median size of 146mm$^2$ (IQR 105-262mm$^2$). Fracture sizes were larger in the femur (median 173mm$^2$, IQR 105-278mm$^2$) than patella (median 137mm$^2$, IQR 105-235mm$^2$), although the difference was not statistically significant ($p = 0.363$).

A subgroup analysis was performed after excluding patients with an osteochondral fracture in both the patella and femurs as they were too few in number. Comparison of the location of the osteochondral fractures between the sexes showed that the proportion of patellar compared to femoral fractures was higher in females (76%) than males (53%) (Chi-square $= 6.87$, degrees of freedom $= 1$, $p = 0.009$; Figure 24, Table 5). Comparison of patients in skeletal maturity or the occurrence of osteochondral fracture in primary versus recurrent dislocation showed no eligible evidence of difference in fracture locations between patients with open and closed physes. Comparison of subgroups in osteochondral fracture size showed that patellar fractures that occurred after primary patellar dislocation were larger than those that occurred after recurrent dislocation (147mm$^2$ in primary vs. 119mm$^2$ in
recurrent, \( p = 0.040 \)). Femoral osteochondral fractures showed no evidence of such a difference. In addition, the sizes of osteochondral fractures did not show any eligible evidence of difference in any other subgroup. Lastly, patient age was not associated the size (\( \rho = -0.02; \ p = 0.841 \)) or location (\( p = 0.279 \)) of the osteochondral fracture.

Figure 24. Distributions of osteochondral fracture locations by sex. © SAGE Publications, published with a permission from SAGE Publications (Creative Commons license BY-NC-ND 4.0), originally published in Orthopedic Journal of Sports Medicine (Study II)
<table>
<thead>
<tr>
<th>Sex</th>
<th>Female</th>
<th>Male</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location of osteochondral fracture, n (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patella</td>
<td>54 (76)</td>
<td>31 (53)</td>
<td>0.009</td>
</tr>
<tr>
<td>Femur</td>
<td>17 (24)</td>
<td>28 (47)</td>
<td></td>
</tr>
<tr>
<td><strong>Size of osteochondral fracture, median (IQR), (mm²)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patella</td>
<td>131 (107-221)</td>
<td>176 (106-261)</td>
<td>0.446</td>
</tr>
<tr>
<td>Femur</td>
<td>148 (114-214)</td>
<td>181 (92-330)</td>
<td>0.880</td>
</tr>
<tr>
<td><strong>Skeletal maturity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open physes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patella</td>
<td>28 (61)</td>
<td>57 (68)</td>
<td>0.543</td>
</tr>
<tr>
<td>Femur</td>
<td>18 (39)</td>
<td>27 (32)</td>
<td></td>
</tr>
<tr>
<td>Closed physes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patella</td>
<td>169 (111-262)</td>
<td>131 (105-229)</td>
<td>0.392</td>
</tr>
<tr>
<td>Femur</td>
<td>129 (95-264)</td>
<td>188 (125-301)</td>
<td>0.306</td>
</tr>
<tr>
<td><strong>Occurrence of osteochondral fracture</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary patellar dislocation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patella</td>
<td>66 (66)</td>
<td>19 (56)</td>
<td>0.252</td>
</tr>
<tr>
<td>Femur</td>
<td>30 (34)</td>
<td>15 (44)</td>
<td></td>
</tr>
<tr>
<td>Recurrent patellar dislocation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patella</td>
<td>147 (113-263)</td>
<td>119 (71-167)</td>
<td>0.040</td>
</tr>
<tr>
<td>Femur</td>
<td>163 (101-277)</td>
<td>174 (125-277)</td>
<td>0.766</td>
</tr>
</tbody>
</table>

IQR, inter-quartile range

*Differences in osteochondral fracture location in the subgroups was tested using a chi-square test and differences in osteochondral fracture size in the subgroups was tested using the Mann-Whitney U-test*
5.3 Study III

A total of 135 eligible patients with an osteochondral fracture were identified using MRI. After adding 20% to this number, the control group comprised 169 patients. After propensity score matching, 111 matched pairs were included in the final analysis (Table 6). Low z-differences (z less than ±1) indicated successful matching with low between-group differences in the matching variables. The anatomical parameters were normally distributed.

**Table 6.** Patient characteristics before and after propensity score matching.

<table>
<thead>
<tr>
<th></th>
<th>All patients</th>
<th>Matched samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OCF group</td>
<td>Control group</td>
</tr>
<tr>
<td></td>
<td>(n = 135)</td>
<td>(n = 169)</td>
</tr>
<tr>
<td>Age, mean (SD)</td>
<td>19.1 (7.3)</td>
<td>21.0 (9.1)</td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>74 (54.8)</td>
<td>116 (68.6)</td>
</tr>
<tr>
<td>Skeletally mature, n (%)</td>
<td>88 (65.2)</td>
<td>108 (63.9)</td>
</tr>
<tr>
<td>Primary vs. recurrent patellar dislocation, n (%)</td>
<td>99 (73.3)</td>
<td>86 (50.9)</td>
</tr>
<tr>
<td>Primary</td>
<td>36 (26.7)</td>
<td>83 (49.1)</td>
</tr>
</tbody>
</table>

OCF = osteochondral fracture

With respect to patellar height, comparison of anatomical parameters showed a higher PTI in the patients with an osteochondral fracture (osteochondral fracture group 0.54, 95% CI 0.52 to 0.57 vs. control group 0.47, 95% CI 0.45 to 0.49; p < 0.001) whereas eligible evidence of a between-group difference was not observed in the ISI or CDI. TT-PCL was longer in the patients with an osteochondral fracture (21.6mm, 95% CI 21.0mm to 22.3mm vs. 20.5mm, 95% CI 20.0mm to 21.1mm; p = 0.013) although no eligible evidence of a difference in TT-TG was observed.

According to the trochlear configuration parameters, trochlear deformity was more severe in the control group, which showed lower trochlear facet asymmetry (osteochondral fracture group 0.54, 95% CI 0.51 to 0.57 vs. control group 0.43, 95% CI 0.42 to 0.45; p < 0.001) and higher trochlear condyle asymmetry (osteochondral fracture group 1.04, 95% CI 1.03 to 1.04 vs. control group 1.05, 95% CI 1.04 to 1.05; p = 0.013) ratios. However, the trochlea was deeper in the control group (osteochondral fracture group 2.5mm, 95% CI 2.3mm to 2.7mm vs. control group 2.5mm, 95% CI 2.3mm to 2.7mm vs. control group...
3.0mm, 95% CI 2.8mm to 3.2mm; p < 0.001). No plausible evidence of between-group differences in the sulcus or lateral inclination angle was found. The sensitivity analysis, conducted only among only the primary patellar dislocation patients, showed parallel results (Table 7).
Table 7. Differences in anatomical parameters between patients with osteochondral fracture and control patients.

<table>
<thead>
<tr>
<th></th>
<th>Matched patients</th>
<th>Sensitivity analysis with primary patellar dislocation patients only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OCF group, n = 111</td>
<td>Non-OCF group, n = 75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Patellar height, mean (95% CI)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISI</td>
<td>1.20 (1.17-1.24)</td>
<td>1.17 (1.13-1.20)</td>
</tr>
<tr>
<td>P1</td>
<td>0.34 (0.25-0.52)</td>
<td>0.47 (0.45-0.49)</td>
</tr>
<tr>
<td><strong>Sulcus angle (º)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>154.5 (153.0-155.9)</td>
<td>155.1 (154.1-156.1)</td>
</tr>
<tr>
<td><strong>Lateral trochlear inclination angle (º)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14.3 (13.5-15.1)</td>
<td>14.0 (13.0-15.0)</td>
</tr>
<tr>
<td><strong>Trochlear depth, mm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>21.6 (21.0-22.3)</td>
<td>20.5 (20.0-21.1)</td>
</tr>
<tr>
<td><strong>Trochlear morphology, mean (95% CI)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>154.5 (153.0-155.9)</td>
<td>153.1 (152.8-153.2)</td>
</tr>
<tr>
<td><strong>Trochlear facet asymmetry ratio</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.54 (0.51-0.57)</td>
<td>0.50 (0.48-0.52)</td>
</tr>
<tr>
<td><strong>Trochlear condyle asymmetry ratio</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.04 (1.03-1.04)</td>
<td>1.05 (1.04-1.05)</td>
</tr>
</tbody>
</table>

*P*-value, calculated using independent samples t-test.

ISI = Insall-Salvati index, CDI = Caton-Deschamps index, PTI = Patellotrochlear index, TT-TG = Tibial tubercle-trochlear groove distance, TT-PCL = tibial tubercle-posterior cruciate ligament distance.
Based on the results of the between-group comparison of anatomical parameters, PTI, TT-PCL, trochlear depth, trochlear facet asymmetry, trochlear condyle asymmetry and trochlear depth were selected for further analysis. Threshold probability values of 50% for osteochondral fracture during patellar dislocation, yielded by predictive logistic modeling, are presented in Figure 25.

![Graphs showing threshold probability values of 50% for osteochondral fractures (OCF) after patellar dislocation.](image)

**Figure 25.** Threshold probability values of 50% for osteochondral fractures (OCF) after patellar dislocation. The solid vertical line represents the threshold value and the dotted lines the lower and upper bounds of the 95% confidence intervals for the threshold. © Springer Nature, published with a permission from Springer Nature, originally published in Knee Surgery, Sports Traumatology and Arthroscopy (Study III)

Abnormal anatomical parameter values were prevalent in both groups (Table 8). Among all patients in both groups, at least one anatomical parameter indicated abnormal anatomy of the knee joint. The most common abnormality was a sulcus angle over 145º. An abnormal value was observed in 93.2% of patients, with a higher proportion in the control group (97.3%) than osteochondral fracture group (89.2%; *p* = 0.032). In addition, abnormal PTI (57.7% vs 36.0%; *p* = 0.002) and trochlear facet asymmetry (36.9% vs. 20.7%; *p* = 0.012) were more common in the control
group. The proportion of patients with abnormal trochlear depth was higher in the osteochondral fracture group than controls (69.4% vs. 47.7%; p = 0.002).

Table 8. Comparison of proportions of abnormal values in anatomical measures in the osteochondral fracture group and control group.

<table>
<thead>
<tr>
<th>Measure</th>
<th>OCF group, n (%)</th>
<th>Control group, n (%)</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abnormal patellar height</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISI &gt; 1.2</td>
<td>36 (32.4)</td>
<td>32 (28.8)</td>
<td>0.662</td>
</tr>
<tr>
<td>CDI &gt; 1.3</td>
<td>57 (51.4)</td>
<td>44 (39.6)</td>
<td>0.106</td>
</tr>
<tr>
<td>PTI &lt; 0.5</td>
<td>40 (36.0)</td>
<td>64 (57.7)</td>
<td>0.002</td>
</tr>
<tr>
<td>Abnormal patellar lateralization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT-TG &gt; 15 mm</td>
<td>44 (39.6)</td>
<td>40 (36.0)</td>
<td>0.678</td>
</tr>
<tr>
<td>TT-PCL &gt; 20 mm</td>
<td>78 (70.3)</td>
<td>67 (60.4)</td>
<td>0.159</td>
</tr>
<tr>
<td>Abnormal trochlear morphology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulcus angle &gt; 145º</td>
<td>99 (89.2)</td>
<td>108 (97.3)</td>
<td>0.032</td>
</tr>
<tr>
<td>Lateral trochlear inclination angle &lt; 11º</td>
<td>27 (24.3)</td>
<td>18 (16.2)</td>
<td>0.171</td>
</tr>
<tr>
<td>Trochlear depth &lt; 3 mm</td>
<td>77 (69.4)</td>
<td>53 (47.7)</td>
<td>0.002</td>
</tr>
<tr>
<td>Trochlear facet asymmetry ratio &lt; 0.4</td>
<td>23 (20.7)</td>
<td>41 (36.9)</td>
<td>0.012</td>
</tr>
<tr>
<td>Trochlear condyle asymmetry ratio &gt; 1.1</td>
<td>2 (1.8)</td>
<td>1 (0.9)</td>
<td>1.000</td>
</tr>
</tbody>
</table>

OCF = osteochondral fracture, ISI = Insall-Salvati index, CDI = Caton-Deschamps index, PTI = Patellotrochlear index, TT-TG = Tibial tubercle-trochlear groove distance, TT-PCL = tibial tubercle-posterior cruciate ligament distance

*pPearson Chi-Square test

Comparison of anatomical parameters between patients with a patellar and those with a femoral osteochondral fracture revealed higher trochlear facet asymmetry in the patients with a patellar injury (patellar osteochondral fracture 0.51, 95% CI 0.47 to 0.54 vs. femoral osteochondral fracture 0.58, 95% CI 0.52 to 0.64; p = 0.032; Table 9). No eligible evidence of a difference between the groups was found any of the other parameters.
Table 9. Comparison of anatomical parameters between the of patellar and femoral osteochondral fracture groups.

<table>
<thead>
<tr>
<th>Osteochondral fracture location</th>
<th>Patella n = 68</th>
<th>Femur n = 40</th>
<th>p**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patellar height *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISI</td>
<td>1.21 (1.17-1.25)</td>
<td>1.19 (1.13-1.25)</td>
<td>0.666</td>
</tr>
<tr>
<td>CDI</td>
<td>1.19 (1.16-1.22)</td>
<td>1.20 (1.13-1.26)</td>
<td>0.856</td>
</tr>
<tr>
<td>PTI</td>
<td>0.55 (0.52-0.59)</td>
<td>0.53 (0.49-0.57)</td>
<td>0.343</td>
</tr>
<tr>
<td>Patellar lateralization *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT-TG (mm)</td>
<td>14.1 (13.2-15.0)</td>
<td>14.8 (13.2-16.3)</td>
<td>0.476</td>
</tr>
<tr>
<td>TT-PCL (mm)</td>
<td>21.9 (21.1-22.7)</td>
<td>21.6 (20.6-22.7)</td>
<td>0.718</td>
</tr>
<tr>
<td>Trochlear morphology *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulcus angle (º)</td>
<td>153.7 (151.9-155.5)</td>
<td>155.6 (153.3-157.9)</td>
<td>0.209</td>
</tr>
<tr>
<td>Lateral trochlear inclination angle (º)</td>
<td>13.4 (12.4-14.5)</td>
<td>13.6 (12.0-15.2)</td>
<td>0.750</td>
</tr>
<tr>
<td>Trochlear depth (mm)</td>
<td>2.5 (2.3-2.8)</td>
<td>2.6 (2.3-3.0)</td>
<td>0.584</td>
</tr>
<tr>
<td>Trochlear facet asymmetry ratio</td>
<td>0.51 (0.47-0.54)</td>
<td>0.58 (0.52-0.64)</td>
<td>0.032</td>
</tr>
<tr>
<td>Trochlear condyle asymmetry ratio</td>
<td>1.04 (1.03-1.04)</td>
<td>1.04 (1.03-1.05)</td>
<td>0.830</td>
</tr>
</tbody>
</table>

ISI = Insall-Salvati index, CDI = Caton-Deschamps index, PTI = Patellotrochlear index, TT-TG = Tibial tubercle-trochlear groove distance, TT-PCL = tibial tubercle-posterior cruciate ligament distance

*mean (95% CI)

**Independent samples t-test

5.4 Study IV

Mean follow-up time was 4.9 (SD 2.7) years and mean patient age at follow-up was 22.0 years (SD 8.4). A slight majority (n = 74, 55%) were female. Physes were closed in 88 patients (66%). Differences between the three groups were modest except for age, the patients in the primary surgery group being younger than those in the other groups (p = 0.032, Table 10).
Table 10. Patient characteristics by treatment group.

<table>
<thead>
<tr>
<th></th>
<th>Primary surgery, n = 73</th>
<th>Late surgery, n = 18</th>
<th>Conservative treatment, n = 43</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female, n (%)</td>
<td>40 (55)</td>
<td>12 (67)</td>
<td>22 (51)</td>
<td>0.537</td>
</tr>
<tr>
<td>Age during the occurrence of OCF, mean (SD)</td>
<td>20.4 (7.4)</td>
<td>24.0 (7.0)</td>
<td>23.7 (10.1)</td>
<td>0.032</td>
</tr>
<tr>
<td>Closed physes, n (%)</td>
<td>43 (59)</td>
<td>15 (83)</td>
<td>30 (70)</td>
<td>0.117</td>
</tr>
<tr>
<td>BMI, mean (SD)</td>
<td>27.9 (5.3)</td>
<td>24.2 (4.6)</td>
<td>29.6 (9.9)</td>
<td>0.542</td>
</tr>
<tr>
<td>Follow-up duration in years, mean (SD)</td>
<td>4.6 (2.5)</td>
<td>5.4 (2.4)</td>
<td>5.1 (3.2)</td>
<td>0.280</td>
</tr>
</tbody>
</table>

OCF = Osteochondral fracture, SD = Standard deviation, BMI = Body mass index
*p-calculated using one-way ANOVA in continuous variables or Chi-square test in categorical variables

The primary treatment approach was conservative in 61 (46%) and surgical in 73 (54%) patients (Figure 26). Of the patients treated conservatively in the primary phase, 18 (30%) were assigned to surgery over the following 90 days after the suspected occurrence of osteochondral fracture. In the late surgery group, the osteochondral fragment was removed in all patients except one. MPFL reconstruction or other stabilizing surgery was performed in late surgery in 12 (66%) patients. Of the patients in whom the fragment was removed, cartilage restoration chondroplasty was performed. After late surgery, a reoperation was needed in three patients. In two of these patients with the osteochondral fragments removed primarily, further stabilizing surgery was required. In the third patient, after primary reimplantation, the fragment was later removed arthroscopically.

Osteochondral fragments were reimplanted in the majority (62%) of the patients treated surgically in the primary phase (Figure 26). In 60 (82%) of the primary surgery patients, MPFL reconstruction was performed and in two (3%), additional bony stabilizing procedures were performed. Eight (18%) of the patients with osteochondral fragments reimplanted primarily, were reoperated, and five (18%) of the patients whose osteochondral fracture had been removed, were reoperated.

In 77% (n = 103) of the patients, the primary treatment approach was definitive (77% of the patients treated conservatively in the primary phase and 82% of the
primary surgery patients). MPFL reconstruction was performed in 82% (n = 74) of the patients who underwent either primary or late phase surgery. Three (4%) of these needed re-do MPFL reconstruction. A total of 17% (n = 15) of patients who underwent surgery needed a reoperation.

Figure 26. Flow chart on treatment approaches.
the proportion of patients with an osteochondral fracture occurring after recurrent patellar dislocation was higher in the late surgery group than in the other groups (p = 0.003, Table 11). The osteochondral fracture was located in the medial patellar facet (46%) or lateral femoral condyle (34%) in the majority of patients. Osteochondral fracture size was largest in the primary surgery patients (p < 0.001). The differences observed in the patellofemoral anatomy parameters did not reach statistical significance (p > 0.05) although the PTI showed a tendency towards more severe patella alta in the late surgery group and normal anatomy in the primary surgery group (p = 0.061) and the TT-TG showed a tendency towards a more lateraled patella in the primary and late surgery patients compared to those in the conservative treatment group (p = 0.074).
Table 11. Clinical characteristics by treatment group.

<table>
<thead>
<tr>
<th></th>
<th>Primary surgery, n = 73</th>
<th>Late surgery, n = 18</th>
<th>Conservative treatment, n = 43</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCF occurred in primary dislocation, n (%)</td>
<td>63 (86)</td>
<td>9 (50)</td>
<td>33 (77)</td>
<td>0.003</td>
</tr>
<tr>
<td>OCF location, n (%)</td>
<td></td>
<td></td>
<td></td>
<td>0.118</td>
</tr>
<tr>
<td>Patellar medial facet</td>
<td>30 (41)</td>
<td>5 (28)</td>
<td>27 (63)</td>
<td></td>
</tr>
<tr>
<td>Patellar ridge</td>
<td>15 (21)</td>
<td>3 (17)</td>
<td>4 (9)</td>
<td></td>
</tr>
<tr>
<td>Femur lateral condyle</td>
<td>25 (34)</td>
<td>9 (50)</td>
<td>12 (28)</td>
<td></td>
</tr>
<tr>
<td>Femur and patella</td>
<td>3 (4)</td>
<td>1 (6)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td>OCF size in cm², mean (SD)</td>
<td>2.6 (1.7)</td>
<td>1.5 (1.0)</td>
<td>1.4 (0.9)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Anatomical measures, mean (SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISI</td>
<td>1.18 (0.18)</td>
<td>1.27 (0.27)</td>
<td>1.19 (0.18)</td>
<td>0.664</td>
</tr>
<tr>
<td>CDI</td>
<td>1.17 (0.14)</td>
<td>1.23 (0.22)</td>
<td>1.19 (0.15)</td>
<td>0.586</td>
</tr>
<tr>
<td>PTI</td>
<td>0.56 (0.11)</td>
<td>0.49 (0.16)</td>
<td>0.52 (0.13)</td>
<td>0.061</td>
</tr>
<tr>
<td>TT-TG</td>
<td>14.8 (4.4)</td>
<td>14.9 (4.3)</td>
<td>13.2 (4.3)</td>
<td>0.074</td>
</tr>
<tr>
<td>TT-PCL</td>
<td>21.8 (3.7)</td>
<td>20.9 (3.3)</td>
<td>21.7 (3.4)</td>
<td>0.806</td>
</tr>
<tr>
<td>Sulcus angle</td>
<td>154.9 (7.1)</td>
<td>155.1 (7.4)</td>
<td>154.2 (7.8)</td>
<td>0.624</td>
</tr>
<tr>
<td>Trochlear depth</td>
<td>2.5 (1.0)</td>
<td>2.3 (1.2)</td>
<td>2.8 (1.0)</td>
<td>0.163</td>
</tr>
<tr>
<td>Trochlear facet asymmetry</td>
<td>0.51 (0.17)</td>
<td>0.54 (0.17)</td>
<td>0.56 (0.12)</td>
<td>0.116</td>
</tr>
<tr>
<td>Trochlear condyle asymmetry</td>
<td>1.04 (0.03)</td>
<td>1.03 (0.03)</td>
<td>1.04 (0.03)</td>
<td>0.192</td>
</tr>
<tr>
<td>Lateral trochlear inclination angle</td>
<td>13.3 (4.1)</td>
<td>12.7 (6.5)</td>
<td>14.7 (3.8)</td>
<td>0.142</td>
</tr>
</tbody>
</table>

OCF = osteochondral fracture, SD = Standard deviation, ISI = Insall-Salvati index, CDI = Caton-Deschamps index, PTI = patellotrochlear index, TT-TG = tibial tubercle-trochlear groove distance, TT-PCL = tibial tubercle-posterior cruciate ligament distance

*p-calculated using one-way ANOVA in continuous variables or chi-square test in categorical variables

The PROMs were acceptable in all patient groups (Table 12). However, the KOOS QoL scores indicated knee-related impairments in quality of life in all groups.
In the late surgery patients, the Kujala, Tegner and KOOS QoL scores were slightly higher than those in the other groups. Similarly, the VAS pain scores showed a tendency towards better outcomes in the late surgery patients. Overall satisfaction with knee condition was lowest in the conservatively treated patients. PROM outcomes between primary surgery patients with osteochondral fracture reimplanted and removed were similar.

**Table 12.** Demographic characteristics and responses of the patients who returned completed patient-reported outcome measure questionnaires by treatment group.

<table>
<thead>
<tr>
<th></th>
<th>Primary surgery, n = 30</th>
<th>Late surgery, n = 7</th>
<th>Conservative treatment, n = 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female, n (%</td>
<td>14 (47)</td>
<td>4 (57)</td>
<td>8 (47)</td>
</tr>
<tr>
<td>Age, mean (SD)</td>
<td>25.7 (7.5)</td>
<td>27.7 (5.0)</td>
<td>30.4 (11.9)</td>
</tr>
<tr>
<td>Recurrent patellar</td>
<td>5 (17)</td>
<td>1 (14)</td>
<td>4 (24)</td>
</tr>
<tr>
<td>dislocations after</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>occurrence of OCF, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PROM scores, mean (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kujala score</td>
<td>85.3 (11.3)</td>
<td>90.9 (12.9)</td>
<td>84.5 (15.3)</td>
</tr>
<tr>
<td>Tegner score</td>
<td>5.2 (1.7)</td>
<td>6.7 (2.2)</td>
<td>5.5 (1.7)</td>
</tr>
<tr>
<td>KOOS QoL</td>
<td>70.0 (20.5)</td>
<td>80.4 (20.9)</td>
<td>66.5 (20.7)</td>
</tr>
<tr>
<td>VAS Pain, mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>16.1 (17.8)</td>
<td>1.4 (2.0)</td>
<td>20.4 (24.8)</td>
</tr>
<tr>
<td>Day</td>
<td>8.5 (12.8)</td>
<td>3.7 (7.0)</td>
<td>11.2 (21.6)</td>
</tr>
<tr>
<td>Night</td>
<td>3.5 (5.6)</td>
<td>0.6 (1.1)</td>
<td>6.8 (15.1)</td>
</tr>
<tr>
<td>Movement</td>
<td>18.7 (21.1)</td>
<td>14.7 (30.3)</td>
<td>17.8 (23.9)</td>
</tr>
<tr>
<td>Rest</td>
<td>4.3 (9.4)</td>
<td>1.9 (2.9)</td>
<td>7.3 (13.7)</td>
</tr>
<tr>
<td>Overall knee condition</td>
<td>84.9 (12.5)</td>
<td>89.3 (9.3)</td>
<td>78.8 (18.0)</td>
</tr>
</tbody>
</table>

OCF = osteochondral fracture, SD = standard deviation, PROM = Patient-reported outcome measure

The four patients with the poorest PROM scores (Kujala < 60 or KOOS QoL < 35 or VAS overall pain > 65), showed no common patterns that may have been related to their poor outcomes (Appendix 1). One of these patients was treated surgically in the primary phase. In this patient, the osteochondral fragment had been reimplanted and MPFL reconstruction performed, and no reoperations had been needed. The remaining three patients had been treated conservatively. One of these had sustained recurrent dislocation. The sizes and locations of the osteochondral
fractures varied markedly. The anatomical measures in these four patients were not more pronounced than those in the other patients.
This dissertation research explored trends in the surgical treatment of patellar dislocation during past few decades and the characteristics, anatomical risk factors and treatment outcomes of common concomitant injuries during patellar dislocation, including osteochondral fractures. Expanding knowledge and advances in surgical techniques have resulted in more targeted treatment approaches that take the individual’s anatomical and injury-related characteristics into account. However, despite comprehensive knowledge on characteristics and knowledge on the treatment and outcomes of patellar dislocation, osteochondral fractures sustained after patellar dislocation have received relatively little attention in the literature. To better understand and manage these common concomitant injuries, the characteristics of injuries and the risk factors for these should be more thoroughly assessed in clinical practice. Moreover, to improve the prevailing treatment practices, reviewing the recent treatment outcomes of osteochondral fractures would provide insights of value in the future development of new treatments.

In Study I, the incidence and the trends of patellar dislocation surgery were examined using nationwide register data from the past two decades. During the study period, while the total incidence of surgical operations for patellar dislocation remained stable, individual procedures showed notable trends. Ligament reconstruction and repair procedures, femoral osteotomies and the reimplantation of osteochondral fragments became increasingly more common whereas debridement and extensor realignment procedures remained unchanged. Lateral release procedures showed a decreasing trend.

The majority of surgical operations for patellar dislocation were performed for female patients. The gender distribution found here is in line with the previously reported higher incidence of patellar dislocation in women than men (Fithian et al., 2004; Nietosvaara et al., 1994; Sanders et al., 2018). The median age of the patients at the time of surgery remained stable at 23 across the study period. Previously, the incidence of first-time patellar dislocations has been reported to peak between ages of 14 and 18 (Sanders et al., 2018). There might be several explanations for this range of ages. First, non-surgical treatment has been the recommended first-line approach for patellar dislocation in the majority of cases. Surgical treatment may be considered
if non-surgical treatment fails and constant patellar instability causes functional knee problems or if dislocation recurs. Another explanation may be that in patients with first-time patellar dislocation after the closure of growth plates the dislocation may not be related to anatomical risk factors for patellar dislocation, such as trochlear dysplasia, high lying patella and lateralization of patellar tracking. In patients with normal patellofemoral joint anatomy, a patellar dislocation may be related to higher energy traumas, such as sports or traffic accidents, which may predispose to concomitant injuries in the knee joint that may require surgical treatment primarily.

During the few past decades, ligament reconstructions or repairs have become the most commonly performed procedures in patellar dislocation surgery. Since the introduction of MPFL reconstruction techniques by Gomez et al. (1992), who used a synthetic polyester ligament graft (Gomes, 1992), and by Avikainen et al. (1993), who used an adductor magnus tenodesis (Avikainen et al., 1993), research on MPFL reconstruction as a treatment for patellar instability has substantially increased (Buchner et al., 2005; Camanho et al., 2009; Christiansen et al., 2008b; Nomura et al., 2000; Nomura et al., 2003a). MPFL reconstruction has proven more effective in reducing recurrent patellar dislocations than conservative treatment; however, functionality outcomes have not been consistently better (Askenberger et al., 2018; Smith et al., 2015b; Yang et al., 2019a; Zheng et al., 2019). Nonetheless, MPFL reconstruction has become the most recommended surgical treatment for patellar dislocation. According to our findings, the impact of increasing research was reflected in the increased use of ligament reconstruction and repair procedures after the year 2007.

However, despite the promising results of the MPFL reconstruction in previous studies, the risk of recurrent patellar dislocation remains high, even after successful MPFL reconstruction, in patients with anatomical risk factors (Lewallen et al., 2015). Thus, MPFL reconstruction alone may not be a sufficient management protocol in patients in this category. In these patients, MPFL reconstruction needs to be combined with other techniques, such as trochleoplasty or femoral osteotomy, according to the patient’s unique anatomy (Lewallen et al., 2015; Nelitz et al., 2013; Nelitz et al., 2015).

In the past two decades, femoral osteotomy procedures, such as varus-producing and torsional osteotomies, have increased the repertoire of surgical techniques for treating patellar dislocation. These procedures have enabled correction of excessive valgus as well as torsional malalignments of the knee joint (Cameron et al., 1996; Dickschas et al., 2012; Marti et al., 2000; Puddu et al., 2000). In addition, by correcting axial malalignments of the knee joint, femoral osteotomies improve the
tracking of the extensor apparatus (Cameron et al., 1996; Dickschas et al., 2012; Marti et al., 2000; Puddu et al., 2000). According to our findings, the adoption of these procedures is relatively recent, and has become notably more popular since 2011. During this time, i.e., across the study period, extensor realignment procedures have remained stable. It is likely that in patients with lateralized patellar tracking due to axial malalignment of the knee joint, femoral osteotomies have offered a further option in extensor realignment procedures.

Originally, remodeling of the dysplastic femur trochlea was introduced by Albee et al. (1915). They presented a trochleoplasty technique that involved elevating the lateral trochlear facet. Trochleoplasty techniques were refined during the 1970s and 1980s by Masse et al., who were the first to introduce trochlear sulcus deepening (Albee, 1915), and by Dejour et al. who further modified the technique (Dejour et al., 1990; Masse, 1978). After the early 2000s, increasing research on trochleoplasty outcomes has yielded promising results (Dejour et al., 2013; Ntagiopoulos et al., 2013; Utting et al., 2008; Verdonk et al., 2005). Although during recent decades the popularity of trochleoplasty was relatively low, it has shown a slightly increasing trend since 2014.

While the popularity of debridement procedures remained stable across the study period, the reimplantation of osteochondral fractures showed a constantly increasing trend towards the end of the study. The increasing trend in the use of reimplantation procedures may be explained by further knowledge on the long-term outcomes of cartilage damage inside the knee joint that has motivated technological advances in reimplantation methods as well as arthroscopic surgery in general (Carr et al., 2015; Chotel et al., 2011; Hughston et al., 1984; Linden, 1977; Messner et al., 1996). For decades, it has been known that a defect in the articular cartilage of the knee joint after patellar dislocation markedly increases the risk of osteoarthritis (Hughston et al., 1984; Linden, 1977; Messner et al., 1996). With this in mind, surgeons may favor reimplantation over the removal of osteochondral fragments. During the study period, arthroscopic technology and effective reimplantation tools, such as biodegradable pins and sutures, have been introduced and applied in clinical practice (Carr et al., 2015; Chotel et al., 2011; Koëter et al., 2006; Li et al., 2019; Walsh et al., 2008; Zhou et al., 2020a).

Overall, the findings of this study indicate that patellar dislocation surgery has evolved in the wake of extensive research. Expanding knowledge on biomechanics, anatomical risk factors, techniques for correcting malformations, and technological advances has oriented patellar dislocation surgery towards the reconstruction of
damaged structures and active modification of different anatomical risk factors for patellar dislocation.

The results of Study II revealed that osteochondral fractures sustained after patellar dislocation are generally located in the medial facet of the patella or lateral edge of the lateral femoral condyle. Osteochondral fractures varied widely in size, although the range in size did not differ between patellar and femoral fractures. The injury patterns of osteochondral fractures observed after patellar dislocation are in line with the assumed injury mechanism. It has been proposed that the injury occurs during patellar dislocation or relocation as the resulting high energy propels the medial patellar facet and lateral femoral condyle towards each other, causing kissing contusions or, more in more severe instances, an osteochondral fracture (Beasley et al., 2004; Nietosvaara et al., 1994).

Seeley et al. reported parallel results in their series of 46 patients with an osteochondral fracture (Seeley et al., 2013). In their study, 76% of the patients sustained the fracture in the patella and 24% in the lateral condyle of the femur (Seeley et al., 2013). The remainder had injury in both locations (Seeley et al., 2013). Compared to these findings, the proportion of patellar injuries in our study was slightly lower and that of femoral injuries higher. The sample studied by Seeley et al. consisted of pediatric primary patellar dislocation patients with a mean age of 15, the majority of whom were male (Seeley et al., 2013). In addition, most of the patients had open growth plates, although the criteria used to identify open growth plates were not presented in the published article (Seeley et al., 2013). In comparison to our sample, patients were not limited in age and thus all patients with an osteochondral fracture after patellar dislocation were included. In the current study, the median age (median 17 years, IQR 14 – 22 years) and proportion of patients with closed growth plates (64.5%) were higher. However, in our study, the ages or proportions of the skeletally mature patients did not differ between those with a patella and those with a femoral osteochondral fracture. Therefore, the findings are in line with Nietosvaara et al., who found that the morphology of the patellofemoral joint remains constant during growth (Nietosvaara et al., 1994). Hence, the physical stress on the articular surfaces of the patellofemoral joint remains unchanged throughout growth. Based on this, it is reasonable to assume that the biomechanics of patellar dislocation do not markedly change either.

In a study by Sillanpää et al. on the incidence of primary patellar dislocation among male conscripts with a mean age of 20, all the patellar dislocations occurred during sports or sports-related military training (Sillanpää et al., 2008a). This finding suggests that first-time patellar dislocations occurring in late adolescence or early
adulthood are in large part related to sports. During sports, the patellofemoral joint is exposed to high energy and rapid changes of direction. Although, in the current study, the patients were younger and the trauma mechanism was not examined, these findings suggest that osteochondral fractures during first-time patellar dislocation may well be associated with high trauma energy during sports.

The gender distribution in the current study is in line with that previously reported among patellar dislocation patients (Fithian et al., 2004; Hsiao et al., 2010; Nietosvaara et al., 1994; Sanders et al., 2018). This finding suggest that the risk for osteochondral fracture is equal between the sexes. In females, osteochondral fractures after patellar dislocation were more frequently located in the patella than femur. In males, the corresponding distribution was rather even. In contrast, Seeley et al., in a sample with a male majority, made no such observations (Seeley et al., 2013). This discrepancy between studies may be explained by the small size of the sample studied by Seeley et al. (Seeley et al., 2013).

In the normal knee, the main stabilizing structure of the patella in the medial direction is the MPFL. During patellar dislocation, the MPFL is injured in almost every case (Nomura et al., 2002; O'Reilly et al., 2003; Sanders et al., 2001; Vainionpää et al., 1986). Thus, after first-time patellar dislocation, the biomechanics of subsequent patellar dislocations are altered, as the patella may move laterally more easily and hence dislocate more easily, even in cases with low trauma energy and lower impact on the articular surfaces of the patellofemoral joint. In our study, osteochondral fractures located in the patella were significantly larger after primary patellar dislocation than those following recurrent dislocations. The locations of osteochondral fractures did not differ between primary and recurrent patellar dislocations. It has been hypothesized that an osteochondral fracture occurs following spontaneous relocation of the patella induced by mild knee joint flexion rather than actual lateral dislocation of the patella (Milgram, 1943; Nietosvaara et al., 1994; Rorabeck et al., 1976; Savarese et al., 1990; Scheller, 1974). On this hypothesis, after actual lateral dislocation of the patella and concomitant MPFL injury in cases of primary dislocation, the biomechanics governing the spontaneous relocation of the patella are the same in both primary and recurrent dislocations. If so, this would mean that the risk for osteochondral fracture is the same in primary and recurrent dislocations. However, the size of the osteochondral fractures differed between primary and recurrent dislocations. It is likely that, during actual primary dislocation, higher impact is directed on the articular surfaces of the patellofemoral joint, causing extensive micro traumas in the subchondral bone, than in recurrent dislocations. This may predispose to larger osteochondral fractures in primary patellar dislocation.
According to the findings of Study III, anatomical malformations are prevalent in patellar dislocation patients with and those without an osteochondral fracture. However, the two groups differed in their knee anatomy. Among the patients without an osteochondral fracture, both trochlear malformation and patella alta were more severe, whereas in patients with an osteochondral fracture patellar lateralization was more severe. No evidence was found of an association between the location of osteochondral fractures and anatomical measures except for trochlear facet asymmetry, which was more severe in patients with an osteochondral fracture located in the patella than in those with an osteochondral fracture in the femur.

The contact surface of the patellofemoral joint is smaller the higher the patella lies in relation to the trochlea. An abnormally high lying patella, patella alta, has repeatedly shown an association with patellar instability (Diederichs et al., 2010; Simmons et al., 1992). In both patient groups in this study, nearly all the patients exhibited patella alta in the means of at least one of the patellar height measures, i.e., the PTI, ISI or CDI. Patients with an osteochondral fracture had a significantly higher PTI. The PTI is a ratio that directly indicates the area of the patellofemoral contact surface in relation to the size of the patella. The observed mean of the CDI was also higher in the osteochondral fracture patients, although the difference between the groups did not meet the predefined eligibility criterion that the the mean of the group without an osteochondral fracture is within the 95% CI of the mean of the group with an osteochondral fracture. The ISI, in turn, did not show a marked difference between the two groups. In theory, better patellofemoral stability may reflect a larger contact surface, as indicated by a higher PTI value, as the patella is more firmly seated against the trochlear groove. Therefore, in patients with a higher PTI, higher energy may be required to dislocate the patella over the lateral condyle of the femur. Thus, the occurrence of patellar dislocation results from the higher forces exerted on the articular surfaces, thereby also elevating the risk for an osteochondral fracture. However, although the PTI values indicated less severe patella alta, the CDI values indicated more severe patella alta in the patients with an osteochondral fracture. Ane explanation for this discrepancy may be that the CDI depends on two relatively distinct parameters. First, the CDI describes the vertical position of the patella in relation to the tibia. Second, the CDI is affected by the size of the patella. In cases where the vertical diameter of the patella is small, the CDI may indicate patella alta even if the patella is properly located, as the smaller the patella and its articular surface, the greater the pressure exerted on the articular surface. As a result, patients with a higher CDI owing to a smaller patella articular surface may also be at higher risk for osteochondral fracture. However, since the
CDI values depend on both the size and vertical location of the patella, dispersion in the observed values is likely to be higher, a situation which increases uncertainty about the association between the CDI and risk for osteochondral fracture.

A laterally located patella, where the patella lies closer to the lateral edge of the lateral trochlear facet, has been shown to predispose to patellar dislocation (Brady et al., 2018; Diederichs et al., 2010). The TT-TG and TT-PCL values indicated that excessive lateralization of the patella was prevalent in both patients with and those without an osteochondral fracture. In patients with higher TT-TG and TT-PCL values, the force needed to dislocate the patella may be lower than in those with lower values. Thus, it would seem reasonable to assume that the risk for osteochondral fracture after patellar dislocation is higher in patients with lower TT-TG and TT-PCL values. Nevertheless, the findings of this study did not support this assumption. Instead, we found that lateralization was more prominent in the patients with an osteochondral fracture. In these patients, the TT-PCL value, although not TT-TG value, met the eligibility criterion. One potential explanation for this observation is that an abnormally lateral lying patella imposes a chronic excessive burden on the lateral trochlear facet. As found in histological studies, a prolonged excessive burden on joint surfaces activates endochondral ossification and degradation of the subchondral bone tissue matrix, which may predispose to the occurrence of microcracks in the subchondral bone (Danova et al., 2003; Muir et al., 2006; Nagaraja et al., 2005). In the prolonged condition, the accumulation of damage may increase the risk for osteochondral fracture during patellar dislocation. To further elaborate the hypothesis, the effects of a lateralized patella on the subchondral bone should be further studied.

With a few exceptions among the patients with an osteochondral fracture, almost all the patients in this study had an abnormal trochlear anatomy. Of the identified anatomical risk factors for patellar dislocation, trochlear dysplasia has been found to most accurately predict the recurrence of patellar dislocations (Lewallen et al., 2015).

In the patients without an osteochondral fracture, trochlear asymmetry, indicating medial hypoplasia, was more prominent. However, the trochlear depth measures also appeared to be higher in these patients. The mean sulcus angle did not show a marked difference, although the proportion of abnormal values was higher in the patients without compared to those with an osteochondral fracture. Due to technical issues in the measurement of trochlear depth, severe malformation of the medial trochlea leads to unreliable values, as the observed value may indicate normal depth even if the trochlea is in fact flat.
Comparison of the patients with a patellar and those with a femoral osteochondral fracture showed higher trochlear facet asymmetry in the patients with a patellar injury. One potential explanation for this finding may reside in patellar morphology. As the patellofemoral joint develops during growth, the articular surfaces of the patella and trochlea conform to each other (Bland et al., 1996; Ito et al., 2000). As a result, in patients developing medial trochlear hypoplasia, the medial patellar facet also becomes hypoplastic. In a patella with a pronounced lateral compared to medial facet, the greater sharpness of the patellar ridge may render it vulnerable to an osteochondral fracture. However, as we did not take patellar morphology into account, this possibility could not be further elaborated.

To summarize, the anatomy of the knee joint differs between patients with and those without an osteochondral fracture after patellar dislocation. Differences were detected in all three aspects of the patellofemoral anatomy, patellar height, patellar lateralization, and trochlear morphology. These differences are likely associated with risk for osteochondral fracture after patellar dislocation. However, since the distributions of the anatomical measures in the groups were highly overlapping, wholly unambiguous predictors of osteochondral fractures could not be identified. The occurrence of an osteochondral fracture is probably a multifactorial phenomenon that is affected by a complex combination of anatomical, histological, and biomechanical factors. Nonetheless, when determining the appropriate treatment for patellar dislocation patients with an osteochondral fracture, it may be beneficial to assess the causes of the osteochondral fracture. In this study, we have provided threshold values indicating increased risk for osteochondral fracture for both the PTI and TT-PCL, and for trochlear facet asymmetry and trochlear condyle asymmetry. A threshold value for trochlear depth was also determined. However, due to the high risk for bias in using this measure in patients with severe medial hypoplasia, the threshold should be applied cautiously.

The findings of Study IV showed that the primary treatment approach, whether conservative or surgical, was definitive in the majority of patients. However, one-fourth of the patients needed later surgery and one-sixth of those who underwent surgery needed a reoperation. Stabilizing procedures were used in almost all the surgical patients. Knee pain was lowest in the late surgery group and highest in the conservative treatment group. Functionality scores showed a similar trend, with the highest scores in the late surgery group and slightly better scores in the primary surgery group compared to conservatively treated patients.

In the study hospitals, the primary treatment decision after patellar dislocation with concomitant osteochondral fracture is based on the clinical characteristics of
both the patient and injury. These characteristics include the location and size of the osteochondral fracture, previous occasions of patellar instability, and anatomical and clinical findings. The target of surgery in the primary phase is either to restore the articular cartilage or stabilize the patella to prevent chronic instability, or both. In the later phase, the patient’s symptoms become more important in the decision on possible surgical procedures. Thus, later procedures may be more targeted to treat the specific symptoms of the patient.

In the majority of the primary surgery patients, the osteochondral fragment was successfully reimplanted. It is likely that in some proportion of the patients with removal of the osteochondral fragment, this was done after failed reimplantation. The osteochondral fractures were larger in the primary surgery group. The smaller osteochondral fractures in the conservatively treated group may indicate a less severe lesion in the articular cartilage as well as less severe symptoms in the longer term. In the late surgery group, the osteochondral fragment was removed in all patients except one. These findings are in line with the treatment protocol and the main goal of restoring articular cartilage surfaces in primary surgery. Late surgery, in turn, was targeted at managing possible symptoms caused by a floating loose fragment, such as knee locking, crepitation and pain, as well as persistent patellar instability. Cartilage restoration was no longer the primary target. A major proportion of surgically treated patients had undergone MPFL reconstruction. Other stabilizing procedures were rarely used. This may reflect the trend towards the prevention of recurrent patellar dislocations, including in patients with an osteochondral fracture following the first patellar dislocation. Cartilage restoration chondroplasties, such as microfracturing, osteochondral autografts and autologous chondrocyte implantation, were only used on rare occasions.

Differences between the groups in patellofemoral anatomy and in the location of osteochondral fractures were modest. Anatomical malformations of the patellofemoral joint allow less restricted laterally directed movement of the patella, thereby decreasing the energy needed for the patella to dislocate (Huntington et al., 2020). Thus, in patients with a normal anatomy, the trauma energy needed is higher and the risk of recurrent dislocations is lower. In the current study, the patellar height parameters and trochlear depth indicated pronounced malformations among the late surgery patients. Among these patients the proportion with previous patellar dislocations before the occurrence of the osteochondral fracture was higher than in the other groups. Along with the low rate of osteochondral fracture reimplantations and high rate of MPFL reconstructions among the late surgery patients, these findings are in line with the treatment protocol, suggesting that the main indication for surgery was patellar instability rather than cartilage restoration. The
Osteochondral fractures differed in size between the patients in the primary surgery and conservative treatment groups, being larger in the primary surgery patients. This suggests that fracture size played a key role in determining the primary treatment approach. In turn, patients suffering from persistent patellar instability or symptoms related to an intra-articular loose fragment may be referred for late surgery while the others are treated according to the primary treatment decision.

Patient-reported outcomes indicated relatively good functionality, pain and knee-related quality of life. However, the primary surgery patients reported worse overall pain and pain during movement than those in the other groups. This may be at least partly related to the larger size of the osteochondral injury in the primary surgery patients. In addition, large size of the cartilage lesion may have accelerated cartilage degeneration during the 6-year follow-up in the primary surgery patients (Guettler et al., 2004), which in turn may be related to higher reported pain. The outcomes were generally acceptable in patients treated either conservatively or with late surgery. This finding may be attributed to the meticulous rehabilitation program in the primary phase. Active primary rehabilitation without immobilization and prolonged pain due to surgery may have improved the long-term outcomes in these patients (Dixit et al., 2017; Moiz et al., 2018; Smith et al., 2010). However, since no data on rehabilitation were available, we could not further elaborate these possibilities. No clearly common factors in injury quality, anatomy, primary treatment approach or recurrence of dislocations were found among the patients with the poorest self-reported outcomes.

Due to the two-dimensional problematic involving both an articular cartilage lesion and patellar instability, the treatment of patellar dislocation with concomitant osteochondral fracture is challenging. In the current study, the outcomes achieved by the presented protocol were generally acceptable. However, surgical procedures are often needed after the primary treatment decision, whether conservative or surgical. The present findings suggest that as the outcomes between the primary surgery patients with a reimplanted and those with a removed osteochondral fragment were comparable, primary reimplantation may not be necessary in all cases. In addition, the conservatively treated patients showed excellent outcomes. Nevertheless, further research is needed to ascertain which patients could best be treated conservatively in the primary phase and which would benefit more from primary reimplantation.
6.1 Strengths and limitations

Study I was performed using register data from the NHDR database. The nationwide population-based sample covered all surgical operations for patellar dislocation in Finland during the 20-year study period. The NHDR has been shown to provide accurate information with good coverage of all surgical treatments in Finland (Huttunen et al., 2014; Mattila et al., 2008; Sund, 2012).

The inability of the NSPC procedure coding system to differentiate specific procedures for treating patellar dislocation may be considered the main weakness of the study. Since several procedure codes may contain a variety of actual procedures, the incidences of specific procedures could not be further examined. Moreover, the procedure codes may include improper procedures. To reduce this potential bias, only procedures performed more than 100 times during the study period were included in the analysis. In addition, only patients who had undergone surgery with a diagnosis of patellar dislocation were included in this study. Therefore, the study population did not contain patellar dislocation patients who had not undergone surgical treatment. In practice, the decision on surgical versus non-surgical treatment is based on a clinical and radiological examination and made by the treating surgeon. Thus, it is unlikely that patients with no effective episodes of patellar dislocation end up having surgical treatment. However, if the MRI taken due to recurrent patellar instability symptoms unambiguously reveals anatomical risk factors for patellar dislocation, the surgeon may decide to operate on the knee even if no effective episodes of patellar dislocation have occurred. Hence, it is possible that the patient sample also includes a few patients with no effective episodes of patellar dislocation.

As the NHDR does not contain information on the side of the operated knee, the data did not allow further examination of reoperation rates or of the techniques used in subsequent operations. Due to this limitation, this study only observed general nation-wide trends in the procedures performed for patellar dislocation. The treatment of individual patients and outcomes and reoperation rates after particular procedures could not be included. A change in the incidence of a procedure does not directly reflect the outcome of that procedure. Therefore, the outcomes of procedures and changes in the trends of patellar dislocation surgery remain unclear. To shed light on this issue, the effect of combining and tailoring surgical techniques according to the individual patient’s anatomy on the recurrence of patellar dislocation, functionality and reoperation rate should be examined in a prospective randomized study.
The sample of patients with an osteochondral fracture in this dissertation research (Studies II, III and IV) was collected from the catchment area of two hospital districts in Finland in a multicenter study design. All patients treated in the study hospitals were screened. Inclusion criteria were relatively strict to promote homogeneity of the injury of interest as well as the comparability of the measures between patients with and without an osteochondral fracture. In addition, the effects of potentially confounding factors were mitigated by properly conducted matching of the patient groups. The final sample comprised the largest series of osteochondral fracture patients after patellar dislocation that has been researched thus far.

Although chondral fractures may be considered as on the same spectrum as patellar dislocation effects as osteochondral fractures, the treatment has been different. Owing to the limited mitotic activity of chondrocytes, cartilage lesions have been believed to have poor healing capacity and hence the chance that a chondral fragment will reattach to bone is also poor (Campbell, 1969; Mankin, 1982). However, if the loose fragment contains subchondral bone, the possibility of healing is thought to be better owing to the belief that bone-to-bone has better healing capability than cartilage-to-bone (Dines et al., 2008; Morris et al., 2016; Nakayama et al., 2014). Thus, in cases of chondral fractures, surgeons may prefer removing the loose fragment before reimplantation, while in cases of osteochondral fractures, reimplantation is the primary goal. However, although reimplantation have not yet been adopted as the dominant treatment approach, case series on the successful reimplantation of chondral fragments have been published (Chan et al., 2014; Churchill et al., 2019; Morris et al., 2016; Nakamura et al., 2004; Nakayama et al., 2014). Due to the difference between the treatment approaches to chondral and osteochondral fractures, chondral fractures were excluded from the current study.

Radiographic examination was conducted by two independent evaluators who were blinded to each other’s results. All discrepancies were resolved by mutual reassessment. The rigorous radiological examination performed in this study improves the reliability of measurements and hence the reliability of the overall results.

The main limitation of this study is its retrospective design. Owing to this design, information on other potential factors related to patellar instability and risk for osteochondral fracture, such as trauma mechanism and generalized joint laxity, could not be retrieved.

Although hospital guidelines state that all primary patellar dislocation patients should be referred for MRI, this had not been the case for almost half of the patients. There might be several reasons for this. First, the emergency physician makes the primary assessment of the knee injury. If the injury is interpreted as non-severe, the
patient may not be referred to the orthopedic unit after primary care despite a diagnosis of patellar dislocation. Further, if the injured knee had recovered well, the patient may not have sought further treatment, and hence an MRI may not have been performed. Moreover, patients with insurance may prefer to seek help from a private sector hospital after primary care in one of the study hospitals. Therefore, we were unable to gain a complete picture of all injuries.

Not all the control patients without an osteochondral fracture may have been the most suitable for the purposes of the study. As the controls were selected randomly from a pool of suitable patients, the risk of selection bias cannot be excluded. To control for this possibility, propensity score matching was used. The matching was conducted by using variables that are known to be associated with the anatomical parameters of the knee joint. Nevertheless, since the development of the human knee is a complex phenomenon, other underlying factors that confound the association between the anatomical parameters and risk of osteochondral fracture may exist.

Lastly, in Study IV, the relatively small number of patients who completed the outcome questionnaires limits the generalizability of the results. In addition, the actual effect of conservative treatment could not be studied owing to the lack of standardized conservative treatment or rehabilitation protocols. Despite these shortcomings, the data for each individual patient were otherwise extensive and granular.
Advances in patellar dislocation treatment during recent decades have increased the trend towards individual patient-tailored surgery with special focus on the patient’s anatomical and injury characteristics. Despite the largely unchanged incidence of surgical operations for patellar dislocation over the past two decades, surgical techniques have shifted towards the reconstruction of damaged structures and the modification of congenital anatomical risk factors for patellar dislocation.

Osteochondral fractures sustained during patellar dislocation were most commonly located in the medial patellar facet or in the lateral femoral condyle and accounted for approximately two-thirds and one-third of cases, respectively. Women were found to have a higher proportion of osteochondral fractures in the patella than men. Osteochondral fractures sustained after primary patellar dislocation were larger than those sustained after recurrent dislocation.

Anatomical malformations of the patellofemoral joint were equally prevalent in patients with and in those without without an osteochondral fracture. However, the patterns of the malformations differed between the two groups in patellar height, patellar lateralization and trochlear morphology. In the patients without an osteochondral fracture, patellar height and trochlear morphology indicated more severe malformation whereas patellar lateralization was more pronounced in the osteochondral fracture patients.

Although in the majority of patients the primary treatment approach was definitive, a high proportion required surgery later on. The main goal in primary phase surgery was to restore the articular cartilage by reimplantation of the osteochondral fragment. Late surgery, in turn, aimed to relieve prolonged symptoms by removing loose fragments that cause pain or loss of functionality and to improve patellar stability. The treatment protocols used in the study hospitals yielded generally good outcomes.

According to this dissertation research, the treatment of patellar dislocation, anatomical malformations, and concomitant injuries have substantially evolved during recent decades. However, patients with osteochondral fractures after patellar dislocation are vulnerable to two types of risk: the risk of chronic patellar instability and cartilaginous injury, and the risk of degeneration of the patellofemoral articular
cartilage in the long term. Therefore, the treatment of patients with patellar dislocation and concomitant osteochondral fracture continues to present clinicians with challenges.

The new findings on the anatomical properties of osteochondral fractures and related knee anatomy presented in this dissertation will facilitate the expansion of tailoring to include the treatment of patellofemoral osteochondral fractures. Further research on tailored surgical procedures and standardized conservative treatment is needed. In addition, long-term outcomes on cartilage degeneration remain to be determined.


First-Time Traumatic Patellar Dislocation: A Randomized Controlled Trial. 


Kuss, O. (2013). The $z$-difference can be used to measure covariate balance in matched propensity score analyses. *J Clin Epidemiol, 66*(11), 1302-1307.


outcome after medial patellofemoral ligament reconstruction and tibial tuberosity medialisation. *Arch Orthop Trauma Surg, 137*(8), 1087-1095.


SUPPLEMENTARY
### Appendix 1. Clinical details of patients with the worst patient-reported outcomes.

<table>
<thead>
<tr>
<th>Group</th>
<th>Sex</th>
<th>Age</th>
<th>Fu years</th>
<th>Previous PD</th>
<th>Outcomes</th>
<th>OCF</th>
<th>Patellar height</th>
<th>Patellar lateralization</th>
<th>Trochlear configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ps</td>
<td>M</td>
<td>21.2</td>
<td>6.9</td>
<td>No</td>
<td>71 31</td>
<td>30</td>
<td>293</td>
<td>Flc</td>
<td>1.32 1.38 0.66</td>
</tr>
<tr>
<td>C</td>
<td>M</td>
<td>19.0</td>
<td>5.6</td>
<td>No</td>
<td>70 38</td>
<td>70</td>
<td>117</td>
<td>Flc</td>
<td>1.33 1.31 0.46</td>
</tr>
<tr>
<td>C</td>
<td>F</td>
<td>25.1</td>
<td>4.7</td>
<td>No</td>
<td>76 25</td>
<td>65</td>
<td>158</td>
<td>Pmf</td>
<td>1.28 1.11 0.50</td>
</tr>
<tr>
<td>C</td>
<td>M</td>
<td>20.9</td>
<td>4.3</td>
<td>Yes</td>
<td>46 44</td>
<td>50</td>
<td>89</td>
<td>Pmf</td>
<td>1.17 1.15 0.43</td>
</tr>
</tbody>
</table>

Ps = Primary surgery, C = Conservative, Fu = Follow-up, PD = patellar dislocation, OCF = osteochondral fracture, SA = Sulcus angle, TD = Trochlear depth, TFA = Trochlear facet asymmetry, TCA = Trochlear condyle asymmetry, LTIA = Lateral trochlear inclination angle, Flc = femur lateral condyle, Pmf = patellar medial facet
Surgery for patellar dislocation has evolved towards anatomical reconstructions with assessment and treatment of anatomical risk factors

Uimonen Mikko, Repo Jussi, Huttunen Tuomas, Nurmi Heikki, Mattila Ville, Paloneva Juha

Knee Surgery, Sports Traumatology and Arthroscopy. https://doi.org/10.1007/s00167-020-06277-x

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Surgery for patellar dislocation has evolved towards anatomical reconstructions with assessment and treatment of anatomical risk factors

Mikko M. Uimonen1 · Jussi P. Repo1 · Tuomas T. Huttunen2,3,4 · Heikki Nurmi1 · Ville M. Mattila3,4,5 · Juha Paloneva1,6

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Abstract

Purpose Increasing knowledge on the treatment of patellar dislocation has resulted in the development of new surgical techniques for patella stabilisation. National incidence and trends in surgery for patellar dislocation were examined using data from the Finnish National Hospital Discharge Register (NHDR). The hypothesis was that an increased understanding of the pathophysiology of patellar instability has increased the popularity of reconstructing damaged structures and modification of anatomical risk factors.

Methods Data from the years 1997–2016 were collected from the NHDR database using ICD-10 diagnostic codes and the Nomesco Classification of Surgical Procedures (NCSP) codes. Surgical procedures were categorised into subgroups representing the main surgical approaches of patellar dislocation. Total incidence of surgery for patellar dislocation and change in incidence during the study period were calculated.

Results A total of 9702 operations for patellar dislocation were performed during the study period. Median (IQR) patient age at time of primary surgery was 23 (18–34) years. The total incidence of surgeries remained stable across the study period at of 8.9 per 100,000 person-years. Incidences of ligament reconstruction, femoral osteotomies and osteochondral fragment reimplantation operations multiplied during the study period. Ligament reconstruction procedures were the most performed operations at the end of the study period.

Conclusion The incidence of surgical procedures for patellar dislocation remained unchanged during the years 1997–2016. Ligament reconstruction procedures increased in popularity. Surgical techniques have shifted towards the reconstruction of damaged structures and the modification of congenital anatomical risk factors for patellar dislocation. Diversified surgical techniques have enabled the tailoring and combining of stabilizing procedures according to the patient’s individual anatomy.

Keywords Patellar dislocation · Patellar dislocation surgery · Incidence · Knee injury

Introduction

Lateral patellar dislocation is a common knee injury in the young, active population [3, 17, 35]. Indeed, previous studies have found the incidence of acute patellar dislocation to be between 23 and 77 per 100,000 person-years, depending on the demographics of the target population [21, 42, 45]. Peak incidence, estimated to be 148 per 100,000 person-years, occurs between the ages of 14 and 18 [43]. The incidence has been shown to decline with age [43]. Among the female population, this decline begins at an earlier age (14–18 years) than among the male population (19–25 years) [43]. According to the findings of a 10-year follow-up study, 23% of patients with patellar dislocation suffered a recurrent dislocation [21]. The risk of recurrent dislocation is
Based on clinical experience, primary acute patellar dislocation is generally treated conservatively. However, in cases of osteochondral fracture, where a loose fragment of bone is detected inside the knee joint, surgery is the first-line treatment [47, 48]. If patellar dislocation recurs, surgical patellar stabilisation may be indicated [47]. At present, however, consensus on the best treatment recommendations and guidelines for primary patellar dislocation is lacking [47]. A recent meta-analysis by Yang et al. comprising 16 randomised controlled trials (RCT) or cohort studies published between 1986 and 2018 cautiously concluded that surgical treatment might also be more favourable than conservative treatment for patients with their first patellar dislocation [53]. This conclusion was based on the finding that surgically treated patients had higher Kujala scores (anterior knee-specific patient-reported outcomes) and a lower rate of re-dislocations compared with conservatively treated patients. Nevertheless, due to the rapid development of surgical techniques during the past few decades, the conclusion was based on heterogenous study populations. Previous results have indicated that not all surgical techniques are as equally effective [2, 5, 46, 50, 53].

The purpose of the present study was to investigate trends in the surgical treatment of patellar dislocations between the years 1997 and 2016 using nationwide data from the Finnish population-based register of medical treatment. The hypothesis was that an increased understanding of the pathophysiology of patellar instability has led to an increase in the popularity of the reconstruction of damaged structures and the modification of anatomical risk factors. Moreover, knowledge on current trends in the surgical treatment of patellar dislocation in relation to recent research may provide an important insight into the future prospects of different approaches to the surgical management of patellar dislocation.

### Materials and methods

Based on the Medical Research Act (488/1999), ethical approval is not required for register-based studies in Finland. Data were extracted from the Finnish National Hospital Discharge Register (NHDR, National Institute of Health and Welfare, Finland). Information on hospital admissions (both inpatient and outpatient) and treatment events in every Finnish hospital are recorded in the NHDR. The NHDR contains data on patient age and sex, length of hospital stay, patient’s domicile, and diagnoses and procedures performed during the hospital stay. The register is mandatory for all private and public sector hospitals in Finland. The coverage and accuracy of the NHDR for surgical treatment have proven to be excellent [24, 31, 49].

All patients who had undergone surgery for patellar dislocation between 1 January 1997 and 31 December 2016 were included in the study. A data search was conducted using the codes S83.0, M22.0 and M22.3 from the International Classification of Diseases, 10th revision (ICD-10, WHO) and applicable codes from the Nomesco Classification of Surgical Procedures (NCSP) (Finnish version). Combining the procedure code with patellar dislocation diagnosis in patient selection was assumed to mitigate the bias caused by the fact that the same procedure codes may apply in diverse procedures. Information was obtained on age, gender, diagnoses and the surgical procedures performed.

To better focus on the most relevant procedures, those procedures performed fewer than 100 times during the study period were excluded from the analysis. In total, 16 surgical procedure codes for patellar dislocation were selected for review. The codes were then grouped as presented in Table 1. Because the procedure codes used in patellar dislocation surgery are not completely specific, explanations of the procedures included for each group were made based on clinical experience.

### Statistical analysis

The total and annual incidences of surgical procedures for patellar dislocation were calculated using annual population register data published by Statistics Finland (https://www.stat.fi/index_en.html). The total incidence of operations was calculated by extracting from the NHDR all the surgical operations for patellar dislocation identified by applying the relevant diagnostic and procedure codes. In calculating the total incidence of operations, an individual operation was counted as one, even if more than one procedure code was recorded in the same operation. In addition, the incidence of each procedure type was examined separately. In contrast to the total incidence calculation, when calculating the incidence of each procedure type, each procedure code was counted as one also in cases where a single operation was recorded under more than one procedure code. Total incidence was reported per 100,000 person-years and annual incidence per 100,000 persons. As the register data used in incidence calculations were based on the total population of the country, the resulting total and annual incidences of each procedure represent the genuine incidence. Thus, no statistical estimation methods, such as 95% confidence interval calculations, were used. The analysis was performed using R 3.6.1 statistics software [40].
Results

By applying the relevant procedure codes, 9702 surgical operations for patellar dislocation were identified in 8333 patients during the study period. Of these, 61% were female \( (n = 5071) \). Median (IQR) patient age at the time of surgery was 23 (18–34) years, ranging from 4 to 88 years. The ages and sex distribution remained stable across the study period (Fig. 1). The incidence of surgical procedures for patellar dislocation remained stable between the years

<table>
<thead>
<tr>
<th>Procedure codes</th>
<th>Includes</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGE60; NGE65</td>
<td>MPFL or MPTL reconstruction or repair</td>
</tr>
<tr>
<td>NGL66; NGL30; NGK99</td>
<td>Tibial tubercle transfer</td>
</tr>
<tr>
<td>NGL66</td>
<td>Patellar tendon shift</td>
</tr>
<tr>
<td>NGL30</td>
<td>Imbrication of vastus medialis</td>
</tr>
<tr>
<td>NGL66</td>
<td>Trochleoplasty</td>
</tr>
<tr>
<td>NGL30</td>
<td>Varus-producing osteotomy of femur</td>
</tr>
<tr>
<td>NGK99</td>
<td>Torsional osteotomy of femur</td>
</tr>
<tr>
<td>NGF30</td>
<td>Open or arthroscopic reimplantation of osteochondral fractures</td>
</tr>
<tr>
<td>NGF35</td>
<td>Arthroscopy</td>
</tr>
<tr>
<td>NFD30; NFD35</td>
<td>Loose fragment removal</td>
</tr>
<tr>
<td>NFD30; NFD35</td>
<td>Plica resection</td>
</tr>
<tr>
<td>NFD30; NFD35</td>
<td>Menisci debridement</td>
</tr>
<tr>
<td>NGE10; NGE15</td>
<td>Lateral capsular release</td>
</tr>
<tr>
<td>NGH20</td>
<td>Unspecified procedures</td>
</tr>
</tbody>
</table>

The included procedure codes were used together with patellar dislocation diagnosis. Each included procedure code was used more than 100 times during the study period.

Fig. 1 Age and sex distributions of the patients during the study period. Points represent median age at the time of the surgery and whiskers show the interquartile range. Bars represent annual count of males and females undergoing surgery
1997 and 2016 (8.9 in 1997 vs. 10.1 in 2016; see Fig. 2) with a total incidence of 8.9 per 100,000 person-years.

At the end of the study period, the most prevalent patellar dislocation operations were ligament reconstructions (Table 2). The incidence of ligament reconstruction procedures accelerated rapidly after the year 2009 and continued to rise until the end of the study period (Fig. 3). In turn, the incidence of debridement procedures, which had been the most performed procedures, remained stable across the study period. The incidence of ligament procedures overtook debridement procedures after the year 2015. The most prominent change occurred in the incidence of femoral osteotomy procedures. The rise in popularity of these procedures began after 2011. Thereafter, the incidence rose by 227% until the end of the study period (Fig. 3). The incidence of trochleoplasties forms a slightly U-shape curve with higher incidence at the beginning of the study period followed by a lower incidence until 2014. Subsequently, the incidence rose towards the end of 2016. The incidence of femoral osteotomy and trochleoplasty procedures was, however, still low when compared to the other procedures. Furthermore, the incidence of procedures concerning the reimplantation of osteochondral fragments after patellar dislocation rose steadily across the study period with a total rise of 152%. Extensor realignment procedures remained stable with only a 2% increase. On the other hand, the incidence of capsular release procedures decreased after 2001 with a total decrease of 82% until the end of the study period. In addition, the popularity of the procedure code for unspecified knee dislocation procedure (NGH20) decreased 79% across the study period.

### Table 2 Incidence and percentage change by procedure type

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Incidence per 100,000 persons</th>
<th>Total change, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ligament reconstruction or repair</td>
<td>1.11</td>
<td>424</td>
</tr>
<tr>
<td>Femoral osteotomy</td>
<td>0.00</td>
<td>NA</td>
</tr>
<tr>
<td>Extensor realignment</td>
<td>0.89</td>
<td>+2</td>
</tr>
<tr>
<td>Trochleoplasty</td>
<td>0.25</td>
<td>+80</td>
</tr>
<tr>
<td>Debridement</td>
<td>4.68</td>
<td>+13</td>
</tr>
<tr>
<td>Reimplantation of OCF</td>
<td>0.64</td>
<td>+152</td>
</tr>
<tr>
<td>Capsular release</td>
<td>0.91</td>
<td>−72</td>
</tr>
<tr>
<td>Unspecified procedures</td>
<td>3.03</td>
<td>−79</td>
</tr>
</tbody>
</table>

*OCF osteochondral fracture, NA non-applicable*

### Discussion

The main finding of this study on patellar dislocation surgery, using nationwide register data, was that the total incidence of surgery for patellar dislocation has remained relatively stable. However, the incidences of ligament reconstruction and repair procedures, femoral osteotomies and the reimplantation of osteochondral fragments increased during the study period. However, the incidence of debridement and extensor realignment procedures have remained unchanged and the incidence of lateral releases has decreased. The peak incidence of patellar dislocation has been reported to occur between the ages of 14 and 18 [43]. In the current study, the median age of the patients was 23 with no prominent changes across the study period.
**Evolution of patellar dislocation surgery**

During the twentieth century, the most common surgical procedures for the treatment of patellar instability were probably those originally described by Roux and Goldthwait, Galeazzi et al. and Hauser et al. In the late nineteenth century, Roux and Goldthwait, presented a technique in which the lateral part of the patellar tendon is transferred medially to enhance the medial support of the patella [19, 22, 41]. Later, in the early twentieth century, Galeazzi et al. introduced a medial patello-tibial ligament reconstruction technique using a semimembranosus tendon graft [18]. Hauser et al. increased the repertoire of techniques for managing patellar instability with a technique combining tibial tubercle distalisation and medialisation with the release of the lateral retinaculum and imbrication of the vastus medialis tendon [22]. In the late twentieth century, arthroscopic procedures enabling mini-invasive surgical procedures, such as isolated arthroscopic lateral capsular release and arthroscopic debridement procedures, were introduced [13]. Open stabilising techniques, such as torsional osteotomies of the femur or tibia, trochleoplasty, tibial tubercle transfer and medial patello-femoral ligament (MPFL) reconstruction, have also been developed during the past three decades [4, 8, 15, 16, 29, 30, 39, 44]. Today, thanks to a greater knowledge of natural history and the anatomical factors associated with patellar instability as well as increasing expertise in management techniques for individual anatomic abnormalities and technological advancements, treatment can be increasingly tailored to the individual patient’s anatomy [10].

**Recent patellar dislocation surgery trends**

According to the results of the present study, ligament reconstruction or repair procedures have become the gold standard in patellar dislocation surgery. The increase in these
procedures took place during the years 2007–2009 and was preceded by a substantial increase in research on MPFL reconstruction [6, 7, 12, 36, 37]. Since Gomez et al. introduced the MPFL reconstruction technique using a synthetic polyester ligament graft [20] and Avikainen et al. presented their technique using abductor magnus tenodesis [4], the number of studies on MPFL reconstruction in cases of patellar instability have increased. The results of these studies have consistently shown efficacy in the reduction of recurrent patellar dislocations in patients receiving MPFL reconstruction compared to those treated non-surgically [2, 47, 53, 54]. However, functionality outcomes have shown more inconsistent results [2, 47, 53, 54]. In the literature, MPFL reconstruction continues to be the most recommended surgical management technique for patellar dislocation. Moreover, if the patient has anatomical risk factors for patellar dislocation, the risk for recurrent dislocation remains high even after successful MPFL reconstruction [26]. Thus, to manage the anatomical risk factors, MPFL reconstruction alone might not be enough and should instead be combined with bony procedures [26, 33, 34].

During last 2 decades, femoral osteotomy procedures for patellar instability caused by axial deformities of the lower extremity have been developed. These techniques include varus-producing osteotomy for correcting excessive valgus malalignment of the knee joint [29, 39] and torsional osteotomies of the femur for correcting torsional malalignment [8, 16]. In the current study, the rise in incidence of these osteotomies were seen after 2011. The present findings suggest that femoral osteotomies are becoming more widespread in patients with patellar instability and may provide an additional approach to ligament reconstruction procedures.

Remodelling of the femur trochlea was originally introduced in the early twentieth century by Albee et al. who presented lateral facet elevation trochleoplasty [1]. During the 1970s and 80 s, Masse et al. presented a new trochleoplasty technique, with deepening of the trochlear sulcus, that was later modified by Dejour et al. [15, 30]. Currently, the main indication for trochleoplasty is dysplastic trochlea, which predisposes the patella to dislocate laterally. Research on the outcomes of trochleoplasty procedures increased during the early 2000s with promising results [14, 38, 50, 52]. According to the results of the current study, the popularity of trochleoplasty remained relatively low across the study period until 2014, from which point the popularity appeared to slightly increase towards the end of the study.

While procedures focusing on the ligaments and bony structures of the patellofemoral joint have considerably increased in number in the current study, a decrease was seen in extensor realignment procedures. It is likely therefore that more recent methods for improving extensor apparatus tracking, such as torsional osteotomy, have offered an option for extensor realignment procedures.

In contrast to debridement procedures, the reimplantation of osteochondral fractures increased during the study period. Studies on the long-term outcomes of patellar dislocation have shown a marked increase in incidence of osteoarthritis in cases where an articular cartilage defect is present in the knee joint [23, 28, 32]. These findings might have led surgeons to favour reimplantation rather than the removal of loose fragments. On the other hand, the development of arthroscopic technology and reimplantation techniques during the study period has also facilitated reimplantation efforts [11]. New reimplantation techniques and tools, such as biodegradable pins and sutures, have been developed and applied in practice [25, 27, 51, 55]. In addition, the increase in reimplantation may reflect technological advancements on a larger scale in knee surgery than in only patellar dislocation surgery [9].

The findings of the present study suggest that surgery for patellar dislocations has evolved towards the reconstruction of damaged structures and the active modification of congenital anatomical risk factors for patellar dislocation. Moreover, techniques have progressed in the wake of expanding research interest. Knowledge has been gained on anatomical risk factors and several methods for correcting these malformations have been developed. This rapid development was reflected in the change in the trends of surgery for patellar dislocation in the 2010s.

It should be noted that even though surgery trends have followed the research literature, the outcomes of the change remain unclear. Changes in the incidence of surgical procedure do not directly reflect the efficacy of the given procedure. Indeed, there might be other factors behind the change, such as the implementation of more rigorous and precise criteria for performing the procedure. In future studies, it would be essential to examine the influence of combining and tailoring methods according to the patient’s individual anatomy with the outcomes of patellar dislocation surgery, such as recurrence of patellar dislocations as well as in reoperations due to patellar instability. Prospective, ideally randomised, controlled studies comparing the latest surgical techniques are therefore advocated.

**Strengths and weaknesses**

Clearly, a strength of the present study is the availability of an accurate, nationwide population-based sample covering all surgical operations for patellar dislocation in Finland during the 20-year study period. The authors are unaware of a previous study that has published on the national incidence of surgery for patellar dislocation. Previous studies have shown the NHDR to be accurate and to have good coverage of surgical treatment in Finland. Therefore, the present results should be interpreted as a good description of clinical reality [24, 31, 49]. The main limitation of the current study is the inability
of the NSPC procedure coding system to adequately differentiate procedures. Many procedure codes, for example, those used in MPFL reconstruction procedures, are not completely specific and accurate. Therefore, the codes used may include completely different techniques, such as reconstruction and repair, and also include procedures on other ligaments. In order to mitigate the given bias, procedures that were performed fewer than 100 times during the study period were excluded. In addition, only those patients who had undergone surgery were included in the current study. Thus, patellar dislocation and instability patients that did not undergo surgery were automatically excluded. As the decision on the surgical treatment of patellar instability is made by the treating surgeon based on clinical and radiological examination, it is unlikely that patients with no effective episodes of dislocation end up in surgical treatment. In some cases, however, it is possible that if MRI clearly reveals anatomical risk factors for patellar instability and dislocation. Thus, the surgeon might decide to operate the knee due to recurrent patellar instability symptoms, even though no effective episodes of dislocations have occurred. It is therefore possible that patients with no effective episodes of patellar dislocations have also been included in the current study. Finally, the NHDR does not differentiate the side of operated knee, which impeded the examination of the reoperation rate and the techniques used in subsequent operations. Therefore, the approach of the current study was to observe general trends in single procedures performed for patellar dislocation rather than the treatment of individual patients.

Conclusion

Although the incidence of surgical operations for patellar dislocation has remained stable over the past two decades, a change in surgical management techniques has occurred. There has been a shift towards the reconstruction of damaged structures and the modification of congenital anatomical risk factors for patellar dislocation. In clinical practice, therefore, the findings of the current study may encourage clinicians to tailor and combine surgical techniques according to the patient’s individual anatomy and injury characteristics.

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Compliance with ethical standards

Conflict of interest None declared.

Ethical approval Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

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Characteristics of Osteochondral Fractures Caused by Patellar Dislocation

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Characteristics of Osteochondral Fractures Caused by Patellar Dislocation

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Investigation performed at Central Finland Hospital, Jyväskylä, Finland, and Tampere University Hospital, Tampere, Finland

Background: Literature describing the anatomic characteristics of osteochondral fractures (OCFs) in the knee joint after patellar dislocation is scarce.

Purpose: To describe the patterns of OCFs in the knee joint after acute or recurrent patellar dislocation in a sample of patients from 2 orthopaedic trauma centers.

Study Design: Case series; Level of evidence, 4.

Methods: In this multicenter study, all patients who had International Classification of Diseases, 10th Revision, diagnostic codes S83.0 and M22.0 between 2012 and 2018 were screened. Of the 2181 patients with clinically diagnosed patellar dislocation, 1189 had undergone magnetic resonance imaging (MRI). Patients with diagnosed patellar dislocation and osteochondral fragment verified on MRI scans were included. Demographic and clinical data were collected from electronic patient records. OCF location and size were assessed from MRI scans. Results were further compared in subgroups by sex, skeletal maturity, and primary versus recurrent patellar dislocation.

Results: An OCF was detected in 134 patients with injured knees, all of whom were included in the final analysis. It occurred in the patella in 63% of patients, in the lateral femoral condyle in 34%, and in both locations in 3%. The median OCF size was 146 mm² (interquartile range, 105-262 mm²). There was no statistically significant difference in OCF size between patellar and lateral femoral condyle fractures. Patellar OCFs were more frequent in female than male patients \((P = .009)\) and were larger after primary than recurrent dislocation \((P = .040)\).

Conclusion: OCFs were mainly located in the medial facet of the patella and in the lateral femoral condyle, with these locations accounting for approximately two-thirds and one-third of all OCFs, respectively. Proportion of patellar OCF was higher in female than in male. Patellar OCFs may be larger after primary than recurrent dislocation.

Keywords: osteochondral fracture; patellar dislocation; knee trauma; magnetic resonance imaging

Patellar dislocation is a frequent knee concern that most commonly occurs during adolescence and early adulthood. Several anatomic risk factors for patellar dislocations have been described, such as a high-lying patella (patella alta), trochlear dysplasia, rotational malalignments, and pronounced valgus malalignment of the knee joint. Lateral patellar dislocation occurs when a semi-flexed knee joint rotates into valgus and the force vector of the extensor apparatus shifts toward the lateral side of the knee joint over the lateral trochlear facet of the femur. If the laterally directed force applied to the patella exceeds the strength of the medial stabilizing structures, mainly the medial patellofemoral ligament, they will be damaged, allowing the patella to dislocate over the lateral femoral condyle. The lateral edge of the lateral trochlear facet directs high energy toward the vertical ridge and medial facet of the patella during dislocation or as the patella reduces into the groove. This may predispose these areas to chondral or osteochondral lesions after patellar dislocation.
dislocation. Intra-articular osteochondral fractures (OCFs) have been reported to occur concomitantly in 2% to 44% of cases of patellar dislocation.\textsuperscript{12,18,22}

Because cartilage damage in excess of 1 cm\textsuperscript{2} has been reported to increase the risk for articular degeneration, the presence of OCF has been regarded as a key factor in determining the treatment of a patellar dislocation.\textsuperscript{5} OCF of the knee has been regarded as a criterion for operative treatment in the acute phase.\textsuperscript{23,25} If the fracture is treated surgically, the primary procedure is reduction and fixation of the OCF fragment into its original location using biodegradable pins or sutures.\textsuperscript{8,10,28,29} If refixation is not possible, microfractures, subchondral drilling, or periosteal or abrasion chondroplasty may be considered.\textsuperscript{9,24}

Despite the theoretical basis of the biomechanics of injury mechanism, literature describing the anatomic characteristics of OCFs in the knee joint after patellar dislocation is limited. Previous studies have been conducted in small patient samples, mostly from pediatric populations. The findings of Seeley et al\textsuperscript{21} and Nietosvaara et al\textsuperscript{12} addressing 46 and 15 patellar dislocation patients with OCF, respectively, are in line with the prevailing understanding of biomechanics of the OCF injury. These studies showed OCFs occurred most commonly in the medial patellar facet (69% of patients with OCFs) and the lateral condyle of the femur (21%). In 10% of the patients, both the patella and the femur were affected. Previous studies have not accounted for differences in injury patterns among patient subgroups.

The aim of the current study was to describe the patterns of OCFs in the knee joint after acute or recurrent patellar dislocation in a sample of patients from 2 orthopaedic trauma centers.

METHODS

Patient Sample

In Finland, ethical approval is not required for register-based studies (Medical Research Act, 488/1999; https://www.finlex.fi/en/). Permission to conduct the study was granted by the hospital’s medical directors (research permit R19529). In reporting, we complied with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.\textsuperscript{27} Patient data for the current multicenter study were collected retrospectively from the electronic patient records of Central Finland Hospital (CFH), Jyväskylä, Finland, and Tampere University Hospital (TAUH), Tampere, Finland. These 2 hospitals serve a population of 700,000 to 800,000 citizens. The electronic search was conducted from the patient records for the years 2012 to 2018 using International Classification of Diseases, 10th Revision, diagnosis codes S83.0 (“acute patellar dislocation”) and M22.0 (“recurrent patellar dislocation”). Medical records of identified patients were screened for inclusion.

The study inclusion criteria were diagnosis of patellar dislocation and osteochondral fragment verified on magnetic resonance imaging (MRI) scans. In the study hospitals, MRI is conducted in the orthopaedic department. The physician in the emergency department (ED) is responsible for the primary care of patellar dislocations and assesses the need for referral to the orthopaedic department. Although the guidelines in the study hospitals specify that all patients with primary patellar dislocation be referred for MRI, the final decision of referral lies with the physician in the ED. Thus, if the physician in the ED interprets the injury as nonsevere and the patient does not seek further treatment from the study hospitals, the patient may not be referred to the orthopaedic department and for MRI in the study hospitals. In addition, patients with insurance may seek treatment in private sector hospitals instead of public hospitals despite the referral to the orthopaedic department. In these patients, additional diagnostics and MRI may be organized in the private sector.

An osteochondral fragment was defined as an intra-articular loose body cleaved from the articular surface of the patellofemoral or tibiofemoral joint and containing components of cartilage and bone. Exclusion criteria are presented in Table 1. The electronic search yielded a total of 2373 patients treated during the study period. After the patients’ medical records were screened, 192 patients with no patellar dislocation were excluded. Of the remaining 2181 patients, 1189 had undergone MRI of the knee.

Descriptive data were collected retrospectively from patient records. To control bias attributed to inaccurate use of diagnosis coding, information on the occurrence of previous patellar dislocations was collected from patient records to verify the correct diagnosis of primary or recurrent dislocation. If a patient had several episodes of patellar dislocation, the episode in which the OCF occurred for the first time was selected for final analysis.

MRI Evaluation

MRI was conducted using 1.5- or 3-T scanners with proton density– and T2-weighted turbo spin echo sequences. Slice thickness was set between 2.5 and 3.5 mm, and slice increment was set between 2.8 and 4.0 mm. During imaging, the examined knee was set to 30° of flexion. A coil was used.

Radiologic parameters were examined from patients’ MRI scans. Two observers at each hospital (M.U. and J.P.R. in CFH and M.U. and V.P. in TAUH) individually

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Study Exclusion Criteria\textsuperscript{a}</th>
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<tr>
<td>Exclusion Criteria</td>
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<tr>
<td>Previous surgery for patellar dislocation</td>
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<tr>
<td>Previous major traumas of the knee joint (ligament ruptures, intra-articular fractures, etc)</td>
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<td>MRI not performed in study hospitals</td>
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<tr>
<td>Loose fragment containing only cartilage or bone</td>
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<tr>
<td>Extra-articular medial patellofemoral ligament avulsion fractures</td>
<td></td>
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<tr>
<td>Chondral or osteochondral impression fractures with no loose fragment</td>
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<tr>
<td>Round-shaped OCF fragment interpreted as an old fracture (ie, did not occur in the most recent dislocation)</td>
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\textsuperscript{a}MRI, magnetic resonance imaging; OCF, osteochondral fracture. |
evaluated all MRI scans. Skeletal maturity was determined by examining growth plate maturity. The definition of skeletal maturity was an opening of the physis <5 mm in any section or complete epiphyseal fusion of the distal femur.4

OCF location was categorized according to the anatomic region in the knee joint (Figure 1). Patellar OCFs were divided into 2 regions: medial facet and patellar ridge. An OCF in the patellar ridge was defined as a fracture area extending to the highest edge of the patellar ridge. Femoral condylar OCFs were defined as being located only at the lateral edge of the articular surface of the lateral condyle. If there were discrepancies in OCF location between observers, consensus was achieved by the same 2 observers jointly double-checking the MRI scans of these patients.

Three-dimensional diameters of the OCF fragment were measured. The size of the OCF area was estimated by multiplying the longest diameter of the fragment by the second longest. If several fragments had cleaved from the same location, the sizes of these fragments were summed to obtain the total fracture area. Observers’ mean measurements were calculated to report the estimated sizes of the areas of the OCF fragments.

Figure 1. MRI findings of OCFs (arrows): (A) medial facet of the patella, (B) patellar ridge, and (C) lateral femoral condyle. (D) Perioperative image of the OCF in the patellar ridge. MRI, magnetic resonance imaging; OCF, osteochondral fracture.

Statistical Analysis

Data are presented as frequencies with percentages or as medians with interquartile ranges (IQRs). Subgroup analyses by sex, skeletal maturity, and primary versus recurrent patellar dislocation were performed separately. Differences in OCF location between the subgroups were examined using a chi-square test. Normality of continuous variables (age and OCF size) was tested using a Shapiro-Wilk test. Given that normality of the variables was violated (Shapiro-Wilk test; P < .05), a nonparametric approach was applied in further analysis. Mann-Whitney U tests were performed to examine differences in OCF size between the subgroups. A Kruskal-Wallis test was used to compare ages among patients with different OCF locations. The association between age and OCF size was examined by calculating Spearman correlation coefficients.
Statistical analyses were performed using R Version 3.6.1 (R Foundation for Statistical Computing).

RESULTS

Of 1189 patients who had undergone MRI, 134 (11%) eligible patients with OCF were identified (Figure 2, Table 2). The sample consisted of 99 (74%) patients with OCF after primary patellar dislocation and 35 (26%) with OCF after recurrent patellar dislocation. The median age of the included patients was 17 years (IQR, 14-22 years), with female patients slightly in the majority (55%). Two-thirds of the patients were skeletally mature. Of 992 patients who had not undergone MRI and thus were excluded, 62% were female and the median age was 24 years (IQR, 19-33 years).

In 85 (63%) patients, the OCF was located in the patella: in the medial facet in 62 (46%) patients and in the patellar ridge in 22 (16%) patients (Figure 3). The lateral femoral condyle was affected in 46 (34%) patients. Four patients (3%) had an OCF in the femur and patella. The median OCF size was 146 mm² (IQR, 105-262 mm²) and was 137 mm² (IQR, 105-235 mm²) in the patella and 173 mm² (IQR, 105-278 mm²) in the femur. Observed differences in OCF sizes among the locations were not statistically significant ($P = .363$).

![Figure 2. Flowchart of patient selection. MPFL, medial patellofemoral ligament; MRI, magnetic resonance imaging; OCF, osteochondral fracture.](image)
Before subgroup analysis was performed, the patients with an OCF in the femur and patella were excluded because they were too few in number. Inspection of the differences in the location of the OCF (patellar vs femur) between subgroups by sex, skeletal maturity, and primary versus recurrent dislocation revealed a significant difference by sex (Table 3). The proportion of patellar versus femoral OCFs was higher in female (76%) than male patients ($\chi^2 = 6.87; df = 1; P = .009$) (Figure 4). The other subgroup analyses showed no differences in OCF location. Furthermore, patellar OCF size was larger in patients with primary than with recurrent patellar dislocations (147 mm$^2$ in primary vs 119 mm$^2$ in recurrent; $P = .040$). Femoral OCF size did not differ between the patients with primary and recurrent patellar dislocations. In addition, no significant differences between any of the other subgroups were observed for OCF size in the patella or femur. Patient age was not significantly associated with OCF size ($r = –0.02; P = .841$) or location ($P = .279$).

**DISCUSSION**

In this series, intra-articular OCFs after patellar dislocation were most commonly located in the medial facet of the patella or lateral edge of the lateral femoral condyle. The finding is in line with the prevailing assumption regarding the injury mechanism; that is, during patellar dislocation and relocation, the medial patellar facet and lateral femoral condyle are exposed to high energy, causing kissing contusions and possible OCF.1,12 Despite the large variation in the sizes of the OCF fragments, the size did not vary significantly by location.

Seeley et al$^{21}$ reported similar results in their study of 46 patients with OCFs after patellar dislocation, of whom 76% had an OCF in the patella, 24% had an OCF in the lateral femoral condyle, and 6.5% had a combined injury. In the current study, the proportion of patellar OCFs was slightly lower and that of lateral femoral condyle OCFs was slightly higher. However, our sample and the sample studied by Seeley and colleagues were markedly different. Their study comprised cases of primary patellar dislocation in a pediatric population with a mean age of 15 years, among whom 85% had open growth plates (although criteria were not defined) and the majority were male.$^{21}$ In this study, we did not limit patient ages; instead, we included all patients with OCFs. The patients in our sample were also notably older (median age, 17 years; IQR, 14-22 years), and 34.3% had open growth plates. However, our groups of patellar and femoral OCFs did not differ in age, skeletal maturity, or the proportions of primary and recurrent dislocations. Our results are in line with those of Nietosvaara et al,$^{12}$ who found that patellofemoral joint morphology remains constant during growth. It is reasonable to assume that the same may apply to the biomechanics of patellar dislocation.

Sillanpää et al$^{22}$ studied the incidence of patellar dislocation in male conscripts with a mean age of 20 years. In their study, all patellar dislocations occurred in sports or sports-related military training. Although we did not observe the actual injury mechanism or situation, the findings of Sillanpää et al suggested that patellar dislocations and concomitant OCFs occurring during late adolescence

![Figure 3](image-url) Distribution of osteochondral fracture locations in an axial view of the patellofemoral joint.

**TABLE 3**

<table>
<thead>
<tr>
<th>Location</th>
<th>Sex</th>
<th>OCF</th>
<th>Skeletal Maturity (Physe)</th>
<th>OCF Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
<td>P Value</td>
<td>Open</td>
</tr>
<tr>
<td>Patella</td>
<td>54 (76)</td>
<td>31 (53)</td>
<td>.009</td>
<td>28 (61)</td>
</tr>
<tr>
<td>Femur</td>
<td>17 (24)</td>
<td>28 (47)</td>
<td></td>
<td>18 (39)</td>
</tr>
<tr>
<td>Size, mm$^2$</td>
<td>Patella</td>
<td>131 (107-221)</td>
<td>176 (106-261)</td>
<td>.446</td>
</tr>
<tr>
<td></td>
<td>Femur</td>
<td>148 (114-214)</td>
<td>181 (92-330)</td>
<td>.880</td>
</tr>
</tbody>
</table>

*Values are presented as No. (%) or median (interquartile range). OCF, osteochondral fracture; PD, patellar dislocation.

$^a$Differences in location of OCFs were tested using a chi-square test.

$^b$Differences in size of OCFs were tested using the Mann-Whitney U test.
The subgroup analysis revealed significant differences between male and female patients in the location of OCFs. In female patients, patellar OCFs were more frequent than were femoral OCFs, whereas in their male counterparts the 2 OCF locations were equally distributed. The difference between the sexes in the distribution of OCF locations in our study contrasts with the distribution of OCF locations in the male-majority sample studied by Seeley et al. However, their results might be explained by their small sample size. The sex distribution in the current study sample is in line with previously reported sex distributions of patients with patellar dislocation. The finding might suggest that the sexes are at equal risk for OCFs.

In patellar dislocation, the main medial stabilizing structure of the patella, the medial patellofemoral ligament, has been shown to be injured in practically every case. After primary patellar dislocation and medial patellofemoral ligament injury, the biomechanics of patellar dislocation alter with recurrent dislocations, as the patella is more easily able to move laterally. As a result, the patella may dislocate after low-energy trauma with lower impact on the articular surfaces of the patellofemoral joint. In the current study, patellar OCFs resulting from recurrent patellar dislocation were significantly smaller than those after primary dislocation. A similar trend was observed in femoral OCFs, although the difference was not statistically significant. Nevertheless, OCF location did not differ between primary and recurrent patellar dislocations. It has been hypothesized that, rather than actual dislocation of the patella, an OCF may occur after spontaneous relocation of the patella with mild flexion of the knee joint after lateral patellar dislocation. Thus, after injury of the stabilizing structures during dislocation of the patella, the biomechanics of spontaneous reduction of the patella are the same in primary and recurrent dislocations, causing equal OCF risk. However, the difference in size of the OCFs between those occurring in primary and recurrent dislocations suggests that there may be differences in the biomechanics of the injury, with the higher impact on the articular surfaces occurring in primary dislocations causing larger OCFs.

This study has several strengths. First, this is the largest study to be conducted on the injury patterns of patients with patellar dislocation with OCF. Previous literature consists of small case series, and the majority of the studies that have examined patellar dislocation excluded patients with OCF. Second, this study was performed as a multicenter study in the catchment area of 2 hospital districts in Finland, allowing for the inclusion of more patients from a wider geographic area and for generalization of the results. The screening of all patients treated for patellar dislocation in the 2 hospitals mitigated selection bias in our sample. Third, 2 independent evaluators blinded to each other’s results performed the MRI-based estimates of OCF size and location. This method enhanced the consistency and reliability of the assessment. Fourth, to promote homogeneity of the injury of interest, relatively strict OCF criteria were set. A homogeneous study population provides more precise and reliable results that well-represent patients meeting the inclusion criteria. The main limitation of the study was the retrospective study design. Despite the hospital guidelines, almost a half of the patients were not referred for MRI. Thus, we did not have a complete picture of all injuries. However, the patients who did not undergo MRI in the study hospitals were older than were patients in the study. In addition, we did not examine the trauma mechanism or joint laxity of the patients, which could have influenced interpretation of the results.

CONCLUSION
OCFs after patellar dislocation were located at the medial patellar facet in approximately two-thirds of patients and at the lateral femoral condyle in one-third. OCF location differed by sex, with female patients showing a higher proportion of patellar than femoral OCFs. OCFs may be larger after primary dislocation than after recurrent dislocation.

REFERENCES


The risk of osteochondral fracture after patellar dislocation is related to patellofemoral anatomy

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The risk of osteochondral fracture after patellar dislocation is related to patellofemoral anatomy

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Abstract

**Purpose** Despite the comprehensive literature on the anatomical risk factors for patellar dislocation, knowledge on the risk factors for subsequent osteochondral fracture (OCF) remains limited.

**Methods** Magnetic resonance imaging was used to compare measures of patellofemoral anatomy in patients with OCF after patellar dislocation and propensity score matched patients without OCF. For differing measures, limit values showing a 50% probability for the occurrence of OCF were calculated using predictive logistic regression modelling. Proportions of abnormal measures in the groups were compared using Chi-square test. The association of anatomical measures with OCF location was examined by comparing subgroup mean values in the different OCF locations.

**Results** Propensity score matching provided a total of 111 matched pairs of patients with OCF and patients without OCF. The patients with and without OCF differed in patellotrochlear index (PTI; 0.54 [95% CI 0.52 to 0.57] vs. 0.47 [95% CI 0.45 to 0.49]; p < 0.001), tibial tubercle-posterior cruciate ligament distance (TT-PCL; 21.6 mm [95% CI 21.0 mm to 22.3 mm] vs. 20.5 mm [95% CI 20.0 mm to 21.1 mm]; p = 0.013), trochlear depth (2.5 mm [95% CI 2.3 mm to 2.7 mm] vs. 3.0 mm [95% CI 2.8 mm to 3.2 mm]; p < 0.001) trochlear facet asymmetry ratio (0.54 [95% CI 0.51 to 0.57] vs. 0.43 [95% CI 0.42 to 0.45]; p < 0.001) and trochlear condyle asymmetry ratio (1.04 [95% CI 1.03 to 1.04] vs. 1.05 [95% CI 1.04 to 1.05]; 0.013. Thresholds for increased OCF risk were >0.51 for PTI, >21.1 mm for TT-PCL, <2.8 mm for trochlear depth, >0.48 for trochlear facet asymmetry ratio and <1.04 for trochlear condyle asymmetry ratio.

**Conclusion** In patients with OCF after patellar dislocation, trochlear configuration and patella vertical location were closer to normal anatomy, whereas patella lateralization was more severe when compared to patients without OCF. These anatomical factors contribute to the risk of OCF during patellar dislocation.
Level of evidence Level III, Case-control study.

Key words Patellar dislocation; Osteochondral fracture; Risk factors; Patellofemoral anatomy; Magnetic resonance imaging.
Introduction

During the past few decades, extensive research has increased understanding of patellar dislocation and associated problems. Anatomical malformations, such as dysplastic trochlea of the femur, high-lying patella (patella alta) and malalignment of the extensor mechanism of the knee joint, are the main cause of patellar instability [5, 7, 15, 21, 30]. In addition, in primary dislocation, the medial patellofemoral ligament (MPFL) often ruptures, predisposing patients to recurrent patellar dislocation [6, 37].

Osteochondral fracture (OCF) is a potential concomitant injury after patellar dislocation. Previous studies have reported OCFs in 2% to 44% of patients with patellar dislocation [29, 32, 36]. Primary patellar dislocation is usually treated non-operatively. However, the occurrence of large or symptomatic OCFs usually leads to operative treatment owing to the elevated risk of degeneration after large cartilage lesion [33].

While risk factors for patellar dislocation have been widely studied, knowledge of the risk factors associated with concomitant OCF remains scarce [19, 29, 34]. Theoretically, in cases of patellar dislocation, the occurrence of OCF may require higher trauma energy and lower resiliency of the structures of the knee joint. Anatomical malformations, such as trochlear dysplasia, allow less restricted lateral movement of the patella when compared to normal anatomy [5, 16]. As a result, malformations may reduce the forces on patellofemoral articular surfaces during patellar dislocation, and hence decrease the risk of OCF. Thus, counter to established beliefs, patellar dislocation with concomitant OCF may comprise an entity that differs, at least in part, from the patellar instability related to anatomical malformations of the knee joint. However, the anatomy of patients with and without OCF after patellar dislocation has not, as yet, been compared. A consideration of the anatomy may provide new insights into pathology, and thereby decisions on the treatment of OCF after patellar dislocation.
The aim of this study was to examine and compare the expression patterns of the anatomical factors related to patellar instability in patients with and without concomitant OCF. The hypothesis was that patellofemoral anatomical malformations are more pronounced in patients without OCF than in patients with OCF.

**Materials and Methods**

This multicentre study was conducted in two separate hospital districts (Central Finland Hospital, Jyvaskyla; Tampere University Hospital, Tampere) in Finland with a combined catchment population of approximately 800,000 citizens [2]. Permission to undertake the study was obtained from the medical directors of the study hospitals, and the study was approved by the hospitals’ research committees (research permit ID: R19529). Due to the retrospective study design with the data gathered only from electronic patient records without affecting the treatment of the patients, an ethical committee approval was not obtained or needed [1]. The study sample was collected retrospectively from the electronic medical records of each hospital for the years 2012-2018. Eligible patients were identified using the ICD-10 diagnosis codes S83.0 (*Acute patellar dislocation*) and M22.0 (*Recurrent patellar dislocation*) [3]. Patient records of all identified cases were screened (MU). To control for bias due to inaccurate diagnosis coding, information on the occurrence of previous patellar dislocations was collected from patient records to verify the diagnosis of primary or recurrent dislocation.

The data collection was conducted in two phases. In the first phase, all patellar dislocation patients with concomitant OCF treated in the study hospitals during the study period were identified and included in the OCF group. The inclusion criterion was a diagnosis of patellar dislocation verified by magnetic resonance imaging (MRI). An osteochondral fragment was defined as an intra-articular loose body containing components of both cartilage and bone cleaved from the articular surface of the patellofemoral joint. In the second phase, a reference group of patellar
dislocation patients with no MRI-identified OCF or other intra-articular loose bodies was collected. To obtain representative matched pairs of patients with and without OCF, the number of patients in the reference group was determined by adding 20% to the number of patients in the OCF group. Patients in the reference group were selected randomly from a pool of identified eligible patients treated in the study hospitals during the study period. Exclusion criteria are presented in Table 1.

Patients with an intra-articular round-shaped osteochondral fragment, which was interpreted to be an old fracture, were excluded, as the timing and the actual cause of the fracture could not be reliably determined from patient records (patients may have had knee trauma other than patellar dislocation that could have caused patellar dislocation).

Evaluation of MRI

Radiological measurements and skeletal maturity were examined from patients’ MRIs. The MRI scans were conducted using a 1.5T or 3T magnet strength scanner with a coil. Images were structured using proton density and T2-weighted turbo spin-echo sequences with a slice thickness of between 2.5 mm and 3.5 mm and a slice increment of between 2.8 mm and 4.0 mm. MRI scans were performed with the knee in 20° to 30° flexion. Skeletal maturity was defined as an opening in the growth plates of less than 5 mm in any section or the complete epiphyseal fusion of the distal femur [18]. In addition, OCF location (patella vs. femur) and size were examined in patients in the OCF group.

Anatomical parameters related to patellar instability were measured from MRIs (Figure 1). Measurements for each patient were performed by two independent observers from the two study hospitals (two of the following on a case-by-case basis: MU, VP and SH in Central Finland Hospital and MU, VP and GK in Tampere University Hospital) and the final measurement was calculated as the mean of the measurements of the two observers. Patellar height was measured using the Insall-Salvati ratio (ISI) [22], the Caton-Deschamps index (CDI) [12] and the
patellotrochlear index (PTI) [8]. Measurements were performed from the sagittal plane, where the vertical length of the patella was longest. The tibial tubercle-trochlear groove distance (TT-TG) [17] and the tibial tubercle-posterior cruciate ligament distance (TT-PCL) [35] were measured to examine the lateralization of patellar tracking. Trochlear configuration was assessed by measuring the trochlear sulcus angle [31], trochlear depth [31], trochlear facet asymmetry ratio [31], trochlear condyle asymmetry ratio [31] and lateral trochlear inclination angle [11]. Measurements of the trochlear configuration were conducted from the first axial plane below the lower bound of the articular surface of the patella. All measurements were performed with an accuracy of millimetres or degrees with one decimal place. The results are presented in millimetres or degrees with one decimal place for absolute distance measures or as a ratio with two decimal places for the index and ratio parameters. Intraclass correlation coefficients were calculated to assess the reliability of the measurements between the two observers. Values over 0.75 indicate good reliability [24]. The coefficient values varied between 0.75 and 0.89 with the lowest value in the sulcus angle.

Statistical analysis

A flow-chart of patient selection is presented in Figure 2. A total of 135 patients with OCF were identified, and the control group consisted of 169 patients without OCF. Propensity score matching resulted in 111 matched pairs comprising a total of 222 patients (Table 3). Propensity score matching was conducted according to age, sex, skeletal maturity and patients with primary dislocation versus patients with recurrent dislocation. The matching variables were selected according to previous knowledge on the demographic and clinical risk factors for patellar instability. Younger age and open growth plates as well as female sex have consistently been found to be associated with higher risk of patellar instability [4, 20, 21, 30]. The rationale for adjusting for primary versus recurrent dislocation was that a history of patellar dislocation is associated with injury in the medial stabilizing structures of the patella [6, 37]. Thus, when compared to patients with no previous patellar dislocations, patients with previous dislocations of the patella may be
more mobile and may dislocate with lower trauma energy and potentially a reduced risk of OCF. Similarly, in female, skeletally immature and younger patients, the patella may be more mobile, and thus the risk of OCF may be reduced. The propensity score matching was conducted using the nearest neighbour method with a calibre width of 0.15. Covariate balance was measured by calculating the z-difference between the OCF and the reference groups [25]. A z-difference of less than ±1 was considered acceptable.

Normality of the anatomical measures was confirmed using the Shapiro-Wilks test and by inspecting histograms. The mean values and 95% confidence intervals (CI) of the anatomical measures were compared between the OCF and the reference groups. In addition, a sensitivity analysis of the primary patellar dislocation patients was conducted. The eligibility criterion for difference was a reference group mean value outside the 95% CI of the OCF group mean value. For the measures that showed eligible evidence of a difference between the OCF and the reference groups, limit values showing a 50% probability for the occurrence of OCF were calculated with 95% confidence intervals, using predictive logistic regression modelling. The occurrence of OCF was set as a dependent variable and the anatomical measure as an independent variable. Proportions of abnormal measures in the groups were compared using Chi-square test without Yates’s correction for continuity. Abnormality threshold values for each measure were obtained from previous radiologic-anatomical studies (Table 2). Finally, associations between anatomical measures and OCF location were examined by comparing subgroup mean values and 95% CIs in the different OCF locations. Due to non-experimental and observational study design with inclusion of all eligible patients, power calculations were not performed. All analyses were conducted using R (3.6.3) statistical software.

Results
In the matched sample, differences in the matching variables between the two groups were low. Z-differences less than ±1 indicated successful matching. According to the Shapiro-Wilks test and histograms, all measures followed a normal distribution in both groups. In patients in the OCF group, 72 (65%) had OCF in the patella. Of these, 53 (48%) were in the medial facet of the patella and 19 (17%) in the patellar ridge. In addition, OCF in the lateral femoral condyle was found in 42 (38%) patients. In 3 (3%) patients, OCF was located in both the medial facet of the patella and the lateral femoral condyle. The median size of the OCF was 137 mm² (inter-quartile range 105 mm² - 233 mm²).

Examination of the anatomical measurements revealed eligible evidence of a difference between patients with OCF and patients without OCF in PTI, TT-PCL, trochlear depth, trochlear facet asymmetry and trochlear condyle asymmetry (Table 4). A lower PTI and trochlear facet asymmetry ratio and a higher trochlear condyle asymmetry ratio indicated more severe anatomy abnormality in the non-OCF group. Conversely, a longer TT-PCL distance and a shallower trochlear depth, in turn, indicated more severe abnormality in the OCF group. The subgroup analysis of the patients with primary patellar dislocation showed parallel results (Table 4). Predictive logistic modelling yielded threshold values of 50% probability for OCF during patellar dislocation for the differing measures (Figure 3). Due to high dispersion and overlapping of measures in the OCF and non-OCF groups, the 95% CIs were wide.

Abnormal anatomical measures were prevalent in both the OCF and non-OCF groups, with at least one measure classified as abnormal in every patient (Table 5). The most common abnormality was a wide sulcus angle (over 145º), which was observed in 93.2% of patients. The proportions of patients with an abnormal sulcus angle, PTI and trochlear facet asymmetry were higher in the non-OCF group than in the OCF group. By contrast, trochlear depth abnormality was more common in patients with OCF than patients without OCF.
Analysis of OCF location showed more severe trochlear facet asymmetry in the patellar OCF group than in the femoral OCF group (Table 6). No eligible evidence of differences in the other measures was found.

**Discussion**

The main finding of the current study is that patients with and without OCF after patellar dislocation differed in knee joint anatomy. In patients with OCF compared to patients without OCF, trochlear configuration and the vertical location of the patella were closer to normal anatomy, whereas patellar lateralization was more severe. These anatomical factors may contribute to an increased risk of OCF during patellar dislocation. Anatomical malformations were prevalent in both groups. No clear association, however, was observed between OCF location and the vertical location or lateralization of the patella or in trochlear configuration except for facet asymmetry, which was more severe in the patellar OCF than in the femoral OCF group.

The patellotrochlear contact surface diminishes if the patella is abnormally high riding (patella alta), a condition that has repeatedly been found to predispose to patellar instability [4, 5, 21, 30]. In the present study, almost all patients exhibited patella alta in the means of at least one of the patellar height measures. Mean PTI was higher and the proportion of patients with an abnormal PTI value was lower in the OCF group. In contrast, although the evidence of difference did not meet the predefined eligibility criterion with the non-OCF group mean falling within the 95% CI of OCF group mean, the observed mean CDI and the proportion of abnormal values were higher in patients with OCF. With regard to ISI, the difference between groups was rather modest. A higher PTI value indicates a larger patellofemoral articular contact surface. Theoretically, a larger contact surface may therefore be reflected in higher patellofemoral stability, as the patella is seated more firmly against the trochlear groove. Thus, in patients with higher PTI, higher energy may be required to dislocate the patella over the lateral femoral condyle, exerting higher forces on the
articular surfaces and possibly predisposing to OCF. Although the PTI values indicated that patella alta seemed to offer some protection against OCF, the CDI values showed that patella alta tended, conversely, to predispose to OCF. One possible explanation for this is that a higher CDI may not only indicate a higher vertical location of the patella. CDI is calculated by dividing the distance between the anterosuperior tibial edge and the lowest point of the patellar articular surface by the vertical length of the patellar articular surface. Thus, a high CDI value may also indicate a smaller size of patellar articular surface. According to the basic principles of physics, the smaller the contact surface, the greater the pressure exerted on the surface. Hence, patients with a higher CDI due to a smaller patellar articular surface may also be at higher risk of OCF. However, as CDI depends on both size of the patella and vertical location, this may lead to a higher dispersion in values, and hence a more uncertain association with OCF risk.

A laterally lying patella predisposes to patellar dislocation [5, 10, 21, 30]. In this study, the majority of patients in both groups had abnormal TT-PCL values, and one-third had TT-TG values above the cutoff for abnormality. In cases of higher TT-TG and TT-PCL values, the patella lies closer to the lateral edge of the trochlea, and therefore dislocates more easily. In patients with longer TT-TG and TT-PCL, the force needed to dislocate the patella might be lower compared to those patients with shorter TT-TG and TT-PCL values. It would be reasonable therefore to assume that OCF occurs more often in patients with normal TT-TG and TT-PCL values. However, this was not the case in this study. The observed TT-TG and TT-PCL measures indicate that lateralization was more prominent in patients with OCF. Eligible evidence of difference was found for TT-PCL but not for TT-TG. In patients with a lateralized patella, the patella lies pronouncedly towards the lateral trochlear facet. Abnormal patellar position may predispose both the patella and lateral trochlear facet to chronic excessive burden. Previous histological studies have shown that excessive burden on joint surfaces activates endochondral ossification and degradation of the subchondral bone tissue matrix predisposing the subchondral bone to microcracks [13, 27, 28]. This
may further contribute to increased OCF risk after patellar dislocation in patients with pronounced patellar lateralization. However, further studies on the effects of a lateraled patella on the bone structure of the patella and femur are required to further elaborate this hypothesis.

Trochlear dysplasia has been shown to be the most accurate predictor of recurrent patellar instability [4, 5, 7]. In the current study, almost all patients, with few exceptions in the OCF group, had abnormal trochlear morphology. In the non-OCF compared to the OCF group, trochlear facet and condyle asymmetry were more prominent, with pronounced medial hypoplasia. On the other hand, the trochlea was shallower in the OCF group. Although the mean sulcus angle did not differ markedly between groups, a higher proportion of abnormal sulcus angles was observed in the non-OCF group. In cases of severe trochlear asymmetry, owing to a short medial facet and hypoplastic medial condyle, measurement of trochlear depth may be biased, yielding normal values even in those with a flat trochlea.

Examination of the anatomical differences between patients with patellar OCF and patients with femoral OCF revealed that trochlear facet asymmetry was more severe in the former. This finding suggests that patients with more severe facet asymmetry are at higher risk of patellar OCF than femoral OCF. This risk may reflect differing patellar morphology in patients with trochlear facet asymmetry. During growth, the trochlea develops alongside the patella, and the articular surfaces conform to each other [23, 27]. In patients with medial trochlear hypoplasia, the patella mainly lies towards the lateral trochlear facet. It is likely therefore that in patients with a flat trochlea and medial hypoplasia, the medial patellar facet also develops hypoplastic. This, in turn, may be associated with the increased risk of patellar OCF. Nevertheless, as patellar morphology was not observed in this study, the hypothesis could not be examined further.

According to the findings of the present study, the anatomy of the knee joint differs between patients with OCF and patients without OCF after patellar dislocation. All three measured
aspects of patellofemoral anatomy appeared to be associated with OCF risk. However, owing to the high overlap in the measurement distributions of patients with OCF and patients without OCF, it was not possible to clearly determine unambiguous predictors of OCF. It is, however, likely that the occurrence of OCF is a multifactorial phenomenon moderated through multiple anatomical as well as several other factors that combined predispose to OCF. To evaluate the risk of OCF due to anatomical factors, it is beneficial to determine limit values for higher OCF risk. In this study, threshold values were provided for various measures (Figure 2). Of these, the PTI, TT-PCL and trochlear facet as well as condyle asymmetry values are recommended in practice, whereas the trochlear depth value appeared controversial due to the biased measures in patients with an asymmetric trochlea.

This study has several strengths. Although the anatomical risk factors for patellar dislocation have been studied thoroughly, studies on the associations of anatomical factors with OCF risk are scarce. Nietosvaara et al. (1994) reported differences in knee joint anatomy between paediatric patients with and without OCF after patellar dislocation [29]. However, their study included only 15 patients with OCF. The current multicentre study is thus far the largest study on anatomical risk factors for OCF after patellar dislocation. All the present patients with patellar dislocation were screened and those patients with OCF identified. In addition, the properly conducted matching of patients with and without OCF allows the direct comparison of knee anatomy, minimizing the effect of confounders. The injury definitions and the inclusion criteria for both the OCF and non-OCF groups were relatively strictly set to promote homogeneity and comparability, and thereby supporting the reliability of the findings. Finally, all measurements for each individual patient were conducted by two independent observers, which further improved the reliability of the measurements.

There were some limitations in the current study. First, since patellar shape and size were not measured, their association with the risk of OCF after patellar dislocation could not be
elaborated. Second, since propensity score matching was conducted in a 1:1 manner, according to the predefined matching criteria, the sample size was reduced by the unmatched patients. Although the matching criteria were thought to have been determined according to previous knowledge of the factors associated with anatomical measures and patellar dislocation risk, the matching may have also involved uncontrolled subjectivity that may have caused further bias in the results. In addition to those factors accounted for in the matching, there might also have been other underlying factors influencing the anatomical measures, which could not be taken into account. Furthermore, the non-OCF group did not contain all the eligible patients; instead, patients from the non-OCF group were randomly selected from a pool of suitable candidates. Despite the use of random selection to mitigate selection bias, the risk of bias remains. Third, the study was conducted retrospectively. The clinical data were collected from patient records that contain inaccuracies and shortcomings. Thus, data on potential contributing factors, such as joint laxity, patellar mobility as well as trauma mechanism, may not have been available. The magnitude of the observed differences in the anatomical measures appeared relatively small, which may suggest, in addition to patellofemoral anatomy, that there might be other unobserved factors related to the OCF risk. Lastly, since power calculations were not performed due to non-experimental and observational study design, the study may be underpowered.

Finally, this study provides an insight into clinical practice by showing the fundamental differences between the anatomy of patients with OCF and patients without OCF. These differences suggest that these patients comprise at least partially different entities and thus may require different treatment. Knowledge on the causes of the injury is essential in the assessment of the most appropriate treatment. The threshold values of the differing anatomical measures provided in the current study serve as a groundwork in the assessment of causes of OCF after patellar dislocation.

Conclusion
In patients with OCF after patellar dislocation, trochlear configuration and patella vertical location were closer to normal anatomy, whereas patella lateralization was more severe when compared to patients without OCF. Patients with or without minor bony malformations related to patellar instability may be at increased risk of OCF after patellar dislocation.
Table 1. Exclusion criteria.

<table>
<thead>
<tr>
<th>Exclusion criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>• MRI not performed in the study hospitals</td>
</tr>
<tr>
<td>• Previous surgery for patellar dislocation</td>
</tr>
<tr>
<td>• Previous major traumas of knee joint (ligament ruptures, intra-articular fractures, etc.)</td>
</tr>
<tr>
<td>• <strong>Exclusion criteria for OCF group</strong></td>
</tr>
<tr>
<td>• Loose fragment containing only either cartilage or bone</td>
</tr>
<tr>
<td>• Extra-articular medial patellofemoral ligament avulsion fractures</td>
</tr>
<tr>
<td>• Chondral or osteochondral compression fractures with no loose fragment</td>
</tr>
<tr>
<td>• Round-shaped osteochondral fragment interpreted as an old fracture (i.e., did not occur in the most recent dislocation)</td>
</tr>
<tr>
<td>• <strong>Exclusion criteria for non-OCF group</strong></td>
</tr>
<tr>
<td>• Any intra-articular loose fragment</td>
</tr>
</tbody>
</table>

Table 2. Inter-rater reliability of the anatomic parameters and abnormal value thresholds for anatomical measurements suggested in the literature.

<table>
<thead>
<tr>
<th>Anatomical parameter</th>
<th>ICC</th>
<th>Abnormal value threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patellar height</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISI</td>
<td>0.89</td>
<td>&gt;1.30 [26]</td>
</tr>
<tr>
<td>CDI</td>
<td>0.84</td>
<td>&gt;1.20 [16]</td>
</tr>
<tr>
<td>PTI</td>
<td>0.83</td>
<td>&lt;0.50 [8, 9]</td>
</tr>
<tr>
<td><strong>Patellar laterization</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT-TG, mm</td>
<td>0.86</td>
<td>&gt;15.0 [5]</td>
</tr>
<tr>
<td>TT-PCL, mm</td>
<td>0.83</td>
<td>&gt;20.0 [14, 35]</td>
</tr>
<tr>
<td><strong>Trochlear morphology</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulcus angle (°)</td>
<td>0.75</td>
<td>&gt;145.0 [31]</td>
</tr>
<tr>
<td>Lateral trochlear inclination angle (°)</td>
<td>0.79</td>
<td>&lt;11.0 [11]</td>
</tr>
<tr>
<td>Trochlear depth, mm</td>
<td>0.77</td>
<td>&lt;3.0 [31]</td>
</tr>
<tr>
<td>Trochlear facet asymmetry ratio</td>
<td>0.78</td>
<td>&lt;0.40 [31]</td>
</tr>
</tbody>
</table>
Trochlear condyle asymmetry ratio & 0.78 & >1.10 [31] \\

ICC = Intra-class correlation coefficient, ISI = Insall-Salvati index, CDI = Caton-Deschamps index, PTI = Patellotrochlear index, TT-TG = Tibial tubercle-trochlear groove distance, TT-PCL = tibial tubercle-posterior cruciate ligament distance

**Table 3.** Patient characteristics before and after propensity score matching.

<table>
<thead>
<tr>
<th>All patients</th>
<th>Matched patients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OCF group</td>
</tr>
<tr>
<td>n</td>
<td>135</td>
</tr>
<tr>
<td>Age, mean (SD)</td>
<td>19.1 (7.3)</td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>74 (54.8)</td>
</tr>
<tr>
<td>Skeletally mature, n (%)</td>
<td>88 (65.2)</td>
</tr>
<tr>
<td>Primary vs. recurrent patellar dislocation, n (%)</td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>99 (73.3)</td>
</tr>
<tr>
<td>Recurrent</td>
<td>36 (26.7)</td>
</tr>
</tbody>
</table>
Table 4. Differences in anatomical measures between patients with OCF and without OCF.

<table>
<thead>
<tr>
<th></th>
<th>Matched patients</th>
<th>Sensitivity analysis with matched primary patellar dislocation patients only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OCF group, n = 111</td>
<td>Non-OCF group, n = 111</td>
</tr>
<tr>
<td><strong>Patellar height, mean (95% CI)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISI</td>
<td>1.21 (1.17 to 1.24)</td>
<td>1.20 (1.17 to 1.23)</td>
</tr>
<tr>
<td>CDI</td>
<td>1.20 (1.16 to 1.23)</td>
<td>1.17 (1.13 to 1.20)</td>
</tr>
<tr>
<td>PTI</td>
<td>0.54 (0.52 to 0.57)</td>
<td>0.47 (0.45 to 0.49)</td>
</tr>
<tr>
<td><strong>Patellar lateralization, mean (95% CI)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT-TG, mm</td>
<td>14.3 (13.5 to 15.1)</td>
<td>13.4 (12.5 to 14.2)</td>
</tr>
<tr>
<td>TT-PCL, mm</td>
<td>21.6 (21.0 to 22.3)</td>
<td>20.5 (20.0 to 21.1)</td>
</tr>
<tr>
<td><strong>Trochlear morphology, mean (95% CI)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulcus angle (°)</td>
<td>154.5 (153.0 to 155.9)</td>
<td>155.1 (154.1 to 156.1)</td>
</tr>
<tr>
<td>Lateral trochlear inclination angle (°)</td>
<td>13.5 (12.7 to 14.4)</td>
<td>14.3 (13.5 to 15.0)</td>
</tr>
<tr>
<td>Trochlear depth, mm</td>
<td>2.5 (2.3 to 2.7)</td>
<td>3.0 (2.8 to 3.2)</td>
</tr>
<tr>
<td>Trochlear facet asymmetry ratio</td>
<td>0.54 (0.51 to 0.57)</td>
<td>0.43 (0.42 to 0.45)</td>
</tr>
<tr>
<td>Trochlear condyle asymmetry ratio</td>
<td>1.04 (1.03 to 1.04)</td>
<td>1.05 (1.04 to 1.05)</td>
</tr>
</tbody>
</table>

ISI = Insall-Salvati index, CDI = Caton-Deschamps index, PTI = Patellotrochlear index, TT-TG = Tibial tubercle-trochlear groove distance, TT-PCL = tibial tubercle-posterior cruciate ligament distance, n.s. = non-significant

*Independent samples t-test
### Table 5. Proportions of abnormal values in anatomical measures in the OCF and non-OCF groups.

<table>
<thead>
<tr>
<th></th>
<th>OCF group</th>
<th>Non-OCF group</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abnormal patellar height</strong></td>
<td>n (%)</td>
<td>n (%)</td>
<td></td>
</tr>
<tr>
<td>ISI &gt; 1.2</td>
<td>36 (32.4)</td>
<td>32 (28.8)</td>
<td>n.s.</td>
</tr>
<tr>
<td>CDI &gt; 1.3</td>
<td>57 (51.4)</td>
<td>44 (39.6)</td>
<td>n.s.</td>
</tr>
<tr>
<td>PTI &lt; 0.5</td>
<td>40 (36.0)</td>
<td>64 (57.7)</td>
<td>0.002</td>
</tr>
<tr>
<td><strong>Abnormal patellar lateralization</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT-TG &gt; 15 mm</td>
<td>44 (39.6)</td>
<td>40 (36.0)</td>
<td>n.s.</td>
</tr>
<tr>
<td>TT-PCL &gt; 20 mm</td>
<td>78 (70.3)</td>
<td>67 (60.4)</td>
<td>n.s.</td>
</tr>
<tr>
<td><strong>Abnormal trochlear morphology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulcus angle &gt; 145º</td>
<td>99 (89.2)</td>
<td>108 (97.3)</td>
<td>0.032</td>
</tr>
<tr>
<td>Lateral trochlear inclination angle &lt; 11º</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trochlear depth &lt; 3 mm</td>
<td>77 (69.4)</td>
<td>53 (47.7)</td>
<td>0.002</td>
</tr>
<tr>
<td>Trochlear facet asymmetry ratio &lt; 0.4</td>
<td>23 (20.7)</td>
<td>41 (36.9)</td>
<td>0.012</td>
</tr>
<tr>
<td>Trochlear condyle asymmetry ratio &gt; 1.1</td>
<td>2 (1.8)</td>
<td>1 (0.9)</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

ISI = Insall-Salvati index, CDI = Caton-Deschamps index, PTI = Patellotrochlear index, TT-TG = Tibial tubercle-trochlear groove distance, TT-PCL = tibial tubercle-posterior cruciate ligament distance, n.s. = non-significant

*Pearson Chi-Square test

### Table 6. Comparison of measures between patellar OCF and femoral OCF groups.

<table>
<thead>
<tr>
<th>Location of OCF</th>
<th>Patella, n = 68</th>
<th>Femur, n = 40</th>
<th>p-value*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patellar height, mean (95% CI)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISI</td>
<td>1.21 (1.17 to 1.25)</td>
<td>1.19 (1.13 to 1.25)</td>
<td>n.s.</td>
</tr>
<tr>
<td>CDI</td>
<td>1.19 (1.16 to 1.22)</td>
<td>1.20 (1.13 to 1.26)</td>
<td>n.s.</td>
</tr>
<tr>
<td>PTI</td>
<td>0.55 (0.52 to 0.59)</td>
<td>0.53 (0.49 to 0.57)</td>
<td>n.s.</td>
</tr>
<tr>
<td><strong>Patellar lateralization, mean (95% CI)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TT-TG, mm</td>
<td>14.1 (13.2 to 15.0)</td>
<td>14.8 (13.2 to 16.3)</td>
<td>n.s.</td>
</tr>
<tr>
<td>TT-PCL, mm</td>
<td>21.9 (21.1 to 22.7)</td>
<td>21.6 (20.6 to 22.7)</td>
<td>n.s.</td>
</tr>
<tr>
<td><strong>Trochlear morphology, mean (95% CI)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measure</td>
<td>Value 1 (Range)</td>
<td>Value 2 (Range)</td>
<td>p-value</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>-----------------------------</td>
<td>-----------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Sulcus angle (º)</td>
<td>153.7 (151.9 to 155.5)</td>
<td>155.6 (153.3 to 157.9)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Lateral trochlear inclination angle (º)</td>
<td>13.4 (12.4 to 14.5)</td>
<td>13.6 (12.0 to 15.2)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Trochlear depth, mm</td>
<td>2.5 (2.3 to 2.8)</td>
<td>2.6 (2.3 to 3.0)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Trochlear facet asymmetry ratio</td>
<td>0.51 (0.47 to 0.54)</td>
<td>0.58 (0.52 to 0.64)</td>
<td>0.032</td>
</tr>
<tr>
<td>Trochlear condyle asymmetry ratio</td>
<td>1.04 (1.03 to 1.04)</td>
<td>1.04 (1.03 to 1.05)</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

ISI = Insall-Salvati index, CDI = Caton-Deschamps index, PTI = Patellotrochlear index, TT-TG = Tibial tubercle-trochlear groove distance, TT-PCL = tibial tubercle-posterior cruciate ligament distance, n.s. = non-significant

*Independent samples t-test
Figure 1. Anatomical measurements of the patellofemoral joint. The patellar vertical location measurements are shown in the side view of the knee joint as follows: ISI = B / A; CDI = D / C; PTI = E / C. The tibial tubercle-trochlear groove (TT-TG) distance measurement is shown in the top right and tibial tubercle-posterior cruciate ligament (TT-PCL) distance measurement in the middle right. The Trochlear configuration measurements are shown in the bottom right as follows: sulcus angle = L; lateral trochlear inclination angle = M; trochlear depth = [(G + I) / 2] – H; trochlear facet asymmetry ratio = J / K; trochlear condyle asymmetry ratio = I / G.
2,373 patients with patellar dislocation diagnosis (S83.0 or M22.0)

- Exclusion of 195 patients with erroneous diagnosis
- Exclusion of 34 patients with previous knee surgery due to patellar dislocation or other major traumas of knee joint
- Exclusion of 876 patients who had not undergone MRI in the study hospitals (of which 11 patients with OCF diagnosed using native X-ray or computed tomography imaging)

- Exclusion of 42 patients with chondral fragment

- Exclusion of 11 patients with round-shaped fragment

- Exclusion of 1,080 patients with no intra-articular loose fragments (including extra-articular MPFL-avulsion fragments and compression fractures without loose fragments)

135 patients with osteochondral fracture
- 99 patients with OCF after primary patellar dislocation
- 36 patients with OCF after recurrent patellar dislocation

169 reference patients with no osteochondral fracture

**Figure 2.** Flow chart of patient selection.
**Figure 3.** Results of predictive logistic modelling. Solid vertical line represents the threshold value of 50% probability for osteochondral fractures (OCF) after patellar dislocation, and the dotted line represents lower and upper bound of the 95% confidence intervals for the threshold.
References

Influence of Primary Treatment Approach on Outcomes in Patients with Osteochondral Fracture After Patellar Dislocation: A Case Series

Uimonen Mikko, Ponkilainen Ville, Mattila Ville, Nurmi Heikki, Paloneva Juha, Repo Jussi
